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Integrity assessment of large rotating machine components based on their resonance characteristics (1) — Measurement method and numerical simulation —

大型回転機部材の共振特性に基づく健全性評価 (1)
—測定手法と数値シミュレーション—

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1. Introduction

The rotor wedges of the turbine generator are subjected to high centrifugal forces acting on the rotor coil contained in the slot of the iron core. The centrifugal force acts mainly on the part of the wedge that hooks into the slot, which causes cracks. To prevent a catastrophic breakdown, the person in charge needs to perform periodic health diagnoses. For this purpose, MHz-band ultrasonic pulse-echo method(1) is commonly applied for nondestructive inspection. Still, it has drawbacks, such as the need to scan the entire surface of the component and the existence of shadow zones of ultrasonic propagation. One needs to remove oil or wear powder from the surface of the component before measurement. To overcome these problems, the authors have proposed a fixed-point measurement method using the mechanical resonance frequencies of the component under test(2,3). A pair of point-contact piezoelectric sensors are used to vibrate the specimen and detect the natural vibration mode frequency, which changes differently for each mode due to a crack. In this paper, the relationship between the frequency shift and the eigenmode distribution in the presence/absence of cracks is discussed based on the measured data and the finite element analysis for a sample.

2. Sample configuration and finite element model

Fig. 1 illustrates the test piece to be inspected, the crack-prone area, and the measurement method. The target part is made of stainless steel with a length of 300 mm, a width of 51 mm, and a height of 25 mm, and has three through holes. Hundreds of these are installed in a practical large rotating machine, and the only surface accessible for inspection is the top one shown in the figure. A set of the multilayered piezoelectric element with brass back weight and convex lens bonded to them is used as the sensor. A chirp signal is input to one side to excite the existing resonances and received by the other side to obtain the transfer function. The frequency response of the transfer function has several peaks at the eigenmode frequencies of the member under test, and some of the peaks shift to lower frequencies due to the presence of cracks.

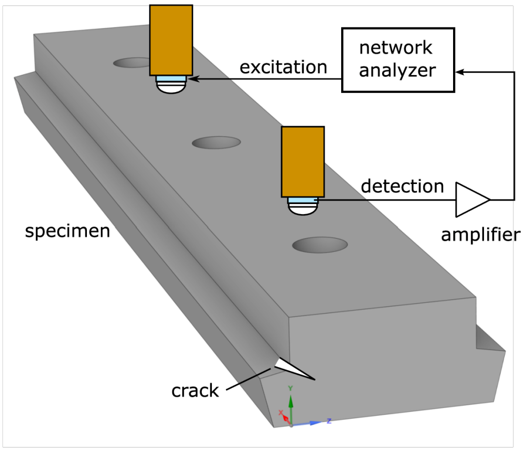

Fig. 1 Sample under test with a crack, and measurement setup.

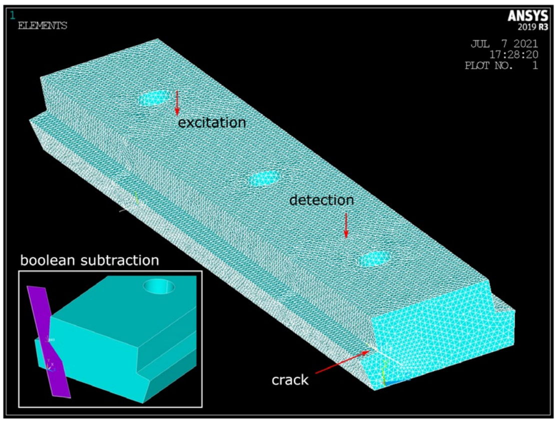

Fig. 2 Finite element model of sample with crack.

Fig. 2 figure shows a finite element model with a crack. The crack is created by performing a

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boolean difference operation on the CAD of the healthy member and is divided by a tetrahedral quadratic element with an element size of 2 mm. In the harmonic vibration analysis, the excitation is assumed as a point excitation by an external force. The received signal is the displacement of one of the surface nodes located at the measurement position. ANSYS 2019 R3 was used for the analysis.

