DOI 10.5162/SMSI2023/P16

Material Characterization by Ignition Spark Excited Lamb Waves

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Summary:
Material characterization using contactless excited and detected guided acoustic waves is a well proven, but overall expensive approach, since a cheap method of excitation is missing so far. Ignition-spark-excitation of Lamb waves could be such a method but has not shown to be suitable for material characterization yet. Covering various thicknesses and materials of metal plates, systematic dependencies of the spectral amplitude of the ignition-spark-excited Lamb waves are presented in this work. This enables the approach to be an alternative for exciting Lamb waves for material characterization.

Keywords: contactless excitation, Lamb waves, electric spark, non-destructive testing, material characterization

Background and motivation

For several decades, the use of Lamb waves as a type of guided acoustic waves (GAW) promised to be a useful approach for characterizing material properties [1,2]. However, if a contactless and non-destructive technique of excitation is required, the only common choices are laser-based excitation and measurement [3] as well as electromagnetic acoustic transducers (EMAT) [4]. As this comes along with a high financial effort, a cheaper technique for contactless and non-destructive Lamb wave generation is desired. Krempel et al. [5] presented such a technique using a very basic ignition coil - spark plug design. With this, they successfully excited the antisymmetric Lamb A0 mode in a metal plate at a broad and low frequency range up to 200 kHz with a maximum at about 30 kHz. However, the potential of using the so generated Lamb waves for material analysis, was still unclear.

Therefore, in this work, the setup of [5] is adapted to investigate the possibility of material characterization with the excited Lamb waves.

Methodology

The experimental setup is shown in Fig. 1. A suppressed spark plug of type NGK Iridium CR7HIX (1) with removed counter electrode, supplied by a non-suppressed ignition coil Jinan Qingqi QM50QT-6(A), was connected with a self-made electronic switchbox (2). The box was powered by a 30 V DC power supply Tenma 72-7245 and was controlled by a periodic pulse from a function generator of type Agilent 33521B with 200 µs pulse width and a repetition rate of 33.3 Hz. Every time the current was interrupted by the switch, the spark plug generated an electric spark on a metal plate (3) serving as the counter electrode (distance between metal plate and spark plug was 1.4 mm). This spark caused electromagnetic interferences which could be captured via an oscilloscope LeCroy HDO6034.

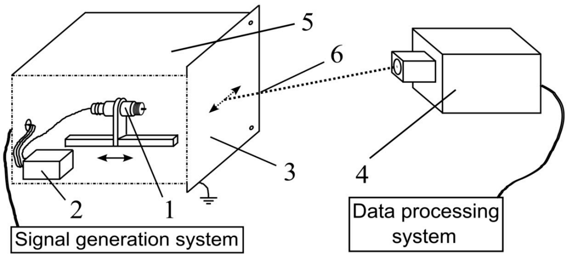

Fig. 1. Illustration of the experimental setup

Out of this, it then generated a trigger signal which was transmitted to the control unit of a laser scanning vibrometer of type Polytec PSV-400-M (4). For reasons of electromagnetic compatibility, the spark plug as well as the ignition coil and the switchbox were installed in a stainless steel box (5). To analyze the propagation of the Lamb waves generated by the electric sparkover, a horizontal line (6) on the outer surface of the metal plate was scanned by the vibrometer. For each of the 316 scanning points (0.44 mm distance) in this line, the surface deflection of the metal plate was captured for 500 µs (10.24 MHz sample frequency). Further data processing especially included the performance of one- and two-dimensional Fourier transforms for characterizing the resulting Lamb wave in the frequency domain.

During the experiments six different plate thicknesses as well as three different materials were investigated to evaluate whether they cause remarkable changes in the signal.

Results

The amplitude spectrum for using a range of 1 mm thick metal plates is shown in Fig. 2.

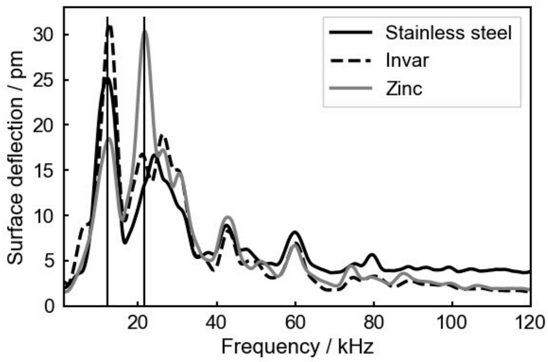

Fig. 2. Surface deflection vs frequency for different plate materials including main peaks (vertical lines)

At about 12 kHz, Invar shows the highest spectral amplitude followed by stainless steel and Zinc. Whereas at 21.5 kHz, Zinc shows a much higher amplitude than Invar and stainless steel.

Having the same material - stainless steel - but different thicknesses, has an even stronger effect on the location of the spectral main peak. When decreasing the plate thickness, the peaks are shifted towards lower frequencies and lower wavenumbers. Depicting the phase velocity with respect to the product of central frequency (maximal amplitude) and thickness gives a progression which is well represented by a linear relation (Fig. 3.).

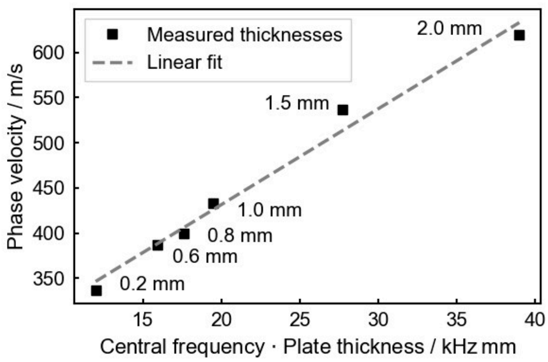

Fig. 3. Phase velocity vs frequency-thickness-product for different stainless steel plate thicknesses

Consequently, this approach enables to distinguish between different plate materials and thicknesses with the generated Lamb waves.

Repeatability measurements showed that related changes in the amplitude spectrum were small compared with those of different materials and thicknesses. Besides, various distances between the spark plug electrode and the plate surface demonstrated to change the absolute spectral amplitude only, but not the peak locations or ratios. In addition, microscopic investigations revealed no noticeable damage of the plate surfaces, so it is reasonable to call it a non-destructive approach.

Conclusions and outlook

Summarizing the results of the presented investigation, the spark-excited Lamb waves show systematic dependencies on plate thickness and material properties. Since repeatability measurements confirm the results, the so excited Lamb waves offer a possibility for being used for distinguishing between different plate thicknesses and materials. This opens the potential for the presented approach to be a low-cost alternative for contactless excitation of Lamb waves. Going beyond the presented results there are strong indications for a pressure wave as the dominating physical reason (over thermal expansion) for the Lamb wave excitation. This must be investigated further in order to completely understand the physical processes happening when exciting Lamb waves using ignition sparks.

Acknowledgements

The authors thank the various supporters of the project at ISAT, especially Sabrina Tietze, Florian Dötzer, Jürgen Fahrenberger, and the European Fund of Regional Development (EFRE) within the project "InnoTerm".

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