THE STATIC AND DYNAMIC BEHAVIOR OF A VERY LONG SHAFT MADE OF A COMPOSITE

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Abstract: A very long rubbing roller with a small deflection is required the manufacture of large LCD thin films. In order to accomplish this, the shaft for the roller is often made with a composite material. As composite material shafts are expensive and require a long time to manufacture, a simulation to check the deflection of the shaft should be conducted during the design step. However, simulations of extremely long composite materials are seldom reported. Thus, an accurate simulation technique should be studied. Therefore, this report presents the static and dynamic simulations of a very long composite material shaft. The simulation was in good agreement with the test data; hence, the simulation technique can help model other composite material shafts.

Keywords: Dynamic Behavior, Rubbing Roller, LCD, Thin Long Rotor, CFRP, Deflection, FEM 1 Introduction

1 Introduction

The static and dynamic behaviors of a very long rubbing roller were investigated using static/dynamic analyses in this study. A very long rubbing roller with a small deflection is required in the manufacture of large LCD thin films. In order to realize this, the shaft for the roller is often made using a composite material. In this study, rubbing rollers for the manufacture of liquid crystal display (LCD) thin films are created from composite material, aluminum and stainless steel (SUS). These commercial rubbing rollers are typically very long, at approximately three meters; longer rollers are under development. The shape of the rubbing roller is usually very thin, and the static and dynamic displacement of the rollers must be minimized[1]. For this reason, a rubbing roller is made using a composite material to enhance the stiffness and ensure that it is lightweight; it is necessary to research the static and dynamic behaviors in the development of a very long composite shaft. For the evaluation of the deformation behavior, this study proposes a multibody dynamic analysis regarding very long shafts made of a special composite material. First, the static deflection is investigated in a finite element (FE) analysis with proper material properties and element types. Following this, the rotating deflection of the shaft is computed in a flexible body dynamic analysis.

2 The Static and dynamic analysis

This study proposes static and dynamic analysis for evaluation of the deformation behavior of shaft. First, the static deflection is investigated using a finite element(FE) analysis with a proper material properties and element types. Following this, the rotating deflection of the shaft is computed in a flexible body dynamic analysis.

2.1 Properties of shaft and element type for the static deflection analysis

The commercial FE software ANSYS was used for the static analysis [2]. Fig. 1 shows a drawing of a very long composite material shaft. The rubbing roller is composed of three materials. The composite material is known as CFRP, and this material makes up the body of the roller shaft. Another material used is SUS, which is coated over the CFRP. Aluminum is used to make a flange placed at the edge of the shaft. The total length of the rubbing roller is 3750 mm and its diameter is 140mm.
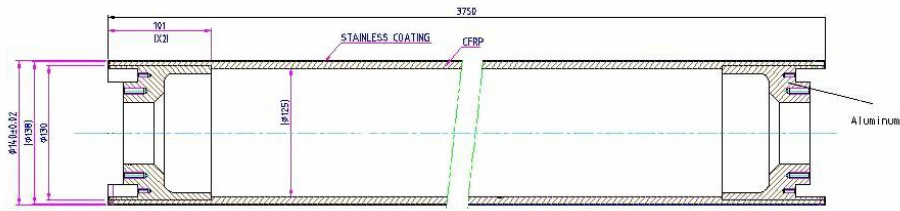
Figure 1 Drawing of the composite material shaft

The CFRP is composed by total 13 materials layered according to the angel. Table 1 shows the material information of each layer.

Table 1 Material information of each layer of the CFRP

No	Material	Angle (°)	Thickness(mm)	No	material	Angle (°)	Thickness(mm)
1	Fabric x 1ply	0	0.23	8	UD x 4ply	0	0.68
2	UD x 4ply	0	0.68	9	UD x 2ply	90	0.34
3	UD x 2ply	90	0.34	10	H-UD x 3ply	0	0.75
4	H-UD x 3ply	0	0.75	11	UD x 2ply	90	0.34
5	UD x 2ply	90	0.34	12	H-UD x 3ply	0	0.75
6	H-UD x 3ply	0	0.75	13	UD x 2ply	90	0.34
7	UD x 2ply	90	0.34				

ANSYS can realize the static analysis not only with the equivalent of the material properties of each layer but also with the material properties of each layers. However, this depends on the element type. Table 2 shows equivalent material properties of CFRP, SUS and Aluminum.[3]

Table 2 Material properties of the highly long shaft

	SUS	Aluminum	CFRP
E(GPa)	200	70	Ex = 380 Ey = 5.1 Ez = 5.1
v_{12}	0.33	0.33	v_{12} = 0.281 v_{13} = 0.281 v_{23} = 0.470
G (GPa)	-	-	Gxy = 5.55 Gyz = 5.55 Gxz = 4.55
Dens(kg/m³)	7870	2700	1580

In the modeling process of the composite material shaft, both solid and shell elements can be used. Although two types of shell elements may be used for the analysis, the shell element is unsuitable if the object is to express the radial direction behavior of the shaft. However, the solid element was applied in this study. Furthermore, only a solid element model can be converted to a flexible body model in ADAMS for a dynamic analysis. Thus, the solid element was used to apply the equivalent material properties.

