MECHANICAL MEASUREMENTS

MODELING AND MEASURING PARAMETERS OF THE DEFORMATION OF BANK-NOTE PAPER DURING METALLOGRAPHIC PRINTING

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This article presents the first description of a method and equipment for modeling and measuring the longitudinal and transverse deformation of paper used to make bank notes in metallographic printing. A kinematic diagram of the system used for the modeling is presented and a description is given of inductive and fiber-optic displacement gages and an optical tracking device used in the measurement.

The quality and durability of bank notes depend to a significant extent on the physicomechanical properties of the paper used to make them. One of the approaches taken to evaluating these properties entails modeling and measurement of parameters characterizing the deformation that occurs during metallographic printing.

The most important of these parameters are the compressibility of the paper (the reduction in its thickness) and the changes in transverse geometric dimensions that lead to its "spreading." The thickness reduction and spreading adversely affect the quality of the finished bank notes, the efficiency of the production process as a whole, and the productivity of the printing equipment.

Since the compressibility of the paper has been ignored in studies of the production process itself and its results, there is no literature data on the character and dimensions of the paper's deformation based on its "flattening." In light of this, it has become necessary to develop methods and equipment for modeling and measuring such deformation under laboratory conditions. The resulting experimental data can then be put to use in industry.

Modeling Deformation. The unit used to model the deformation of paper specimens should simulate the action of the equipment typically used for metallographic printing. The following characteristics are typical, according to operational data:

- length of rollers: 750 mm;
- width of contact of rollers with paper: 9-11 mm;
- unit pressure in the rollers: 14.5-17.7 kgf/mm²;
- printing speed: 2.5-3.0 m/sec.

It follows from this that the total force developed in the rollers reaches values on the order of 1.2·10⁵ kgf, while the time of contact of the paper with the equipment is within the range 3.0-4.5 msec. These two parameters are in fact the parameters used to choose the type of equipment for modeling the deformation of the paper and its kinematic scheme. An impact press or a tape transport mechanism could also be used to model the equipment. The latter is preferable from the viewpoint of the similarity of the model to the physical phenomena that occur during deformation of the paper, convenience, and safety in the modeling process. A functional diagram of the mechanism is shown in Fig. 1. For a paper specimen with the dimensions 10 × 30 mm², this unit provides a unit pressure on the order of 10-20 kgf/mm² with a transport speed of 2.0-2.5 m/sec. It can be seen from Fig. 1 that with the steel rollers exerting a compressive force Q = 200 kgf, the required pressure can be created by using a double-reduction gear and an AIR UT71 V2 UKh-L4.U2.04 motor. The gear should be built in the closed configuration.

Measurement of Paper Thickness. The main part of the thickness gage is the displacement transducer. The sensitive element of the transducer can be of the contact or noncontact type. Inductive contact transducers are the type of contact transducer most easily produced by industry. The principle of operation of the transducer is conversion of the mechanical displacement of the tip of the sensitive element into a proportional analog voltage. The transducer is powered from an ac generator with a frequency of 2-5 kHz. The output signal of the transducer is sent through an electronic input block, an adder, and an amplifier before entering a demodulator. After rectification, the signal is then displayed on a panel.
Fig. 1. Functional diagram of mechanism used to model the deformation of bank-note paper: 1) strain gage; 2) rod; 3) rollers; 4) gear wheels; 5) electric motor; 6) pinion; 7) specimen; 8) paper feeder.

The transducer (Fig. 2) is housed in a steel casing 2 on ball bearings inside a moving rod 3 with a measurement tip 1. The top part of the rod is provided with a ferrite armature and a bushing 4. That bushing, acting together with bushing 6, limits the translational motion of the rod 3 while allowing its rotation. The armature moves relative to the two induction coils 10 and 11. The coils are installed in a steel yoke with a slit closed at its ends by two ferrite washers 5 and 7. The magnetic core of the transducer is enclosed in a brass housing. The main error of the transducer ranges from $\pm 0.1$ to $\pm 2.0 \mu m$ and depends on the measurement range (from 6 to 120 $\mu m$). The drift of the instrument over 1 h of continuous operation is no greater than 0.1 $\mu m$. Here, the instability of the network voltage and frequency should remain within the range $220 \pm 15\%$ V and $50 \pm 1$ Hz.

One promising type of noncontact transducer for measuring microscopic displacements is a fiber-optic transducer with an optical fiber as the sensitive element. A fairly detailed description was given in [1, 2] of fiber-optic microdisplacement transducers based on different principles of modulation of a light flow by the object being measured. These transducers are sometimes designed so as to make use of the dependence of the amount of light transmitted on the mutual displacement of the ends of a slit fiber. In this case, the transducer contains a light source, and there is a gap between the ends of the fiber and the photodiode. The fiber is slit at the Brewster angle at the site of the air gap to minimize loss of the light as it passes from one half of the fiber to the other.

Another design of fiber-optic transducer for measuring microdisplacements is based on use of the dependence of light loss in the fiber on its flexural deformation. Displacements as small as 20 $\mu m$ can be measured with a resolution of 0.02 $\mu m$ by an interferometric transducer consisting of two Michelson interferometers, a light source, a drive, photodiode, microprocessor, recorder, optical fiber, and two mirrors. The measurement results are independent of the parameters of the fiber, and the sensitive elements of the transducer can be replaced without the need for subsequent calibration.

Vertical displacements are usually measured with the use of blind fiber-optic vibration pickups or transducers operating in reflected light and having a sensitivity of up to 1 mV/$\mu m$. Measurements can be made over a distance ranging from 1 to