A study on the spacing of roving body placement for natural frequency-based crack detection

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Summary

Efforts to use natural frequency measurements to identify the presence of cracks in structures, as well as to locate them and assess their severity, remain an active subject of research [1-3]. The determination of natural frequencies for structures with cracks of known location and severity is relatively straightforward, with several methods—both exact and semi-analytical—commonly employed depending on the type of structure [4, 5]. However, determining the presence, location, and severity of cracks involves solving an inverse problem, which is considerably more challenging, as multiple combinations of crack number, location, and severity can lead to the same natural frequencies. While the use of measured frequencies from multiple modes can help, it still demands substantial computational effort. One promising approach leverages the characteristic that the natural frequencies of skeletal structures exhibit a steep change when the position of a roving auxiliary body is shifted across a crack [2]. This phenomenon arises from the discontinuity introduced by the crack's rotational flexibility and the rotary inertia of the attached body. In practical applications, the auxiliary body can only be attached over a finite area rather than at a point, resulting in a steep—but not abrupt—change in frequency.

Previous experimental work we conducted [1] demonstrated that the expected frequency change across a crack can be obscured by the inherent variation in natural frequency caused by the changing location of the roving mass itself. Specifically, our findings indicated that the observed frequency differences between adjacent positions of the roving body were not always due to the presence of a crack; instead, they could result from the mass-induced shift in the structure's dynamic response. For the beam tested and the roving body designed (Figure 1), it was a challenge to distinguish between frequency changes due to mass relocation and those due to the crack, for example as shown in Figure 2.

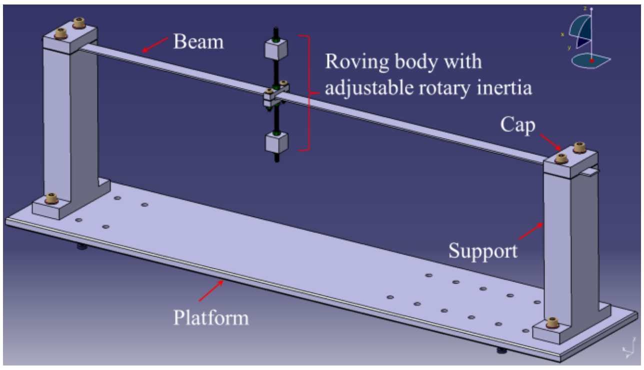

Figure 1. Experimental Setup in [1]

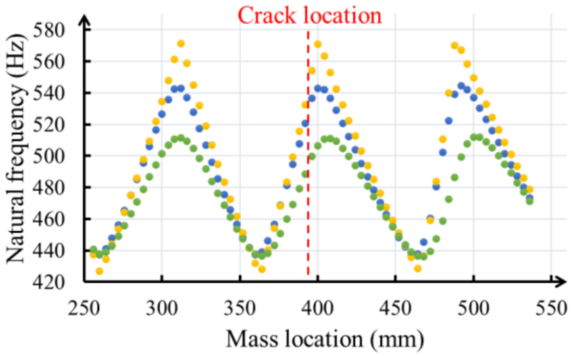

Figure 2. The 7th natural frequency versus mass location (20% crack. Green dots – experiment results using impact hammer test; blue dots – simulation results using ANSYS; yellow dots – analytical results using Dynamic Stiffness Method).

One aspect of our current work to address the above challenge is discussed here. That is to investigate how the spacing of roving body placement affects the measurability of frequency shifts due to crack as the body passes over a crack. Understanding this may help to find a way to determine a suitable spacing that is small enough to ensure that the effect of the frequency due to the mass relocation can be eliminated. The discussion is based on the experimental setup described in [1], wherein the same clamped-clamped cracked beam model and the same magnitude of mass and rotary inertia are used, and the crack depth remains 20% of the beam height. The results were generated using the Dynamic Stiffness Method (DSM).

The natural frequency change, denoted as Δf, resulting from shifting the mass across a crack, includes two components: the frequency change due to the mass relocation itself (Δf_{mass}) and the frequency change due to the crack as the mass passes it (Δf_{crack}). It is given by,

$$\Delta f = \Delta f_{mass} + \Delta f_{crack}. \tag{1}$$

Δf_{crack} is useful for crack detection but can be obscured by Δf_{mass}.Therefore, to extract Δf_{crack}, Δf_{mass} can be deducted from Δf.

In this study, Δf_{mass} is obtained by shifting the same auxiliary mass on an intact (uncracked) beam and calculating the frequency change between adjacent mass locations, while Δf is calculated under two different configurations. In the first configuration, the 20% crack is located at 0.394m from the left boundary (as in [1]) and the mass is incrementally shifted by Δx after each frequency calculation, as shown in Figure 3.