2.2 The static analysis for deformation behavior of the composite material shaft

To create the FE model, the roller part, which was composed of CFRP, and a coated stainless part were modelled with 8 node block solid element. Additionally, an aluminum part was used that consisted of a solid element. This study assumes that all faces of the roller body that use different materials are strongly bonded together. The geometries of the model are reflected by the real shape of the rubbing roller. However, to avoid numerical errors caused geometry that is overly complicated, some of the roller shapes were simplified. Analysis results are largely influenced by the supporting conditions of the aluminum flange. Thus, three cases of the boundary condition were applied to both the measurement of the roller and the FE analysis. Figure 2 represents one of the boundary conditions of the roller model. Additionally, for the analysis, gravity acceleration of 9.81 m/s^2 was applied using a load.
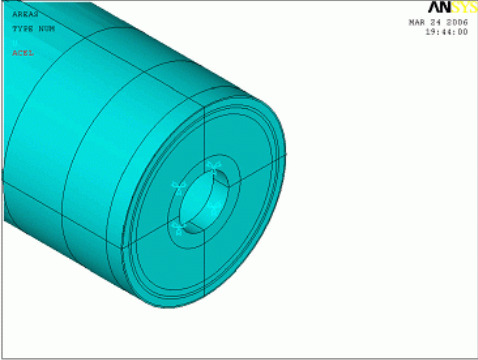

Figure 2 Boundary condition of the roller

To confirm the reliability of the FE model, measurement data of the rubbing roller, which was 2750mm in length, were compared with the analysis data. This data was provided by the creation of the rubbing roller. Figure 3 present same rubbing roller of measurement process about simple and clamping boundary conditions

Figure 3 Photograph of test apparatus

Figure 4 presents the ANSYS result of a simple support condition. Figure 3 shows that the FE model was reliable, as the results and the measurements show only small differences.
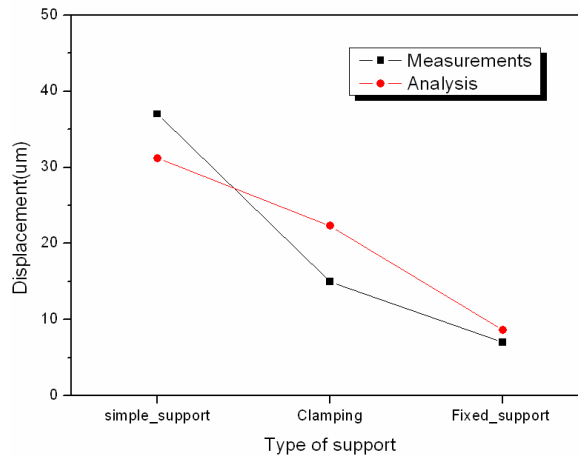

Figure 4 The comparing data between analysis and measurements(length= 2790 mm)

The composite material shaft model, which was 3750mm in length, was analyzed using the same method. The results of the analysis were 58.4 μm in the simple support condition. Figure 5 shows the static behaviour analysis result of the rubbing roller.
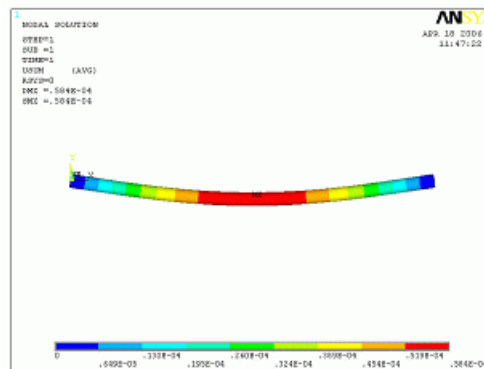

Figure 5 Static analysis result of the rubbing roller which has 3750mm length

2.3 Creation process of the dynamic model and the boundary condition

The multibody dynamic software ADAMS was used to observe the dynamic behaviors of the shaft. The first step of the analysis was the creation of a model of the shaft using ADAMS [4]. The results of the static analysis show that the center of the rubbing roller has large displacements. This should be considered in the dynamic analysis [5]. The deflection of the body can be included in the flexible body model [6]. Therefore, to consider the effects of the static deflections, the entire composite material shaft was built as a flexible body [7]. The next step for the analysis was the application of the boundary condition. As the boundary condition of the dynamic analysis model, a spherical joint with three rotational DOF was applied at the end of the rubbing roller. Figure 6 shows the position of the joint.

