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Reliability Evaluation for Hinge of Folder Devices Using ESPI

Kyungyoung Jhang*
School of Mechanical Engineering, Hanyang University
Haengdang-dong, Seongdong-Gu, Seoul 133-791, Korea

Minkwan Hyun and Taehun Lee
Graduate School of Hanyang University
Haengdang-dong, Seongdong-Gu Seoul 133-791, Korea

Seokwon Chang
Reliability Analysis Research Center, HIT 402, Hanyang University
Haengdang-dong, Seongdong-Gu, Seoul 133-791, Korea

Abstract. Folder type electronic devices have hinge to support the rotational motion of folder. This hinge is stressed by the rotational inertia moment of folder at the maximum open limit position of folder. This stress is repeated whenever the folder is open, and it is a cause of hinge fracture. In this paper, the reliability evaluation for the hinge fracture in the folder type cellular phone is discussed. For this, the durability testing machine using crank-rocker mechanism is developed to evaluate the life cycle of the hinge, and the degradation after repetitions of opening and shutting is evaluated from the deformation around the hinge, where the deformation is measured by ESPI (electronic speckle pattern interferometer). Experimental results showed that ESPI was able to measure the deformation of hinge precisely, so we could monitor the change of deformation around the hinge as the repetition number of folder open is increased.

Key Words : *Hinge, Folder Device, ESPI, Durability, Non-destructive Evaluation.*

1. INTRODUCTION

Recently, the use of mobile electronic devices is greatly increasing, and especially the cellular phone becomes a essential personal equipment. Then we can easily find the crack or fracture on the hinge in the folder type cellular phones as shown in Fig. 1, even in

* Corresponding Author
E-mail address: kyjhang@hanyang.ac.kr

only one or two years used one. Although it has no direct relation with the main function, but it may reduce the life cycle of machine and give damages in the brand image. So, the life cycle evaluation and the failure analysis of these parts are important.

There are several reasons to cause the hinge fracture; shock by falling down, degradation of material property, and fatigue by the repetition of impact when the folder is opened, etc.

In this paper, we have interest in the fatigue failure. Hinge is used to support the rotational motion of folder, so it is stressed by the rotational inertia moment of folder at the maximum open limit position. This stress is repeated whenever the folder is open, and it might be a cause of hinge fracture. For the study, the mechanism of the hinge motion used in the folder type cellular phone was analyzed and the automatic durability test system was designed to open and shut the folder repeatedly. In this machine, crank-rocker mechanism is used to convert the rotational motion of driving motor into the oscillatory motion of rocker that opens and shuts the folder.

Next, the degradation of hinge after a certain repetitions of folder open is evaluated from the deformation around the hinge under a constant torsional loading. The deformation is measured by ESPI (electronic speckle pattern interferometer). The ESPI has been known as a useful tool to measure the deformation and vibration of structure with high accuracy and in high speed. Also since it can be directly applied to the real product, we can evaluate the deformation and vibration in the real environment. The details of ESPI can be referred in Rastogy(1994), Johns(1989) and Rastogy(2001).

In this study, we confirm that the deformation of hinge is measurable by ESPI, and then the best loading force to obtain the proper fringes is investigated. Also the difference of deformation between the left and the right hinges are compared and we have checked how the fringe pattern changes after durability test. The results of this study are expected to be applicable to other folder type electronic devices, too.

Fig. 1. Samples of hinge failure in the cellular phones

2. DEVELOPMENT OF THE DURABILITY-TESTING MACHINE

In the durability-testing machine, a device that opens and shuts the folder of cellular phone automatically is needed. For this, we have considered the crank-and-rocker mechanism that converts the revolutionary motion of a crank into the oscillatory motion of a rocker, as shown in Fig. 2. This mechanism is referred in Shigley(1999). In this mechanism, when the crank (link DA) makes a complete rotation the rocker (link CB) oscillates along the path ①.

