Influence of the variation of its geometry on the disk failure

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디스크 형상 변화에 따른 파손에 끼치는 영향

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Key Words : Disk(디스크), Disk failure(디스크 파손), Geometry(형상), J-integral(J 적분값)

Abstract

The speed competition of optical disk drive has been accelerated with the fast advancement of its storage density and data transmission technology. The continuous increase of the spinning speed of CD meets the unexpected and catastrophic failure of disk during the operation. The effect of its thickness and outer radius of disk were investigated to reduce stresses and J-integral around the crack tip. The effect of its thickness was considered ahead of the crack tip. In the effect of outer radius of disk, linear elastic fracture mechanics was used to obtain the critical crack length, which indicates the onset length for unstable crack growth. This approach is so significant as to detect the growing crack by disk drive before the catastrophic failure, which will provide the standard size of its safety for high-speed disk drive.

1. Introduction

Since the development of compact disk(CD) in the 1980s, the rotational velocity of disk drive has been increased to satisfy the requirement of the consumer's faster data transmission and data storage. The speed competition has been also applied to the manufacture of DVD(digital versatile disk) drive these days. The speed competition of DVD drive is expected to surpass the one of CD drive, which stops as the speed limit of 10,500 R.P.M.

This speed competition meets mechanical failure of disk due to the several reasons, such as centrifugal force, thermal stress, mass imbalance, and so on. This failure phenomenon has been investigated with the knowledge of elasticity, fracture mechanics and fatigue phenomena.[1-4] Though disk failure problem has not been commonly occurred, the coming faster speed competition might give the devastating damage on the users due to the fragmented pieces of optical disk. The effort to strengthen the front case of the disk drive has been required to protect users directly from the catastrophic fragments of disk. However, this is not a fundamental solution to remove such an unexpected disk failure problem. Therefore, the objective of this paper suggests the feasible strengthening method of disk to reduce the failure phenomena and provides the standard dimension of disk to detect crack by the disk drive before the failure.

2. Theoretical Review

The expressions of stresses for the rotating disk have been well established with the plane stress assumption.[5] This assumption is essentially applicable to the stress analysis of a thin rotating disk.

Considering the boundary conditions of the spinning disk, two kinds of boundary conditions could be reasonable to describe the real conditions of disk in a drive. One of them is a general free boundary condition at the edges of disk. This free boundary condition is very widely used boundary conditions for free rotating objects. The other boundary condition is clamped one, which considers the clamping of the spinning disk in an

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optical disk drive. The appropriate boundary condition will be chosen for its purpose. In this paper, the free boundary condition at the edges of the disk was applied for the calculation of the stresses and J-integral. It is simple for the disk with the constant thickness to solve analytically for the stresses. But if the thickness is variable, it is better to solve numerically with less time and effort.

To guarantee the accuracy of its numerical solution results for the rotating disk, it was compared with exact solution result in terms of its radial stress and tangential stress in Figure 1. Two solutions show good agreement in the stresses.

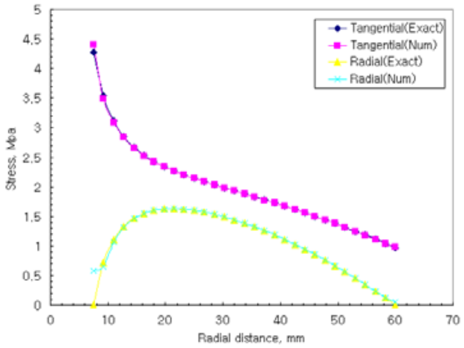


Fig. 1 The comparison of the stresses of rotating disk between analytical solution and numerical solution at 10,500 R.P.M.

3. Experimental and modeling

The phenomenon for disk failure was observed at a simple laboratory test, as shown in Figure 1. An experimental setup consists of disk drive, stroboscope, motor drive circuit jig, power-supply, and block safety cover case.

The CD-R that was used as an experimental specimen was purchased from a variety of disk manufactures. Before testing, a certain initial length of crack length at the inner edge was created by applying transverse displacement on the inner edge of the disk.

