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Modal interaction in ultrasonic welding block sonotrodes induced by the mistuning of the material properties

Francois Brouet [a,*], Jens Twiefel [b], Jörg Wallaschek [b]

[a] *Herrmann Ultraschalltechnik, Descostr. 3–9, 76307 Karlsbad, Germany*
[b] *Institut für Dynamik und Schwingungen, Leibniz Universität Hannover, Appelstr. 11, 30167 Hannover, Germany*

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ABSTRACT

In many ultrasonic applications, block sonotrodes are serially coupled with other tuned components to transmit the longitudinal vibration to the workpiece. Uniform vibration amplitude of the output surface is an important criterion for determining quality. It is known that amplitude uniformity is related to other non-tuned modes. In this paper, another type of modal interaction is used to quantify distortion of the first longitudinal mode, when the system exhibits a loss of symmetry (mistuning) and near natural frequencies.

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* Corresponding author.
E-mail address: francois.brouet@herrmannultraschall.com (F. Brouet)
URL: http://www.herrmannultraschall.com (F. Brouet).

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1. Introduction

High-power ultrasonic devices are used in a wide range of industrial applications, such as welding, bonding and cutting. In general, sonotrodes are driven in the first longitudinal vibration mode by an ultrasonic transducer, typically in the frequency range of 20–40 kHz, equal to the ultrasonic system depicted in Fig. 1. Due to the complex geometries of sonotrodes, non-tuned modes can cause mutual interactions. Review of the different types of modal interactions in ultrasonic devices revealed some coupling mechanisms due to the presence of other modes near the operating mode and due to special relationships between eigenfrequencies.

In practice, the first effect of a modal interaction is an undesired modification of the uniformity of the vibration amplitude, which is crucial for the welding quality. Derks [1] stated that nearby modes can be coupled to the first longitudinal mode of vibration of block sonotrodes and are associated with a poor vibration amplitude uniformity. The isolation of the longitudinal mode from nearby modes results in a good amplitude uniformity and in the elimination of parasitic flexural motion [2].

The second consequence of a modal interaction features a poor operating performance and an increase of audible noise levels. Modal interactions may occur if special relationships exist between the excitation frequency and one or more modal frequencies, see Cartmell et al. [2,3]. Excitation of the longitudinal mode can excite one or two other modes through internal resonance. A significant amount of energy is leaking into low-frequency non-tuned modes because of the specific frequency relationships. The sonotrode may exhibit parasitic flexural or torsional responses, causing failure or audible noise [4,5].

Mode degeneration and frequency veering in dynamic structures was discussed by Afolabi [6]. The phenomenon of degenerating modes is investigated in this manuscript, since it exhibits the same features of swapping eigenshapes when non-tuned modes are close to the operating mode. It is well known to suppliers of ultrasonic equipment that designing blade sonotrodes of about 130–150 mm width at 20 kHz can be troublesome [1]. The block sonotrodes show strong radial amplitude at some critical aspect ratios because of coupling with a secondary mode. A thin cylindrical ultrasonic tool shows two modes with the same number of nodes but with different axial and radial components [7]. While the shape aspect ratio is changed, the mode frequencies approach each other and abruptly veer away again, taking on the trajectory of the other along two asymptotes. All modal properties, such as damping ratios and eigenvectors, are swapped in the frequency veering regions. The curve behaviour is well known as *frequency veering*, in contrast to *frequency crossing*, as depicted in Fig. 2. The consequence for the eigenshapes is *mode degeneration* or *mode localization* encountered in cyclic structures, such as turbomachineries, bridges or rotating cantilever beams.

In the simulated modal analysis, it is a big challenge to design a reliable sonotrode geometry in order to avoid these problematic consequences. Combination resonances have been widely investigated in the literature and the dynamic

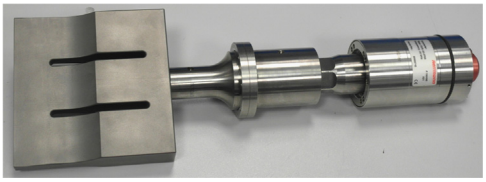

Fig. 1. Ultrasonic welding system operating at 20 kHz.

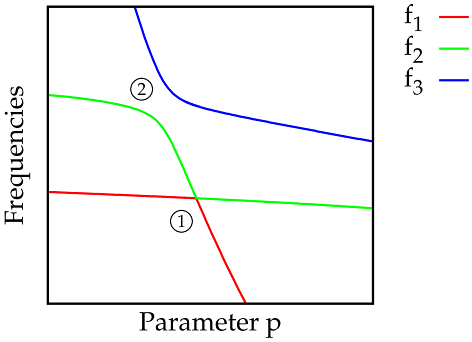

Fig. 2. Illustration of frequency crossing (1) and frequency veering (2).