Nondestructive Evaluation of Flaws Using SQUIDS

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Using high- T_c SQUIDS, we have designed a nondestructive evaluation system to probe buried flaws. The frequency of the excitation magnetic fields was varied from 10 to 800 Hz and the magnetic fields generated from the eddy current was lock-in detected. The SQUIDS output data revealed the most effective excitation frequencies for the flaws with different depths and widths. The signal-to-noise ratio of the deep flaws can be further enhanced either by using higher excitation fields or using the SQUIDS with higher low-frequency sensitivity.

1. INTRODUCTION

The low-noise high- T_c SQUIDS are valuable for application in nondestructive evaluation (NDE) for its unparalleled sensitivity [1–3]. For a conductive sample, the eddy current SQUID NDE technique is more suitable than the ultrasonic technique when a good acoustical coupling with the sample is not available. In order to probe the deeper flaws with the eddy current NDE system, one may use the most effective excitation frequency [2] to obtain higher signal-to-noise ratio. In this work, we present the results of the most effective excitation frequencies to enhance the signal-to-noise ratio of the NDE system.

2. EXPERIMENTAL DETAILS

The sensor of the NDE system [4] was a dc SQUID magnetometer controlled by the SQUID electronics (Conductus Inc. Model IMC 303). The magnetometer was mounted inside a liquid-nitrogen fiberglass dewar shielded with a μ -metal cylinder to reduce environmental noise. A double-D excitation coil was mounted beneath the dewar and the diameter of the coil was 28 mm. The position of the double-D coil was adjusted to minimize the excitation field in the SQUID. The distance between the excitation coil and the SQUID was about 10 mm while the distance between the excitation coil and the sample was 3 mm. The sample was mounted on a computer-controlled x-y table. The alternating magnetic field was applied by a function generator

and the excited signal sensed by the SQUID was detected by a lock-in detector (Stanford Research, Model SR530).

3. RESULTS AND DISCUSSION

The peak-to-peak magnetic field ΔB_{slot} detected by the SQUID from a 4.2 mm-deep slot at different excitation frequencies is shown in Figure 1. The corresponding field signal from the edge of the stack

Figure 1. Response of the 4.2 mm-deep slot at excitation frequencies of 10, 90 and 160 Hz. ΔB_{slot} and ΔB_{edge} for the excitation frequency of 90 Hz are indicated in the figure and in the inset respectively.

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Figure 2. A slot covered with aluminum plates to simulate a buried crack. The scanning direction and the alignment of the double-D coil are also shown here.

ΔB_{edge} is shown in the inset of Figure 1. The sample was a stack of aluminum plates with a slot of width 2 mm in one plate to simulate a buried crack. The geometry of the sample is shown in Figure 2. Both ΔB_{slot} and ΔB_{edge} were found to be weak at the excitation frequency of 10 Hz. At the higher frequencies of 90 and 160 Hz, ΔB_{slot} increases at first and then decreases.

The frequency dependences of ΔB_{slot} and ΔB_{edge} for the slot at different buried depths are shown in Figure 3. The frequency dependence of ΔB_{edge} at the edge is shown in the inset. It was found that ΔB_{edge} increased monotonically with increasing frequency up to 800 Hz. On the other hand, the most effective excitation frequencies f_m [2] for ΔB_{slot} were found to be at 200, 120, and 70 Hz respectively for buried slots of depth 1.4, 2.8 and 4.2 mm. In other words, the value of f_m for the slot is lower as the slot is deeper. Besides, the value of f_m for a buried slot of 0.6-mm wide was found to be 120 Hz in contrast to 200 Hz for the 2 mm-wide slot at the same buried depth of 1.4 mm as shown in the dashed line of Figure 3. Hence, for the same slot depth, f_m is lower if the width of the buried slot is narrower. We note that the value of ΔB_{slot} is 0.2 nT for a buried slot of depth 4.2 mm and width 2 mm excited at an optimal frequency of 70 Hz. The noise level of the SQUID in an unshielded environment is $0.02 \text{ nT/Hz}^{1/2}$ at 70 Hz. Although one may use a lower f_m to optimize ΔB_{slot} for the deeper slots, the ΔB_{slot} becomes weaker for the deeper slots. In this case, the noise level of the SQUIDs at the low frequencies may exceed the detected signal ΔB_{slot} . Therefore, a SQUID with

Figure 3. ΔB_{slot} at various excitation frequencies for the 2 mm slot at the depth of 1.4, 2.8, and 4.2 mm. The dash curve is the result for a 0.6 mm-wide, 1.4 mm-deep slot. The inset is ΔB_{edge} of the stack at various excitation frequencies

better low frequency noise level is essential in order to probe deeper slots.

4. CONCLUSION

In summary, the most effective excitation frequency f_m for the SQUID NDE system depends on the depth and the width of the crack. For a deeper crack, the f_m is found to be lower. Besides, the higher the noise resolution at low frequencies, the better the signal to noise ratio the SQUID NDE system can have.

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