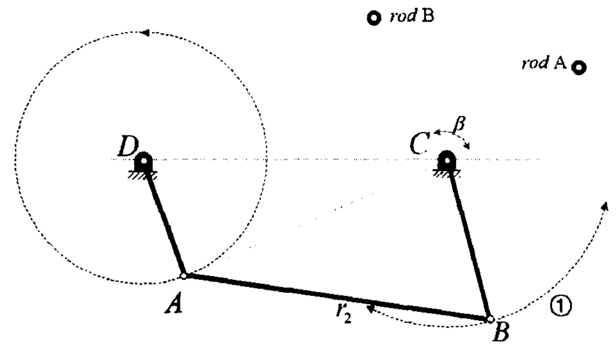


Fig. 2. Crack-and-rocker mechanism

In the development of the machine, a motor is used as the crank driver. Also the crank and the rocker are designed with a circular disk in order to reduce the eccentric force that may occur when they turn. The rod A and B are attached on the rocker disk so they oscillate in the same manner of the rocker. The folder of cellular phone is located initially on the rod A. When the crank starts the rotation, then the rod A pushes the folder to open. At certain open angle of folder, the folder is open by itself and stops at the maximum limit position between the rod A and B. Next the rocker will rotate backward and the rod B pushes the folder to shut. At a certain close angle of folder the folder is shut down by itself. This is the operation during the one rotation of the crank. Fig. 3 shows the developed durability-testing machine. An optical sensor is used to count the repetition number automatically.

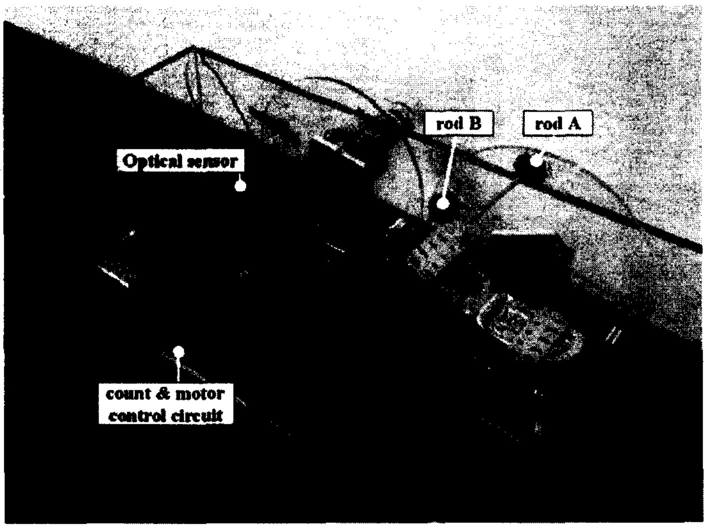


Fig. 3. The durability-testing machine

3. ESPI SET-UP

3.1 ESPI

As it has been already known, ESPI is a useful tool to measure the deformation and vibration of structure with high accuracy and in high speed. Also it can directly apply on the real product we can evaluate the deformation and vibration in the real environment. In this study, ESPI is used for the investigation of hinge deformation after the durability test. ESPI technique is based on the speckle: When we illuminate the coherent light like as laser to a rough surface of object and take an image by camera, we can see irregular speckles as shown in Fig. 4. This speckle is the result of the multiple interference of the light diffused from the surface. Since each speckle confronts with the surface each other, distribution of speckle is also changed when the surface is deformed. As shown in Fig. 5, the difference of speckle pattern between before and after deformation makes the fringe pattern and from this fringe ESPI measures the deformation of object.

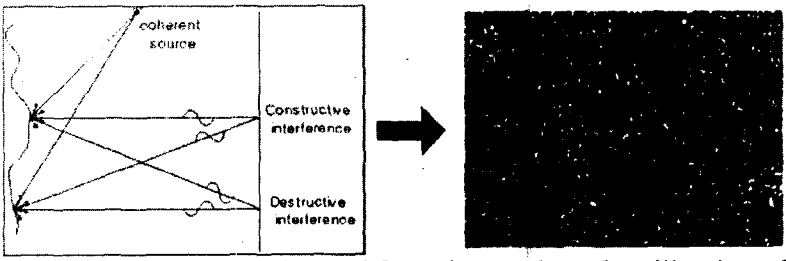
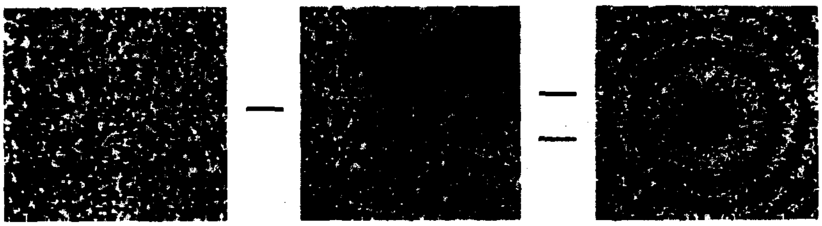


