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THE DETECTION OF DEFECTS OF MECHANICAL STRUCTURES USING SURFACE ACOUSTIC WAVES (SAW)

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Abstract: *The article gives the general view to the detection of defects (rather the cracks) of mechanical structures through initializing and receiving so-called Rayleigh waves, which have value over 1 MHz (ultrasonic). The detection of cracks in solids using ultrasound is known for several decades, but as a method continuous monitoring (on-line) of cracks during operation of structures is being developed only a few years. Main physical properties SAW are; waves may be created and propagated only at surface materials (with small dissipation) and ability surface waves to penetrate into the certain depth under surface. In addition, depth of penetration depended of wave frequency. In conjunction with the fact, that the surface-breaking crack behaves as a low-pass filter, the SAW have a perspective in detection of cracks. This is the subject of analysis. In addition, attention focus to selection potential appropriate parameters for detection, which would detect cracks effective and also monitor ones propagate in the material.*

Keywords: ***Nondestructive testing, surface acoustic waves, on-line method, cracks.***

1. Introduction

Properly on-line nondestructive testing method of detection of surface-breaking cracks for mechanical structures must satisfy several criteria:

- Method must use the smallest sensors and equipment because crack is being created often in difficult to access place.
- Method should not be calibrated for individual case of structural monitoring.
- The detection of crack must have un-ambiguous results.
- On-line monitoring system must be robust towards environmental noise and varying conditions of mechanical structures.
- Crack should be detected as soon as possible.
- Easy in terms of interpret and computational time.

Many articles, which were published in conferences and journals showed that on-line method, which use ultrasonic surface waves, may satisfy criteria presented above. This method use small and powerful sensors and measuring equipments with high sensitivity. Due the high frequency transducers robustness of method towards environmental noise can be attained. The inverse proportional between penetrate depth d and wave frequency f cause high sensitivity of method. Even, this method reaches better sensitivity than for example optical or gage method. Indeed, SAW or Rayleigh waves penetrate approximately one wavelength λ into the material (Vanlanduit et al., 2003). Up to 95 % wave energy transmits in this penetration depth. Rayleigh wave velocity is c (for steel is c = 3240 m.s^{-1}).

$$f = \frac{c}{\lambda} = \frac{c}{d} \tag{1}$$

The penetration depth in function of its frequency is showed in figure 1. We can use this property of SAW to the cracks detection, because discontinuities cause reflection of surface waves. Therefore, the surface-breaking crack causes complete scattering (reflection) of spectral part of the signal, which is formed SAW having wavelengths smaller than crack length. Unfortunately, this theorem doesn´t true quite. Waves scattering depend on the stress-state of place with crack. In other words, when the crack

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is closed (e.g. caused by bending beam), through crack is transmitted full signal energy without reflection. Thus, statistic parameters must use for detection and monitoring of cracks.

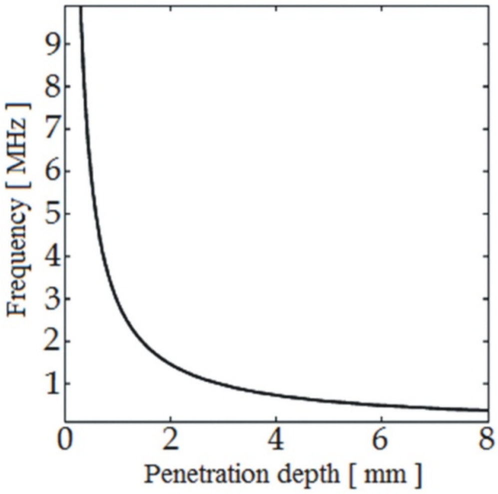

Fig. 1: Penetration depth versus its frequency.

2. The describe of the potential appropriate parameters

Proposed the on-line methods of cracks detection use information about transmitted (there are two sensors, crack is between the; pitch-catch mode) or reflected (there are one sensor; pulse-echo mode) signals in time and frequency domains. Firstly, attention to possible transmission of signal through tightly closed crack is given.

