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AUTOMATION OF INTERNAL FRICTION MEASUREMENT APPARATUS OF INVERTED TORSION PENDULUM TYPE


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Abstract. - The design of an automated internal friction apparatus of inverted torsion pendulum type is described. The wave-form analysis, instead of the traditional wave-height analysis, was employed. In addition to the omission of manual operation or supervision, the accuracy of measurement was increased so much, because, through Fourier transformation of the wave form of a damped oscillation, the disturbing components of parasitic motions such as lateral or precessional one of the pendulum are separated out from the genuine torsional motion and eliminated on calculating the decay constant.

1. Introduction. - Carbon or nitrogen atoms in solution are essentially responsible for yielding property, aging hardenability, ductility, and other important mechanical properties of sheet steel products. Therefore, the Snoek peak measurement is considered to have a particularly important practical meaning, while it is, nevertheless, seriously handicapped that a conventional method of torsion pendulum is a very laborious and time wasting experiment. The automation of internal friction measurement was highly desired and various "new" apparatuses have been reported (1)-(6).

Another objection against the conventional method is that unavoidable disturbances such as lateral or precessional vibration of the specimen is often involved, which seriously limit the accuracy or sensitivity of the measurement.

We have succeeded in constructing a fully automated apparatus which is linked to a computer processing system. A wave-form analysis was adopted instead of the traditional wave-height analysis, so that the accuracy of measurement was incomparatively improved. It is worth pointing that the apparatus described here is particularly suitable for Snoek peak measurement on steel specimens.

2. System of Automatic Measurement. - Main parts of the apparatus is schematically shown in Fig.1. The automation system consists of automatic repetition of excitation and stopping of the oscillation. A block diagram of the system is shown in Fig.2. By the action of a

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timer $T_1$, the relay is closed so that a self exciting feedback circuit is completed and the oscillation amplified. The role of the limiter is to detect the amplitude, and make the relay open immediately when the amplitude reaches a certain predetermined value, so that the pendulum is switched over to a damped oscillation. The whole procedures are repeated by timers. Any manual supervision or control is unnecessary. With increasing temperature of the specimen a set of damped oscillation curves are recorded on an oscillograph.

The output of the pick-up coil is fed to a data acquisition system and A-D converted with a sampling interval of 12 milliseconds. Digital data are sent to and stored provisionally in a front end computer U-400, which consists a part of the hierarchical data acquisition system. 2048 data are sampled for each damped oscillation. After measurement, data stored in U-400 are transferred to a system host computer FACOM 230-38, and processed according to the analysis described in the next section. Temperature data are also sent to and stored in U-400.

3. Analysis of damped oscillation.

The wave form $f(t)$, which is the electromagnetic force generated in the pick-up coil, is assumed to consist of following three components:

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

Fig. 1: Schematic diagram of inverted torsion pendulum.

Fig. 2: Data and signal flow of the system.
where $f_1(t)$ is the main component of the damped oscillation. It can be expressed as follows:

$$f(t) = |A| e^{-t/t_1} \cdot \cos(2\pi t/t_2 + \text{arg}A)$$

$$= \frac{1}{2} \left( A \exp[j\omega_1 t] + A^* \exp[-j\omega_1^* t] \right) \tag{2}$$

where, $t_1$ and $t_2$ are the time constant of damping and the period of oscillation, respectively. $A$ is the complex amplitude and $A^*$ is its complex conjugate. The complex angular frequency $\omega_1$ is defined as

$$\omega_1 = \frac{2\pi}{t_2} + j\frac{\omega_1^*}{t_1} \tag{3}$$

From the equation (2) it is easy to see that

$$f_2(t) \text{ represents a sum of parasitic motions such as flexural or precessional one and is estimated to consist of several simple harmonic motions, whose angular frequencies are fairly distant from } \omega_1. \ f_3(t) \text{ represents all components of } f(t) \text{ other than } f_1(t) \text{ and } f_2(t), \text{ and is assumed to consist of small random noises.}$$

The wave form of the equation (1) is Fourier transformed. A standard discrete Fourier transform (DFT) by a computer is adopted for $f(t)$ in a finite time interval, $t_3$.