The time to take the failure of disk is affected by an initial crack length. Many specimens were failed in the shape of debris that is hardly recognizable due to the impact with drive case.

But some of the specimen was failed in the shape of Figure 3. The specimen in Figure 3 shows the failure by the growth of the initial crack without companying the secondary failure.

Fig. 2 Experimental testing apparatus

Fig. 3 Failed specimen after 10,500 R.P.M testing

In order to investigate this phenomenon, a simple 2-D quadrilateral element type model was introduced and calculated with MSC. MARC(FEM) solver. Material properties and geometric dimensions are mentioned in Table 1. Figure 4 shows tangential stress distribution of the disk that the initial crack has already grown to the outer edge at 10,500 R.P.M. It seems that the maximum stress is applied to the opposite inner edge from the initial crack, but its value is less than the typical yield strength of polycarbonate(~60 Mpa). If there is small defect existed at the inner edge except for the initial crack, the applied stress can induce the secondary failure from such an existed defect. It is an important role for condition of the inner edge of disk to the disk failure mechanism.

Table 1 Material property and geometry of disk

Property	Value	Dimension	Length(mm)
Elastic modulus(Gpa)	2.316	Thickness	1.2
Possion's ratio	0.3	Inner radius	7.5
Density(kg/m^3)	1190	Outer radius	60

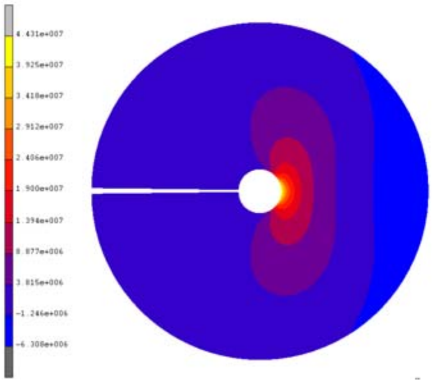


Fig. 4 Distribution of tangential stress at 10,500 R.P.M

4. Discussion

Disk failure was known to be occurred the crack propagation from the inner edge. Therefore, the geometry ahead of the crack tip might affect the crack propagation rate and the outer radius affects the driving force of crack propagation. These two points are mainly discussed to lower such a catastrophic disk failure.

4.1 The effect of its thickness

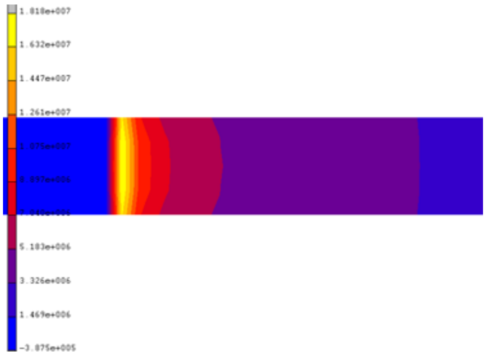


Fig. 5 The cross-section of disk with 7.5 mm length crack at 10,500 R.P.M

It was generally assumed that tangential stress through the thickness is constant within a small percent error for the stress analysis of disk. In the numerical solution shown in Fig. 5, there is a gradient of the stress through the thickness around the crack tip. That gives the similar relationship in the J-integral, which is the maximum in the middle of its thickness.[6]

Figure 6 shows the cross-section of the failed specimen, which shows the continuous growth ring of the crack. The growth ring pattern seems to be closely related with the J-integral value. The crack propagation leads in the middle of its thickness.