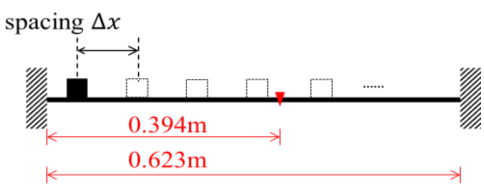

Figure 3. The first configuration for Δf calculation.

In the second configuration, the 20% crack is not located in a fixed position, instead, it is assumed that as the mass is shifted along the beam, it always passes over the crack in the subsequent placement, as illustrated in Figure 4.

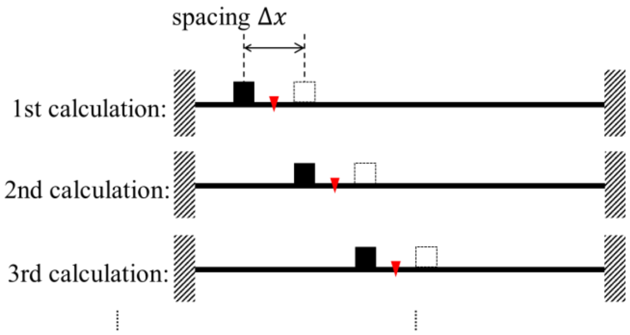

Figure 4. The second configuration for Δf calculation.

Based on the first configuration, after subtracting Δf_{mass} from Δf, the results of Δf_{crack} versus mass location for the first four natural frequencies with spacings of 4mm, 10mm, and 20mm are shown in Figure 4. The results indicate that after removing the influence of Δf_{mass}, it is possible to locate the 20% crack using all three mass spacings, while in [1], it was challenging to pinpoint the crack location using 4mm spacing although the crack-induced frequency change was still measurable. However, it should be noted that the methodology in [1] relies solely on data obtained from the cracked beam, whereas the approach adopted here involves deducting Δf_{mass} from Δf, essentially introducing the response of the uncracked beam as baseline information, which may not be readily available in practice. However, the results here show that using a small spacing effectively suppresses fluctuations in Δf_{crack} curves due to the relocation of the mass.

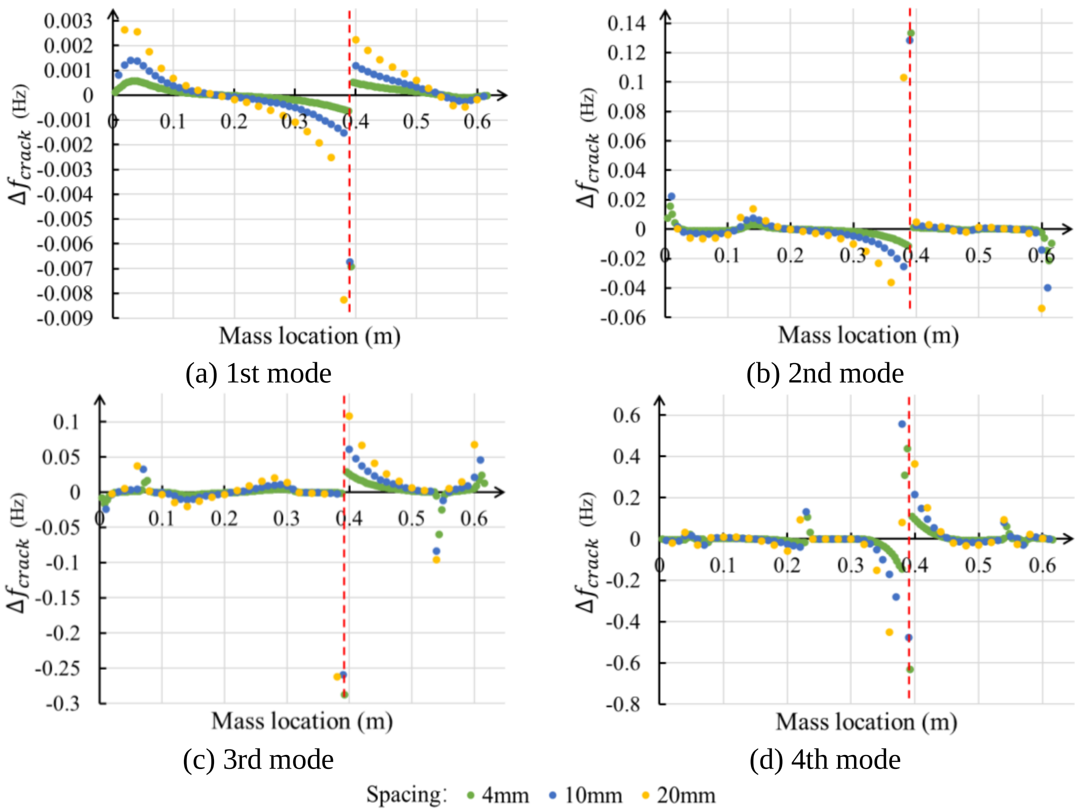

Figure 5. The results of Δf_{crack} using three different spacings based on the 1st configuration (the red dashed line indicates crack location).