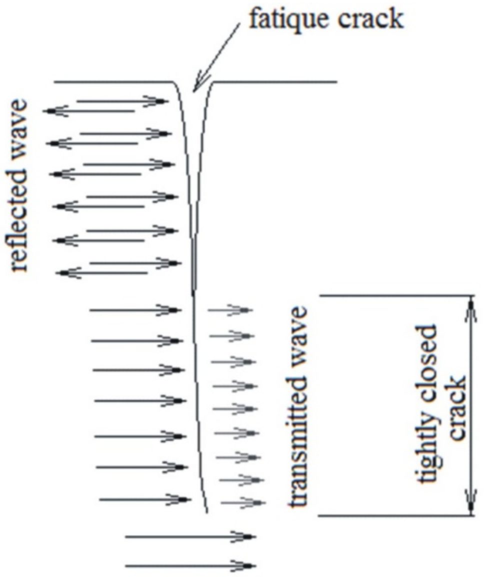

Fig. 2: The different interactions of crack with SAW.

The different interaction of surface waves with tightly closed crack is given in Fig. 2. Roughly half of energy SAW is transmitted through crack, because crack is partially closed (crack areas are touching). This state may cause bad detection of crack, i.e. underestimating of size of a crack and suppression of detection of small cracks (Harri et al., 2006). Therefore, statistical parameters must be used in evaluation of crack monitoring, when load cause opening and closing of fatigue crack. Satisfactory experimental results of fatigue cracks detection was achieved sensing of the receiving signal amplitude (especially in frequency domain). Crack can be either open or close, when mechanical system is subjected operating load. Then, if surface waves from transducer are transmitted (with greater frequency as the load) through crack, amplitudes of received waves have varying values. Of course, crack length must be larger that wavelength, also frequency of waves sending must be higher as the load frequency. So-called effect the breathing crack causes varying the amplitude values. Therefore, minimum amplitude may be satisfactory experimental parameter. The experimental results (amplitude of transmitted spectral component) for crack detection are showed in Fig. 3 (Harri et al., 2006). The dispersion of the amplitude components (2 and 5 MHz) started to grow in certain moment. Effect the breathing crack caused decrease of the minimum amplitude. Because the maximum amplitude of transmitted signal remained constant, the dispersion of the amplitude (the difference between maximum and minimum amplitude) increased proportionally with the number of load cycles (number of measurements).

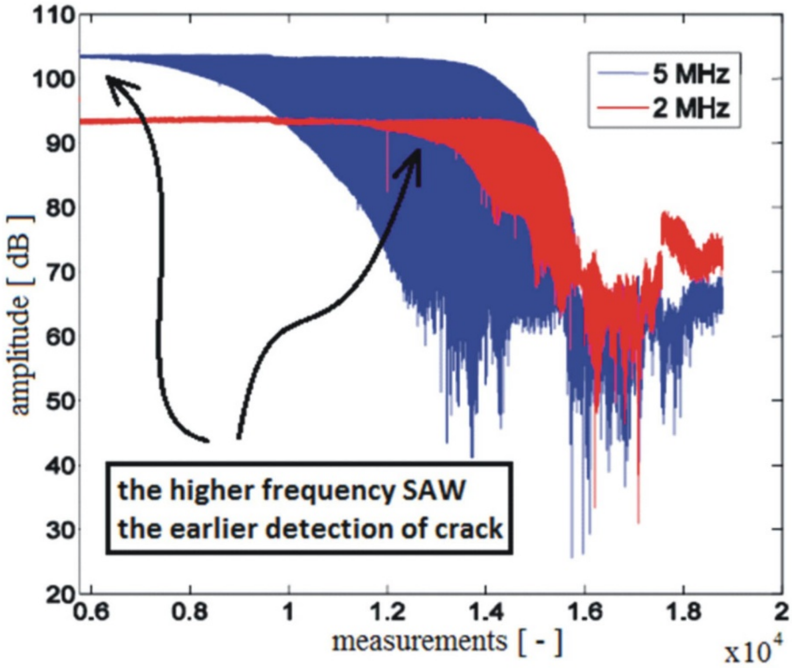

Fig. 3: Amplitude of the 2 and 5 MHz spectral components.

