APPLICATION OF SIGNAL ANALYSIS TO INTERNAL FRICTION MEASUREMENTS

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APPLICATION OF SIGNAL ANALYSIS TO INTERNAL FRICTION MEASUREMENTS

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Résumé - Un système entièrement automatisé de mesure de frottement intérieur (FI) a été construit. Il mesure le FI par analyse de forme de la décroissance libre. Cette méthode élimine les perturbations dues aux mouvements parasites de l'échantillon et présente une faible dispersion même aux petites amplitudes de déformation. Elle permet de mesurer de courtes décroissances libres gardant ainsi l'échantillon en vibrations quasi stationnaires.
Le système a été utilisé pour mesurer le FI dans des échantillons vibrant en torsion dans le domaine du Hz et dans des échantillons vibrant en flexion dans le domaine du kHz. Un ordinateur de table contrôle tous les paramètres expérimentaux et pilote le système. Les résultats sont affichés en temps réel sur un écran graphique et stockés sur un support magnétique.
Des résultats expérimentaux typiques sont présentés.

Abstract - A fully automatized internal friction (IF) measuring system was constructed. It measures IF by proceeding a waveform analysis of the free decay vibration. The choosen method eliminates disturbances due to parasitic motions of specimen and shows a weak dispersion even at low strain amplitudes. It allows to measure short free decay keeping the specimen vibrating in quasi stationnary conditions.
This system was used to measure IF of specimens vibrating in torsional mode in the Hz range and also of specimens vibrating in flexural or cantilever mode in the kHz range. It is driven by a desktop computer which controls all experimental parameters. Results are displayed in real time on a graphic screen and stored on a magnetic medium. Experimental results are presented.

INTRODUCTION - Many mechanical properties of metals like plastic deformation or damping capacity are due to interactions between dislocations and point defects. A good method to study these interactions is the measurement of internal friction (IF). These measurements are particularly difficult due to the fact that very small changes of IF should be detected on a wide range of strain amplitude. Therefore a good accuracy of IF measurements is desired, specially in the interesting region of very small strain amplitudes ($\sim 10^{-7}$).
Another problem characterizing the study of these interactions is the mobility of the point defects near the dislocations [1,2]. During an IF measurement, the dislocations oscillate around their equilibrium position, which induces a reorganization of the spatial distribution of the mobile point defects surrounding the dislocations. Using free decay to measure IF will disturb the spatial distribution of these defects. Therefore it is necessary to keep the strain amplitude as constant as possible during an IF measurement, so that the measured specimen stays in stationary conditions.

Above mentioned contradictory requirements, i.e. - good accuracy, small strain amplitudes and constant amplitude during measurement - show that the traditional method using a wave height analysis during a free decay is not suitable for our studies.
A fully automatized IF measuring system using a waveform analysis was constructed.

This technique described by Yoshida and al [3] calculates IF by Fourier transform of the oscillations of the specimen vibrating in free decay. The waveform analysis gives a very good accuracy on IF measurements even at low strain amplitudes where poor signal to noise ratio is achieved. The choosen method eliminates perturbations due to parasitic motions of the specimen. Furthermore it allows to decrease the variation of strain amplitude during the free decay.
This measuring system is driven by a desktop computer which displays the experimental results in real time. It was used to measure the IF of specimens vibrating in torsional mode in the Hz range and also of specimens vibrating in flexural or cantilever mode in the kHz range.

WAVEFORM ANALYSIS OF FREE DECAY SIGNAL - The method of IF measurement by a waveform analysis is based on the fact that the frequency spectrum of damped oscillations shows an enlarged peak. The study of the peak shape permits to calculate the IF. During a free decay, the specimen motion can be assumed to be :

$$f(t) = f_1(t) + f_2(t) + f_3(t) \qquad (1)$$

where $f_1(t)$ is the main component of the damped oscillation and can be written :

$$\begin{aligned} f_1(t) &= A \exp(^{-t}/t_1) \cos(\omega_0 t + \operatorname{Arg} A) \\ &= \tfrac{1}{2} \{A \exp(j\omega_1 t) + A^* \exp(-j\omega_1 t)\} \end{aligned}$$

where t_1 is the time constant of damping and ω_1 is the complex angular frequency defined as :

$$\omega_1 = \omega_0 + j \cdot {}^1/t_1$$

IF is then simply :

$$IF = 2/\omega_0 t_1$$

$f_2(t)$ represents contributions due to parasitic motions such as e.g. a precessional one in the case of torsional vibrations. These motions are supposed to consist of several simple harmonic motions with angular frequencies far away from ω_0.
The third term f_3 of eq. (1) represents all components of the specimen motion other than $f_1(t)$ and $f_2(t)$. It is considered as a small random noise.