The DFT's corresponding to the first, second and third term of the right-hand side of the equation (1) shall be written as $F_1(s)$, $F_2(s)$ and $F_3(s)$, respectively, where

$$s = 0, 1, 2, \ldots, 2^n - 1. \tag{5}$$

$F_1(s)$ is calculated as

$$F_1(s) = \frac{A}{2} \left( \frac{1 - \exp[j\omega_1 t_3]}{1 - \exp[j(\omega_1 t_3 - 2\pi)]/2^n} \right) + \frac{A^*}{2} \left( \frac{1 - \exp[-j\omega_1^* t_3]}{1 - \exp[-j(\omega_1^* t_3 - 2\pi)]/2^n} \right) \tag{6}$$

The first term of the right-hand side of the equation (6) makes a peak around $s = \omega_1 t_3/2$, and is approximated as

$$F_1(s) = \frac{A}{2} \left[ \frac{1 - \exp[j\omega_1 t_3]}{-j(\omega_1 t_3 - 2\pi)} \right] \cdot 2^n \tag{7}$$

with an assumption

$$2^n >> \omega_1 t_3/2\pi >> 1. \tag{8}$$

As the second term of the right-hand side of the equation (6) has, on the contrary to the first term, no peak around $s = \omega_1 t_3/2\pi$, it is allowable to approximate it with a linear function of $s$ around $s = \omega_1 t_3/2\pi$. $F_2(s)$ can be approximated with a linear function of $s$ around $s = \omega_1 t_3/2\pi$, too. $F_3(s)$, combined with error terms occurring from approximations made on $F_1(s)$ and $F_2(s)$, shall be expressed as $D(s)$. $D(s)$ is estimated in most cases negligibly small.

From above considerations we conclude that $F(s)$ assumes a form
\[ F(s) = \frac{A}{2} \frac{(1-e^{j\omega t_3})2^n}{-j(\omega t_3-2\pi s)} + B + Cs + D(s) \]  

(9)

around \( s = \omega t_3/2\pi \), where \( B \) and \( C \) are constants. Using four \( F(s) \) values around the peak of \( F(s) \) we can eliminate \( B \) and \( C \) by an ordinary difference method. Let those four \( F \)'s be \( F(s_1) \), \( F(s_2) \), \( F(s_3) \) and \( F(s_4) \), respectively, where \( s_2 = s_1 + l \), \( s_3 = s_2 + l \), \( s_4 = s_3 + l \), and \( s_1 \leq s_2 < \text{Re}(\omega t_3/2\pi) \). Then, we get

\[ Q^{-1} = 2 \frac{\text{Im}(R^{-1})}{\text{Re}(s_1 - \frac{3}{R-1})} \]  

(10)

where,

\[ R = \frac{F(s_1) - 2F(s_2) + F(s_3)}{F(s_2) - 2F(s_3) + F(s_4)} \]  

(11)

The relationship between each Fourier component is depicted schematically in Fig.3. It is easy to see that by this wave-form analysis, a Fourier component \( F_2(s) \) is well separated out from \( F_1(s) \), the main component corresponding to the torsional oscillation. Disturbances due to parasitic motions are, therefore, completely suppressed in the analysis.

Another very important advantage of this wave-form analysis, compared to the wave-height, is that the S/N ratio was much improved by the effect of statistical treatment of noises.

4. Examples of Measurement.- Fig.4 is a typical example of Snoek peak obtained by this apparatus. It is of a low carbon sheet steel quenched from 700°C with an intermediate holding at 300°C for 10 seconds. The chemical composition was 0.062C-0.31Mn-0.008S-0.008P-0.0015N-0.042O (weight %, balance Fe).

Fig.5 is another example of Snoek peak of a plate steel containing 0.1C-1.3Mn-0.01N. Fig.6 shows a result of measurement on a series of plate steels with compositions of 0.1C-1.2Mn-N, where N being varied in order to investigate how the toughness is dependent on the quantity of dissolved nitrogen. Fracture Appearance Transition Temperature (FATT) decreased appreciably with decreasing Snoek peak height, showing a prominent improvement in toughness.

5. Summary.- A fully automated internal friction measurement apparatus of inverted torsion pendulum type was constructed. The internal friction is calculated by a Fourier analysis of wave-form, so that the undesirable disturbances such as lateral or precessional vibration
involved in measurement are separated out from the torsional mode. The accuracy of measurement was thus incomparatively improved.

Fig. 3: Schematic diagram showing relationship between each Fourier component.

Fig. 4: Snoek peak of low carbon steel.

Fig. 5: Snoek peak of plate steel.

Fig. 6: Relation between fracture appearance transition temperature and Snoek peak height of plate steel.
References.