3. Results

Fig. 3 demonstrates the obtained frequency response. The experimental values in (a) represent the input-output voltage ratios of the network analyzer, and the values (b) are the input-output ratios of the displacement amplitudes obtained by the finite element method. There is a slight difference in the position of the peak appearance between (a) and (b), but some of the mode at 30–40 kHz is shifted to the lower frequency due to the crack.

Fig. 4 (a) and (b) are the modes for which no peak shift is observed, and (c) and (d) are the modes for which peak shift is observed. Table I summarizes the frequencies and shifts of the above modes. Although there is a slight difference in the amount of shift between the experiments and analysis, the mode without nodes in the width direction does not shift. The mode with bending vibration in the width direction shows a shift of several tens of Hz. The shift direction is consistent between the experiment and analysis. The reason can be thought that in the mode without a nodal line in the width direction, almost no stress is applied at the end of the member, where cracks tend to appear. In contrast, in the mode with bending in the width direction, higher stress is applied at the crack site than at the surrounding area.

4. Conclusion

A method using point-contact piezoelectric sensors and resonance modes was applied for a three-dimensional component to detect a crack. A crack was successfully detected from the down-shift in the natural vibration mode frequencies of the component if appropriate resonance frequencies were selected. This result was confirmed in both experiments and finite element analyses with considerably good consistency.

References

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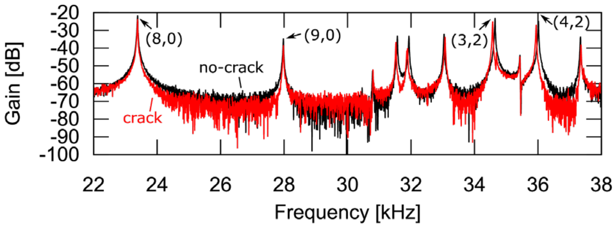
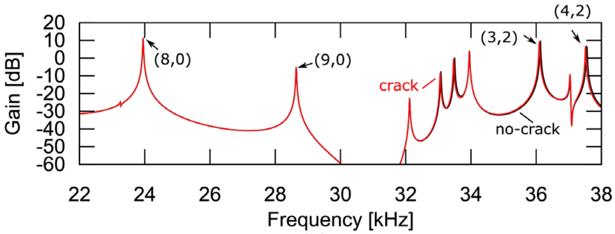


(a) Experiment



(b) FEA

Fig. 3 Frequency characteristics with and without crack from (a) experiment and (b) finite element analysis.

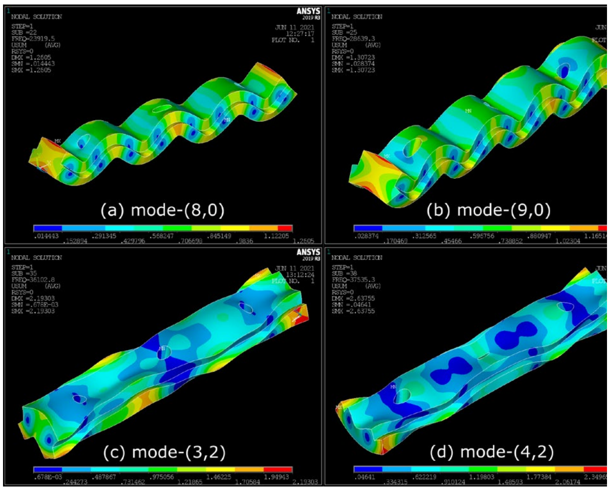


Fig. 4 Resonance modes in 20–40 kHz where (*m*,*n*) means number of nodal lines.

Table I Modal frequencies and peak shift by the crack from experiment and finite element analysis result

Modes [Hz]	(8,0)	(9,0)	(3,2)	(4,2)
Exp. w/o	23,385	27,980	34,650	36,015
Exp. w/	23,385	27,980	34,575	35,945
Peak shift	0	0	-75	-70
FEA w/o	23,919	28,639	36,103	37,535
FEA w/	23,918	28,638	36,068	37,495
Peak shift	-1	-1	-35	-40