The minimal amplitude of 5 MHz spectral components started to grow in earlier moment than minimal amplitude of 2 MHz component. Then, amplitude of the SAW can be used to monitor crack depth and to estimate its length in the material. Note that plastic deformation of the crack root causes decrease of the maximal amplitude. This is due to the fact that the crack is not closed.

The phase indicator is also good statistical parameter for the detection of the crack (only pulse excitation). The creation of the crack causes stiffness decrease of the mechanical systems. Thus the greater depth of the crack the smaller stiffness of mechanical system. If distance between the sensors (pitch-catch mode) is l and phase difference of the SAW is $\Phi = 180°$, the spatial difference can be computed from equation (2)

$$\delta l = \frac{c}{2f} \tag{2}$$

$$\varepsilon = \frac{\delta l}{l} \tag{3}$$

and the strain ε can be computed from equation (3). Therefore, if there is a sudden increase in the strain, crack was created very probably. The phase indicators versus a crack length is given in Fig. 4 (Vanlanduit et al., 2003). Better sensitivity than for the amplitude indicators is showed (the crack was detected for its length about 0.17 mm, i.e. improvement toward previous indicator is 15%; this case).

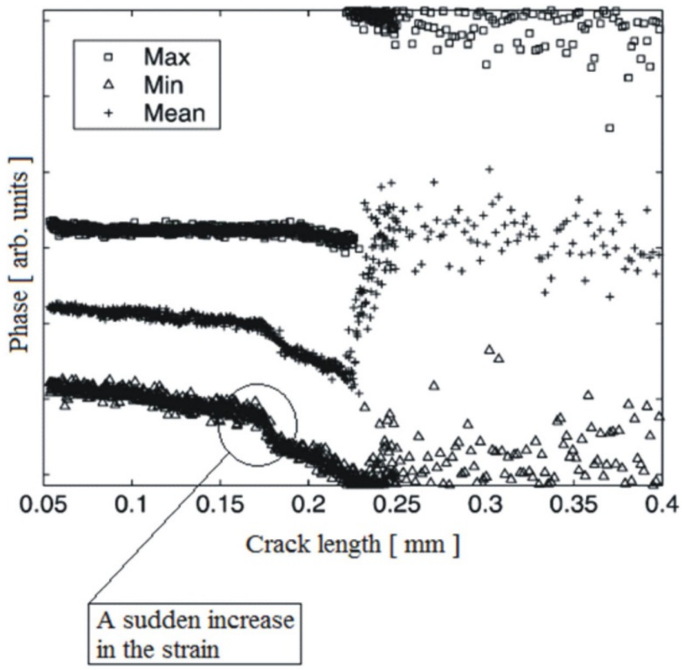

Fig. 4: Phase indicators in function a crack length.

Unfortunately, the monitoring of crack occurs impossible for larger one length, when signal-to-noise ratio has small value. Consequently, the phase indicator is good statistical parameter for detection of small crack.

3. Conclusions

The method of surface acoustic waves (Rayleigh waves) for detection of crack was presented. Firstly, several important criteria for on-line detection of crack and fundamentals of method were explained. Secondly, the appropriate statistical indicators of method were designed - minimum amplitude and phase of SAW. Experiments showed that the minimum amplitude is very good indicator of detection, because we can detect and monitor crack using this parameter quite reliably. The phase indicator is better parameter than minimum amplitude, but one is appropriate only for detection of small cracks, because small value of signal-to-noise ratio attains for larger crack length.

Acknowledgments

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