On Modelling of the Behavior of Fatigue Cracks in Structures Subjected to Vibration or Wave Excitation

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Motivated by the rapid development of NDE techniques and SHM systems for detection and evaluation of fatigue cracks, many theoretical and computational studies attempted to establish a correlation between the vibration and ultrasonic guided wave responses of a structure and the presence, size, shape and location of fatigue cracks. These studies usually neglected detailed modelling of crack behaviour in favor of various simplified assumptions, e.g., assuming that the crack always remains fully open (slit model), or that the crack is fully open for tensile loading and fully closed for compressive loading (breathing crack model). These simplified assumptions, however, ignore the physical reality that real fatigue cracks are likely to be partially closed in the absence of the applied loading; the latter typically correspond to defect and safety inspection conditions. Moreover, a certain load (the crack tip opening load) is required to fully separate crack faces or fully open fatigue crack. The crack closure phenomenon, which is known since 1970th, could be due to several reasons, e.g. due to the formation of the plastic wake behind the crack tip or surface roughness of crack faces. The current work evaluates the adequacy of the popular slit and breathing crack models to simulate fatigue crack behaviour under vibration and guided wave excitations. In particular, the breathing crack model has been widely used in recent studies related to the contact acoustic nonlinearity (CAN) and generation of high-order harmonics by fatigue cracks. The current approach utilises the yield-strip concept and the Distributed Dislocation Technique to study the plasticity-induced crack closure, which normally dominates crack closure mechanisms for relatively long fatigue cracks, say above 5 mm. It is shown that in the absence of the applied loading, approximately a half of a fatigue crack can be closed due the plastic wake and residual compressive stress. It is also demonstrated that the slit model could be applied to describe the behaviour of fatigue cracks subjected to certain vibration excitation conditions, while no such conditions are found for the breathing crack model. Finally, though both models have been utilised in many studies, it is doubtful whether the outcomes of these studies could be reliably implemented in practice without the use of more realistic models of fatigue cracks, which behaviour is generally strongly influenced by crack closure effects.