The discrete Fourier transform (DFT) of f (t) reveals a main peak at the angular frequency ω_0 and several other peaks due to parasitic motions $f_2(t)$. Yoshida and al [3] have shown that in the vicinity of the main frequency peak the DFT of f(t) in a finite time internal t_3 is approximated by :

$$F(s) = \frac{A}{2} \cdot \frac{\{1-\exp(j\omega_1 t_3)\} \cdot 2^n}{-j(\omega_1 t_3 - 2\pi s)} + B + C \cdot s \qquad (2)$$

assuming that $2^n \gg \omega_0 t_3/2\pi \gg 1$ where 2^n is the number of time domain samples. This assumption means that the number N of samples per period of vibration satisfies the condition : $2^n \gg N \gg 1$.

The term $B + C \cdot s$ represents a linear approximation for the contributions of parasitic motions $f_2(t)$ and $f_3(t)$ to the main peak of the frequency spectrum. Using four consecutive values of F(s) $\{F(s_1)$ to $F(s_4)\}$ around $s \approx \omega_0 t_3/2\pi$ we can eliminate the constants B and C. IF is then given by [ref.3] :

$$IF = 2 \frac{\operatorname{Im}(\frac{-3}{R-1})}{\operatorname{Re}(s_1 - \frac{3}{R-1})} \qquad (3)$$

where $$R = \frac{F(s_1) - 2 \cdot F(s_2) + F(s_3)}{F(s_2) - 2 \cdot F(s_3) + F(s_4)}$$

This calculation of IF uses frequency domain data which are close to the frequency ω_0 of the main peak. It is then easy to see that this method suppresses all disturbances whose frequency is fairly distant from the main one. This is very frequent in practice. In some cases, however, the parasitic motions can give additional peaks very close to the main one. It happens particularly when parasitic motions induce an amplitude modulation of the free decay signal. In these cases, the above described method calculates too large values of IF and then must be used with caution.

The great advantage of the waveform analysis for calculating IF is that the effective signal to noise ratio is highly improved by effect of statistical treatment of noise. This method calculates IF from several data per period of specimen vibration. In the classical method using wave height analysis only one point per period is considered. This fact explains why the waveform analysis allows to measure shorter free decay to obtain similar precision to the one in the traditional method. The duration of free decay - i.e. variation of strain amplitude - and the number of samples per period cannot be choosen arbitrarily. They are limited by the assumption in equation (2). This condition, however, is not very restrictive. Generally the sampling of free decay during 10 periods of specimen oscillation satisfies this assumption. A free decay of 10 period means for example that strain amplitude decreases 15% in case of an IF equal to $5 \cdot 10^{-3}$.

REALISATION OF MEASURING SYSTEM

The main part of the system is a rapid DC Voltmeter which samples the free decay signal with sufficient rate. The data are then transmitted from the voltmeter to a BASIC programmable desktop computer where a Fast Fourier Transform (FFT) is proceeded. Consequently the frequency domain results are used to calculate the IF. All the experimental results like IF, frequency, temperature and others are then displayed on the graphic screen of the computer and stored on a magnetic medium. The computer controls entirely all experimental parameters. The use of standard interconnection bus (IEEE 488-HPIB) greatly simplifies main part of the development.

a) Torsional pendulum

Our measuring system was connected to an inverted torsional pendulum. Fig. 1 shows the block diagram of the system. The choosen FFT algorithm using 256 time domain data allows to calculate IF each 40 s.

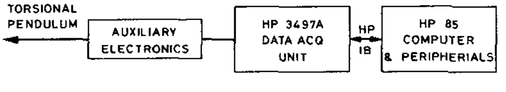

Fig. 1 : Block diagram of electronic part for torsional pendulum

For this application, additional connections were added to the measuring system which allow to measure the electrical resistivity of the specimen. This enhancement in connection with a measurement of the torsional component of the shape change of the specimen is particularly useful for studying phase transitions. Typical experimental results without post-processing are shown in Fig. 2. Fig. 2a gives results for a precipitation peak in an Ag Al 13% alloy and Fig. 2b for a martensitic transformation in a Ti Ni alloy. The weak dispersion of the IF results can be estimated as 10^{-4}.