Fig. 4. Speckle image obtained from the rough surface illuminated by a coherent light source



(a) Before deformation (b) After deformation (c) Fringe pattern

Fig. 5. Fringe pattern obtained from the speckles before and after deformation

Following equations represent the intensity distribution of speckle image obtained before and after the deformation;

$$I_{before} = I_r + I_o + 2\sqrt{I_r I_o} \cos \phi \tag{1}$$

$$I_{after} = I_r + I_o + 2\sqrt{I_r I_o} \cos (\phi + \Delta\phi) \tag{2}$$

On these equations, I_R is the intensity of reference beam, I_O is the intensity of object beam, ϕ is the phase difference between the reference beam and the object beam, and $\Delta\phi$ is the new phase *difference* dew to the deformation. Subtracting two equations, we can get

$$I = \left|(I_{before} - I_{after})\right| = 2\sqrt{I_R I_O}\left|[\cos\phi - \cos(\phi + \Delta\phi)]\right| \\ = 4\sqrt{I_R I_O}\left|\sin(\phi + \frac{1}{2}\Delta\phi)\sin(\frac{1}{2}\Delta\phi)\right| \quad (3)$$

Eq. (3) shows that the resultant intensity distribution I, which can be varied between maximum (white) and zero (black) according to $\Delta\phi$. If the deformation is continuously increasing, as we can see in the case of a bended cantilever beam, then $\Delta\phi$ increases as well, so the value of $\sin(\Delta\phi/2)$ repeated the maximum at every 2π increase of $\Delta\phi$. This generates the fringe pattern.

3.2 Measurement method of displacement using ESPI

There are two methods of displacement measurement using ESPI. One is the measurement of out of plane displacement and another is the measurement of in-plane displacement. The optical set-up is a little bit different in these methods. Details of these methods are introduced in Johns(1989) and Rastogy(2001).

The out-of-plane displacement d_n is the displacement in the perpendicular direction to the object surface and is measured from the following relationship.

$$d_n = \frac{N\lambda}{2\cos(\alpha/2)} \quad (4)$$

Where, λ is the wavelength of laser, N is the number of fringes and α is the angle between the illuminating and the measuring directions.

While, the in-plane displacement d_i means the displacement in the parallel direction to the object surface and is measured from the following relationship.

$$d_i = \frac{N\lambda}{2\sin(\alpha/2)} \quad (5)$$

In this study, 3-D ESPI system is used, where both of out-of-plane displacement and in-plane displacement can be measured simultaneously.

3.3 Experimental set up

3-D ESPI system of the Steinbichler-Optics (Germany) was used in the experiment. Above system consists of the measuring head including a CCD camera and a laser transmitter, a piezo-control unit to control the direction and order of the laser illumination, a power supply part and a computer for data processing. And the cellular phone after durability test is located so that the in-plane and out-of-plane displacement around the hinge is measured, as shown in Fig. 6.

