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OPTIMISED SAMPLING STRATEGIES FOR SELF-REFERENCED THERMOELASTIC STRESS ANALYSIS

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1. Introduction

The ability to analyze the temperature frequency content on materials under dynamic loading may enhance the analysis of thermomechanical couplings [1,2]. A peculiar signature in the frequency domain is indeed left by the thermoelastic effect, where elastic straining produces temperature variations. Other peculiar signatures may arise after the onset of damage, e.g.: stress relief following cracking, phase transitions, thermo-mechanical heat dissipation, etc. Specifically, Thermoelastic Stress Analysis (TSA) is renowned for providing quantitative stress parameters, subject to an accurate knowledge of the loading frequency, needed for an effective Temperature frequency demodulation. In the absence of such knowledge, coherent sampling cannot be ensured, potentially resulting in spectral leakage and poor noise filtering [3].

This study examines the conditions necessary to avoid spectral leakage and the risk of aliasing in self-referenced TSA. The impact of spectral leakage is evaluated with diverse signal processing techniques. The occurrence of aliasing collision frequencies is discussed concerning the choice of sampling parameters, and the role of synchronous and asynchronous sampling is discussed.

2. Materials and methods

TSA requires the filtering of harmonics from a temperature signal sampled over a time interval. Three signal processing schemes have been implemented: Digital Cross-Correlation (DCC) [2], Discrete Fourier Transform (DFT) [3] and Least Square Fitting (LSF) [1,4].

DCC provides the in-phase, *X*, and in-quadrature, *Y*, harmonic components with respect to a reference signal built upon the frequency being filtered:

$$X = \frac{2}{N}\cdot\sum_{j=1}^{N} T_j \cdot \sin\left(\frac{2\pi}{N}k\cdot j + \phi_r\right);\quad Y = \frac{2}{N}\cdot\sum_{j=1}^{N} T_j \cdot \cos\left(\frac{2\pi}{N}k\cdot j + \phi_r\right) \tag{1}$$

where N is the number of samples, ϕ_r is the phase shift between the self-reference signal and the initial sampling time [2], and $f_L=k\times f_f$ is the filtered frequency, with k being an integer multiple of the fundamental frequency $f_f=f_s/N$ and f_s the sampling frequency. The DFT formula of the k_{th} harmonic can be written as:

$$H_k = \sum_{j=1}^{N} T_j \cdot \left[\cos\left(\frac{2\pi}{N}k\cdot j\right) - i\cdot\sin\left(\frac{2\pi}{N}k\cdot j\right)\right] \tag{2}$$

where eqs. (1) and (2) are equivalent when k represents the frequency bin-number of the Fourier frequency domain. Finally, the implemented LSF is based on the minimisation of the sum of the square difference between the sampled temperature and its analytical model represented by:

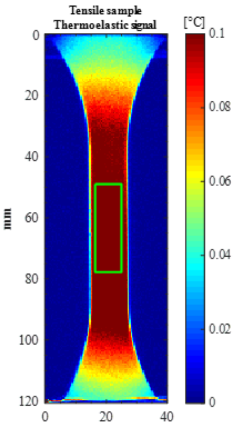
$$T_{\text{mod}}(t) = E \cdot \sin(2\pi f_L \cdot t + \phi_E) + D \cdot \sin(2\pi \cdot 2 f_L \cdot t + \phi_D) + \sum_{k=others} H_k \sin(2\pi \cdot n_k f_L \cdot t + \phi_k) \quad (3)$$

If k=0:(N-1)/2 terms are considered and an integer number of periods is included in the sampling time interval, then the LSF analytically coincides with the DFT [4].

The above signal processing schemes have been implemented to analyze a dog bone tensile specimen of stainless steel AISI 304l, under sinusoidal R=0.1 loading. The temperature is sampled with a FLIR X6540sc IR camera, with f_s=150 Hz.

3. Results and conclusions

A map of the thermoelastic signal amplitude ΔT and a table reporting average values obtained with varying N, f_L and k are reported in fig. 1.



		f_L= (k-1)*fs/N			f_L=15 Hz			DCC with physical reference signal
		DFT	DCC	LSF	DFT	DCC	LSF	FLIR-THESA
***N*=4550** k=455 – f_L=15	**Δ*T* [°C]**	0.104	0.104	0.104	0.104	0.104	0.104	0.104
	St. dev [°C]	0.003	0.003	0.003	0.003	0.003	0.003	0.004
***N*=4553** k=455.3	**Δ*T* [°C]**	0.0894	0.0894	0.0894	×	0.125	0.104	
	St. dev [°C]	0.003	0.003	0.003	×	0.003	0.003	
	Err %	14.0	14.0	14.0	×	-20.2	0.0	
***N*=4555** k=455.5	**Δ*T* [°C]**	0.067	0.067	0.067	×	0.163	0.104	
	St. dev [°C]	0.002	0.002	0.002	×	0.003	0.003	
	Err %	35.6	35.6	35.6	×	-56.7	0.0	

Fig. 1. Thermoelastic map and thermoelastic signal values for different processing schemes, frequency bins and numbers of processed samples.

It is found that DCC and DFT produce different errors due to non-coherent sampling and spectral leakage. LSF is not affected by non-coherent sampling if it is performed knowing the correct loading frequency. For DCC and DFT to provide accurate results, the following coherent sampling conditions must be ensured:

$$\frac{f_L}{f_s} = \frac{(k-1)}{N} \quad \text{where } k \text{ and } N \text{ must be integers} \qquad (4)$$

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