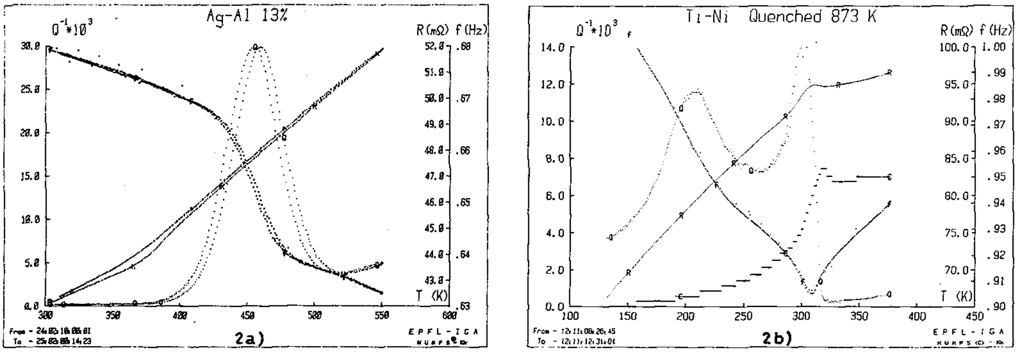

Fig.2 : Results obtained in torsional pendulum :
a) Precipitation peak in Ag-Al 13% alloy (heating and cooling)
b) Martensitic transformation in Ti Ni alloy (note torsional component of the shape change).

b) Kilohertz frequency range apparatus

Different mechanical set-ups using free flexural or cantilever vibrations were connected to the measuring system. The relatively high vibrating frequencies of these set-ups implied the choice of a rapid waveform recorder (see condition for the approximated equation (2)). Figure 3 shows the configuration of system for kilohertz range.

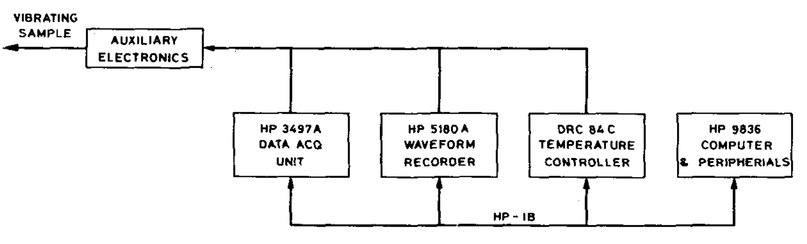

Fig. 3 : Block diagram of electronic part for kilocycle range apparatus.

FFT was performed on 1024 time domain data. The choice of a more efficient desktop computer than for torsional pendulum allows to obtain experimental results each 30s. Figure 4 shows typical experimental results in case of a gold specimen at different strain amplitudes. It can be seen that even at very low amplitude (6×10^{-8}) dispersion of IF is less than 10^{-4}. For strain amplitude higher than $5 \cdot 10^{-7}$ dispersion becomes very small (in the order of 10^{-5}). It should be noted that figure 4 gives raw experimental values without post processing. In these experiments variation of strain amplitude due to free decay was always smaller than 20%.

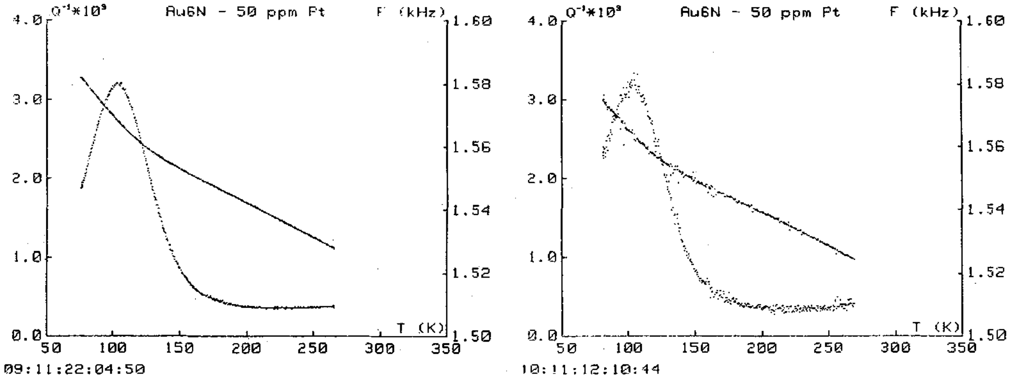

Fig. 4 : Results obtained in kilocycle range apparatus :
Bordoni peak in Au 6N -50 ppm Pt at different strain amplitudes :
a) $8 \cdot 10^{-7}$ b) $6 \cdot 10^{-8}$

CONCLUSION - The above described measuring system enables measurements of IF with a good accuracy by use of a waveform analysis. This method eliminates disturbances due to parasitic motions and gives weak dispersion even at low strain amplitudes. It allows to measure IF during short free decay.

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