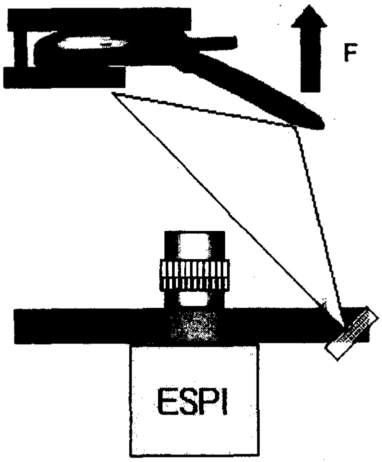


Fig. 6. Experimental set-up for ESPI measurement

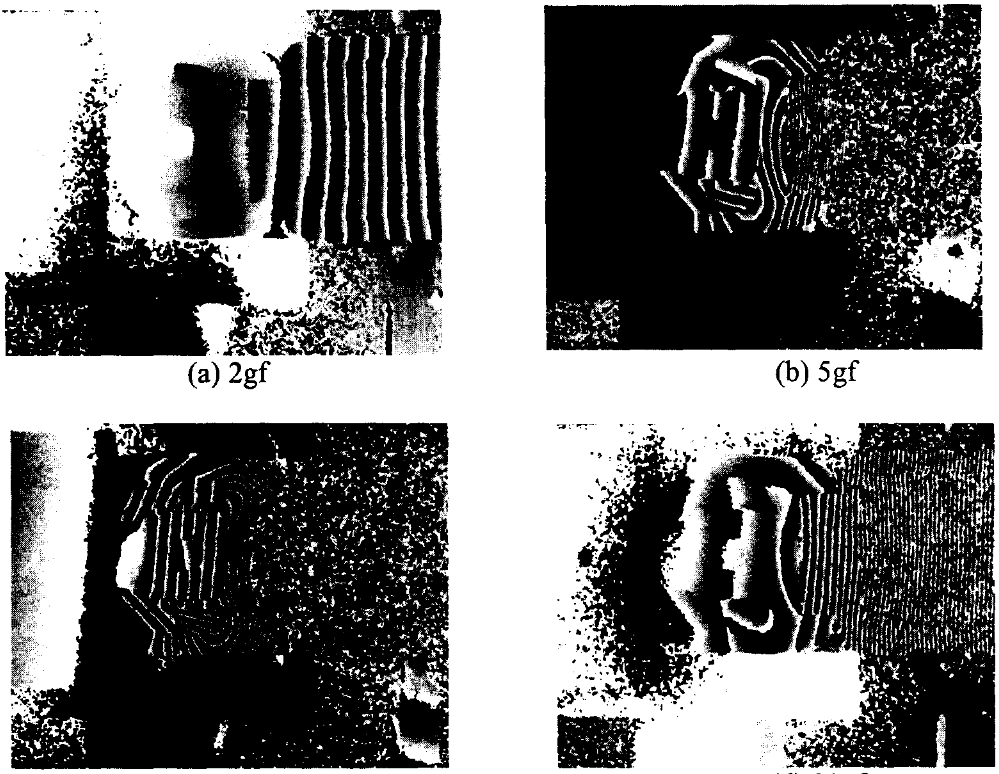
In the figure, F is the constant force to make a torsional loading on the hinge, which is controlled by a force gage. ESPI gets images before and after of this loading.

Now, the proper loading force should be determined before experiment, since too large deformation makes the fringe pattern very complicated to analyze, while too less deformation makes no fringe pattern. Fig. 7 shows the pre-experimental results of the fringe patterns for different loading forces from 2gf to 20gf. In the case of 2gf, the fringe pattern does not appear around the hinge, while in the case of 20gf, the fringes are too complicate to analyze. Resultantly, 10gf looks best so we selected 10gf for the loading force.

4. RELIABILITY EVALUATION USING ESPI

4.1 ESPI measurement results for the initial sample

Fig. 8 shows the fringe pattern obtained from the initial sample before the durability test. We can find that the deformation is concentrated on the hinge and the hinge is much stressed compared to other parts. Also we can see that the right side hinge showed larger deformation than the left side. This means that the right side is less strong. This seems due to the difference of structure. That is, in this sample, a lamp and the antenna are located on the right side, and the structure seems much complicated than the left side. Actually, in the durability test, the right hinge was cracked faster than the left one. Fig. 9 shows the unwrapped phase and the absolute displacement along trace lines on the left and right hinge. We can see that the change rate of displacement is greater in the right hinge than in the left.



(a) 2gf (b) 5gf

(c) 10gf (d) 20gf

Fig. 7. Fringe patterns obtained for the different loading forces.

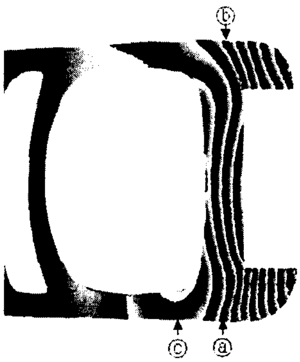


Fig. 8. Fringe pattern obtained from the initial sample before the durability test