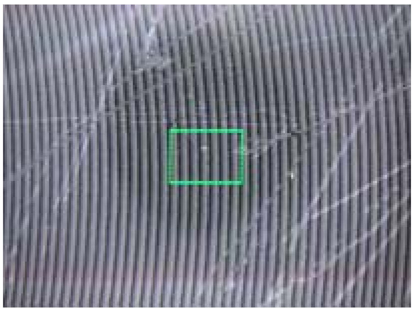
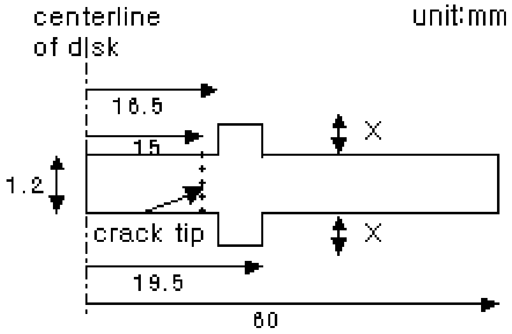
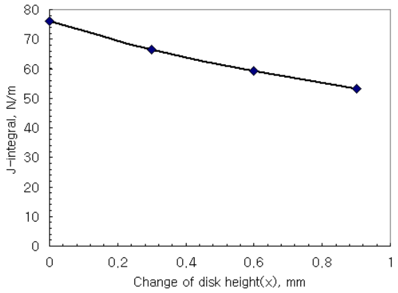


Fig. 6 The cross section view of the failed specimen at 10,500 R.P.M

To figure out the effect of its thickness in the crack propagation, 7.5 mm length crack from the inner edge was introduced into the disk with a different thickness on both transverse directions away from the crack tip by 1.5 mm in Figure 7(a). Figure 7(b) shows that the J-integral was decreased with the increase of the same thickness(x) on both direction from the surfaces of the disk. Therefore, the disk with the thicker thickness could be effective to decelerate the crack propagation. The crack propagation rate seems to be affected by its thickness ahead of the crack tip under the same rotational velocity.



(a) Cross-section view of disk



(b) Variation of J-integral with the thickness of disk

Fig.7 Influence of disk thickness(x) on crack propagation

4.2 Effect of outer radius

Centrifugal force is a driving one for the crack propagation of the rotating disk. One of the effective ways to lower the driving force is to decrease the outer radius of disk with respect to the inner radius. The maximum tangential stress, which is an important stress component in terms of crack propagation, is occurred at the inner edge in Figure 8. Figure 9(a) shows the variation of the maximum tangential stress with the increase of outer radius. The maximum tangential stress is squarely proportional to the outer radius. The maximum tangential stress could be related to the critical crack length. Figure 9(b) also shows the relationship between the critical crack length and outer radius. The increase of outer radius causes the elevation of the stress and decreases the critical crack length, finally decelerates the crack propagation to the catastrophic failure.[7]

It could be one of the safest ways for its user to detect the growing crack by the disk drive before the failure. If the growing crack invades the recording region of the disk, there will be the recording error not to read a data by the disk drive.

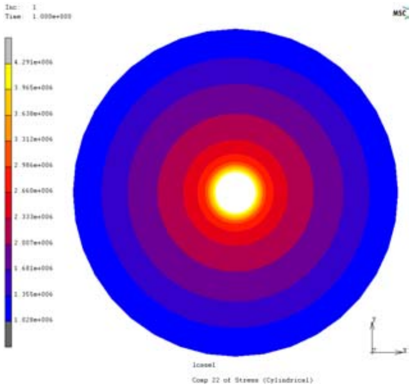
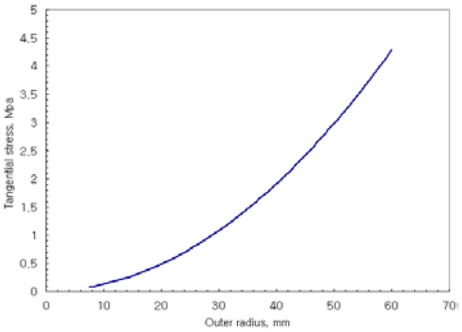
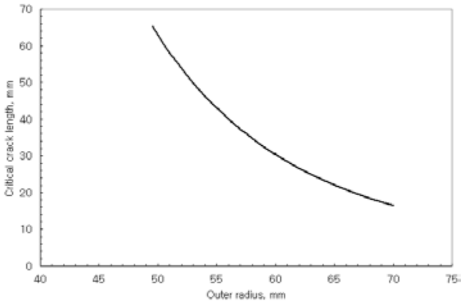


