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MODELING OF THE ULTRASONIC WELDER/SPECIMEN CONTACT FOR VIBROTHERMOGRAPHY

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ABSTRACT

Vibrothermography nondestructive evaluation, also known as Sonic IR and thermosonics, finds cracks by vibration-induced crack heating. The most common vibration source in the industrial practice of vibrothermography is the ultrasonic welder, which generates high amplitude single frequency vibration. In most applications, the single frequency excitation of the welder is transduced into the broadband resonances of the specimen by repeated impact between welder tip and specimen. We present progress in modeling and verification of a predictive model for ultrasonic welder excitation for vibrothermography.

INTRODUCTION

Vibrothermography nondestructive evaluation [1], also known as Sonic IR and thermosonics, finds cracks by vibration-induced crack heating. Some kind of vibration source is required. In the laboratory sometimes tunable broadband vibration sources such as piezoelectric stack actuators are used for precision measurements, but these generally lack the power demanded for industrial applications. The most common vibration source in the industrial practice of vibrothermography is the ultrasonic welder. Ultrasonic welders are tuned resonators that convert electrical energy into ultrasonic vibration at very high efficiencies. Because they are tuned, they are narrowband and generate vibration at only a single frequency, which is determined during manufacturing. Commercially manufactured ultrasonic welders are available at a few standard frequencies such as 20 kHz and 40 kHz.

Because vibrothermographic heating is usually dominated by resonance effects [2], in order for the welder to be effective some mechanism must be provided to transduce the narrowband vibration generated by the welder into a broader range of frequencies that can excite resonances in the specimen. The most common method for this is a contact nonlinearity. Sometimes termed "acoustic chaos" [3], a dry contact between welder tip and specimen supports compression but not tension, so that as the welder tip vibrates there is a repeated series of impacts as welder and specimen move.

MODELING

Modeling the welder excitation is difficult because it involves a highly nonlinear process – the impact of welder tip against the specimen. It is also difficult because accurate vibration prediction is notoriously difficult, largely because it requires meaningful models of the dynamic behavior of mounting boundary conditions. We address these difficulties by breaking the problem down into pieces, so to the largest extent possible any problems in each piece can be addressed independently.

Specifically, we break the welder-contact-specimen assembly into separate models of the welder, contact, and specimen. An equivalent mechanical circuit illustrating the three components is shown in Fig. 1. significantly simplifies the model because the welder and specimen can be treated as linear elements connected by the nonlinearity of the contact. We treat the contact

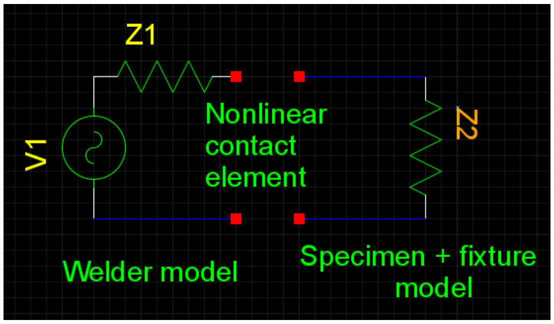

Figure 1. Equivalent circuit model for ultrasonic welder, nonlinear contact, and specimen

as a nonlinear spring that can hold compression but no (or almost no) tension.

The three component models have been developed separately. Since no accurate electromechanical model for the welder is available, we have measured the welder behavior empirically by monitoring its response to a step unloading force to obtain an empirical Green's function. Since the specimen is likely to change drastically from application to application, it is modeled numerically using finite element calculations on a linear elastic model in the time domain to obtain a numerical approximation of its Green's function. The nonlinear contact between the linear welder model and the linear specimen model is represented by a nonlinear spring.

INTEGRATION OF WELDER MODELS

The combination of welder, contact, and specimen models can be integrated using Euler's method. Initial attempts to perform this integration ran afoul of convergence problems because of phase errors in the empirically observed welder response. In the numerically integrated welder model we tend to observe the natural frequencies of the specimen, excited by repeated impact of welder and specimen. A sample spectrum is shown in Fig. 2.

SUMMARY

The ultrasonic welder excitation used in vibrothermography can be modeled as a system of three components: The welder, the specimen, and the nonlinear contact. Breaking the system into those components drastically simplifies the model and makes it possible to validate each component against experiment as an intermediate step, likely leading to a more accurate model.

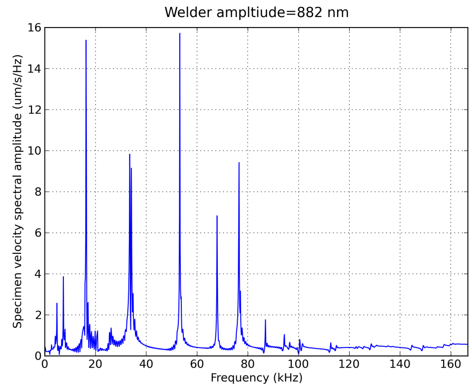

Figure 2. Example output spectrum from ultrasonic welder model.

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