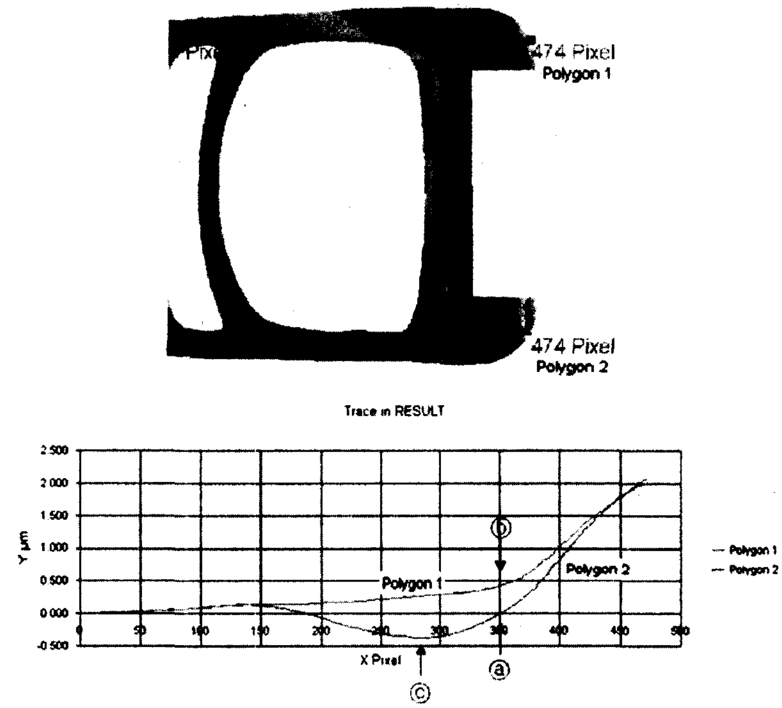


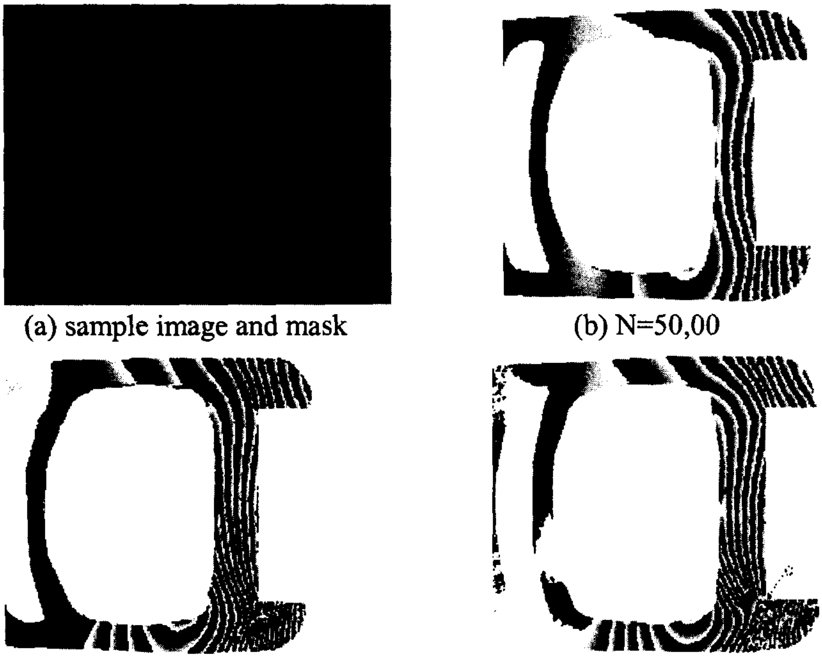
Fig. 9. The unwrapped phase image and the absolute displacement along the trace lines (circled a, b, c are corresponding to the position shown in Fig. 8)

4.2 ESPI measurement results for the durability tested samples

Fig. 10 shows the ESPI measurement results for the samples during the durability test; (a) shows the real sample with a mask to capture the image of hinge part only. From (b) to (d) are obtained after 50,000, 100,000, and 120,000 repetitions of folder open, respectively. We can see that the deformation increased as the degradation is increased. Also (c) shows a sudden increase of deformation concentrated on the hinge, which means that the degradation of the hinge reaches to the crack initiation. From (d), we can find the discontinuity in the fringe pattern, where the physical crack is initiated.

5. CONCLUSIONS

In order to evaluate the durability of hinge in the cellular phone, the durability-testing machine was developed, and ESPI method was proposed to evaluate the hinge degradation. The developed durability-testing machine using the crank-rocker mechanism operated normally with the automatic opening and shutting the folder. From the durability test, it was shown that the repetition of folder open was one of the mechanisms of hinge failure. The fringe pattern obtained by ESPI showed discontinuous or rapidly increase deformation on the point where the defects were initiated. These results proved that the ESPI technique could be used to detect the defect in the hinge and evaluate the life cycle.



(a) sample image and mask (b) N=50,00

(c) N=100,000 (d) N=120,000

Fig. 10. Fringe patterns of ESPI for the samples after durability test

ACKNOWLEDGEMENTS

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