Fig. 8 Distribution of tangential stress at 10,500 R.P.M



(a) Variation of maximum tangential stress vs. outer radius



(b) Variation of critical crack length vs. outer radius(Fracture toughness=1.0 Mpa m$^{1/2}$)

Fig. 9 Effect of outer radius on the spinning disk at 10,500 R.P.M

The pre-requirement is that the time to check the error needs to be shorter before the consumed time the crack reaches at the outer edge of disk from the data-recording region. Data in the disk started to be recorded from lead-in region in Figure 10(a). Therefore, the critical crack length is set to equal to the length from the inner edge to the lead-in region in Figure 10(a), which is 15.5 mm critical crack length.

If using the definition of K(fracture toughness) as shown in equation (1),

$$K = C\sigma\sqrt{\pi a} \tag{1}$$

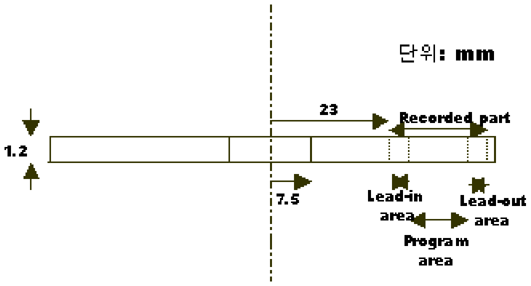
where K=stress intensity factor, C=material constant for geometric configuration, σ=the stress at some reference location remote from the crack, a=crack length.

Using maximum tangential stress for the stress(σ) in equation (1) and K=K_{ic}, the critical outer radius for the crack detection by disk drive is obtained in equation (2).

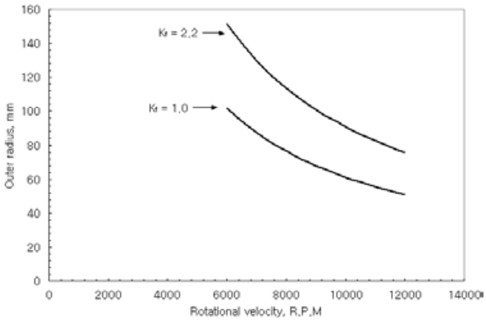
$$r_o = \sqrt{\frac{4K_{ic}}{C(3+\upsilon)\rho\omega^2\sqrt{\pi a}} - \frac{1-\upsilon}{3+\upsilon}r_i^2} \tag{2}$$

where K_{ic}=fracture toughness,ρ=mass density,ω=angular velocity, r_i=inner radius.

Figure 10(b) shows critical outer radius limit corresponding to the angular velocity of the disk with different fracture toughness. Above the critical radius line, a catastrophic failure is highly probable to occur at the disk with the outer radius because the crack propagation rate is so fast that the disk drive could not detect the crack before the failure. Figure 10(b) can be used as a standard of disk size for its safety.



(a) Cross-section view of disk



(b) Critical outer radius vs. rotational velocity

Fig.10 Critical outer radius with K_f(fracture toughness)

5. Summary and Conclusion

A rotating disk at high speed experiences the maximum centrifugal force at the inner edge of the disk. If there is a crack existed at the inner edge, the force contributes the crack propagation and finally a catastrophic failure in a disk drive. To diminish such a disk failure phenomena, two geometric parameters were discussed. One parameter is to increase the thickness of the disk ahead of the crack tip. The calculation of J-integral shows that the thicker thickness is existed ahead of the crack, the slower crack propagation is expected.

The other method is to give a guideline in the determination of disk size for the crack detection by disk drive. In order to detect the crack in the recording region before the crack reaches the outer edge of disk, The maximum allowed limit of the outer radius is determined with the distance between the inner edge and the recording region for the critical crack length.

These two approaches will contribute to the manufactures of disk to determine its size for decreasing the probability of catastrophic disk failure.

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