The spherical joint can function as a simple support condition in the static analysis. When the rubbing roller is a fixed support, the boundary condition of the dynamic analysis should be a revolute joint. The last step in the modeling is the creation of the load step. To start at a static deflection, the

load step includes a time interval at beginning of the load step. During this time, the model moves to a static steady position. The revolution forces then act as a flexible body of the shaft.
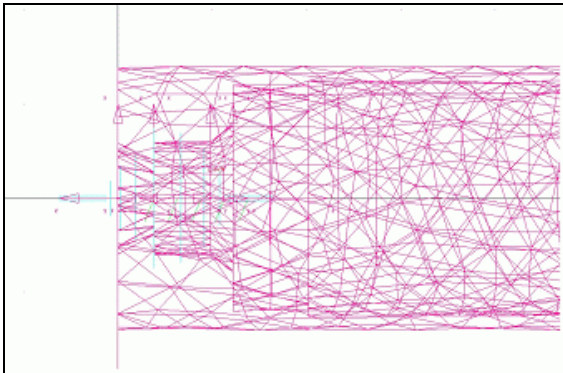

Figure 6 Applied spherical joint of flexible body shaft in a flange part

2.4 The dynamic behavior of the composite material shaft

Figure 7 shows the result of the dynamic analysis at 2000 rpm. Displacement of the central position is approximately -58 μm in a static state, implying that the shaft has no rotating force. Figure 8 shows the resonance of rubbing roller in critical speed(3300rpm) region. A natural frequency of the rubbing roller is 55 Hz.
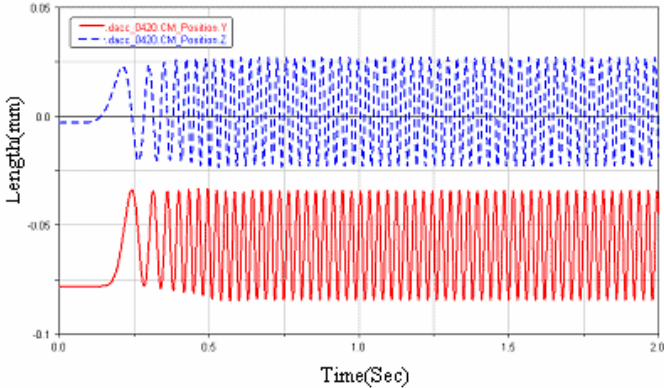

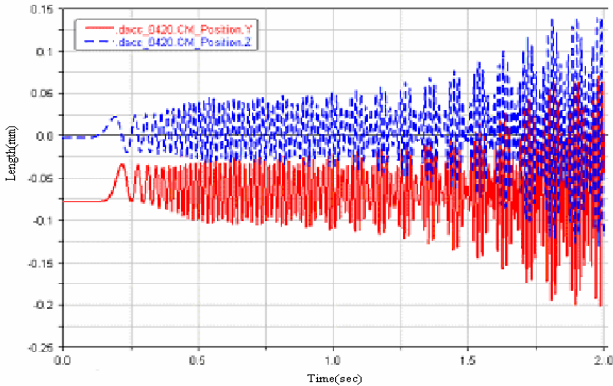Figure 7 Dynamic behaviour of a rubbing roller at 2000rpm

Figure 8 Dynamic behaviour of a rubbing roller in critical speed region at 3300rpm

Displacement is -65 μm while the minimum displacement is -7.5 μm. In addition, Figure 9 shows the results of the dynamic analysis concerning the 3750mm shaft for several rotating speeds.
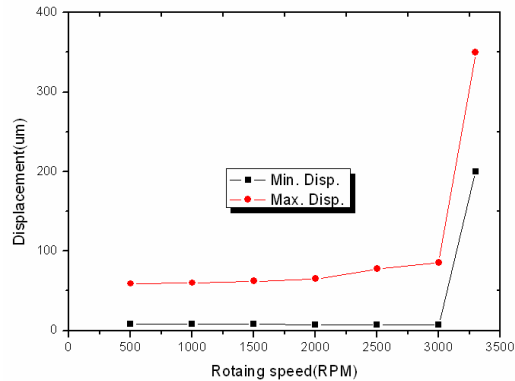

Figure 9 The results of dynamic analysis about the long shaft(length=3750 mm)

3 Conclusions and recommendations

This paper presented a modeling and analysis technique , to obtain more accurate simulation results, for a very long composite material shaft for the manufacture of a LCD thin film. For the static and dynamic analysis, two types of analyses were performed. First, the static deflection was obtained from a FE analysis using ANSYS. To create a FE model of the shaft, the equivalent material properties of the composite material and a modeling method using solid elements were applied in the modeling technique. The accuracy of the static analysis was shown through a comparison of the measurements and analysis data. Second, the computed dynamic analysis was used to observe the dynamic deflection in a rotation state. In this process, a flexible body of a composite material shaft was built. The proper boundary conditions and load steps were selected. As a result of the analysis, the vibration of composite material shaft was calculated using multibody dynamics. These results can be used as reference data for developments such as a change of the material or design of a rubbing roller. Moreover, this study concerning a shaft created using a composite material can assist with similar studies concerning the use of composite materials.

Acknowledgments

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