Similarly, based on the second configuration, the results of Δf_{crack} versus mass location for the first four natural frequencies with spacings of 4mm, 10mm, and 20mm are shown in Figure 5. It can be observed that the influence of the crack on different modes varies with crack location, while the effect of mass placement spacing is less pronounced than in the first configuration. The Δf_{crack} results exhibit anti-symmetry due to the symmetry of the structure, boundary conditions and layout of roving body positions. In different modes, Δf_{crack} approaches zero at different positions, possibly due to the modal curvature approaching zero near those locations, thereby effectively negating the influence of the rotational flexibility introduced by the crack. Thus, it is necessary to use more than two modes for crack detection as relying on a single mode may result in missed detection when the crack is located at positions where that mode is insensitive to its presence. These results show that the effect of the shift in the mass location is one of the factors that pose a challenge in identifying the location of crack through measured frequency shifts. It is acknowledged that other factors must also be considered in developing a reliable system to locate the cracks based on natural frequency measurements for practical applications.

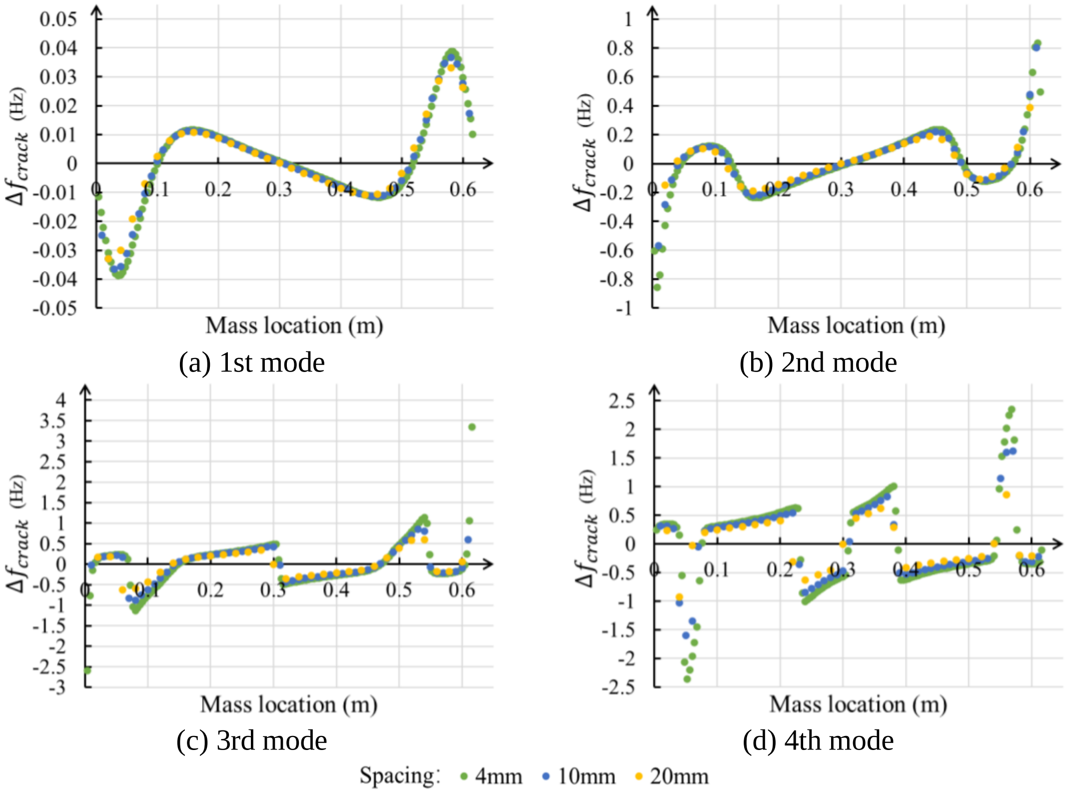

Figure 5. The results of Δf_{crack} using three different spacings based on the 2nd configuration.

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