COERCIMETERS WITH A MOVABLE (ROLLING) SENSOR

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For non-destructive testing of mechanical properties, stress-strain and fatigue states of ferromagnetic materials, are widely used coercimeters with attached transposable magnetic device (MD) [1, 2]. In such coercimeters all stages of estimation of the coercive force (c.f.) are performed with stationary MD at the test point during the entire measurement cycle, i.e. for measuring c.f. at another point, the transducer can only be relocated. Disadvantages of such a discrete in time and space method are: limited performance due to the need to maintain the same position of MD during the measurement cycle (about 5–10 sec.), dependence of the instrument readings on the ratios of items with large surface (plates, sheets, etc.) and small "work site" of MD; inherent discreteness of distribution of the resulting c.f. over the surface of the item, undoubtedly more complicated automation of c.f. measurement process with such a movable transducer.
From these shortcomings are free coercimeters with a mobile MD, where the process of measuring c.f. is continuous both in time and along the testing line [3–7]. Here the mobile MD, as well as its other so far existing relocatable varieties, contains a magnetizing element (ME) and a magnetometric unit (MU), however in it these elements are spaced apart so that when moved over the surface of the tested item, the magnetizing element forms in it a strip of residual magnetization, and the downstream MU performs a continuous readout of a parameter proportional to c.f. of sections of magnetized strip.
For magnetization are used bipolar ME, for example based on the U-shaped systems closed by a tested item. This may be an electromagnet or a device based on a permanent magnet.

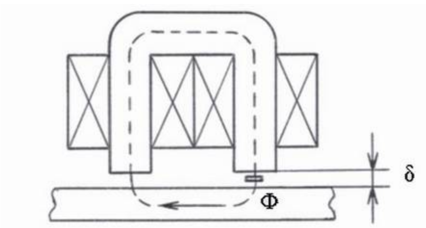

Figure 1a

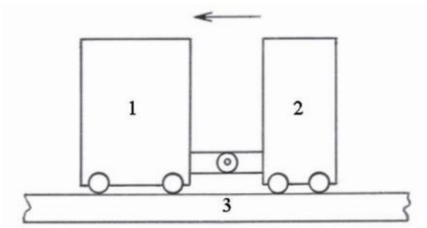

Figure 1b

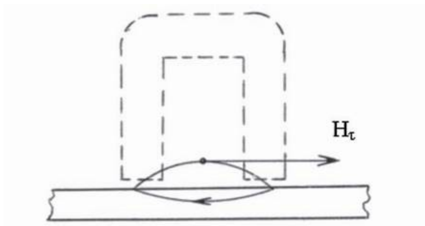

Figure 1c

Figure 1b schematically shows relative positions of these parts of the MD (magnetizing element 1 and magnetometric unit 2, hinged to each other) in relation to the direction of its movement (shown by arrow) on the surface of the tested item 3. Also possible is separate item magnetization in a given direction with element 1 and subsequent (after removal of the magnetizing element) parameter determination of the residual magnetic field over the tested strip with unit 2.
In order to measure the parameters which are proportional to the coercive force on the major hysteresis loop of the item, using mobile MD according to the arrangement shown in Fig. 1b, observance of the following conditions should be provided:
– residual magnetization field of the item after passing over of the magnetizing element should be formed mainly by those volumes (tubes of magnetic flux) of the tested areas, which are magnetized up to the point of technical saturation;
– topography of residual magnetic field of the item with uniform coercive force all along the measurement path should be the same along the entire length (except for the initial and terminal parts of the test strip, where edge effects are possible).
These conditions are fairly well observed when using bipolar magnetizing elements, for example, based on the U-shaped open systems closed by the tested item.

Magnetometer unit of mobile MU should be designed taking into account the configuration of the residual magnetic field whose lines of force lie in the plane perpendicular to the direction of unit movement. Here at least two main options for the read-out of parameters proportional to the coercive force are possible:

1. Traditional method of automatic compensation of the magnetic flux of an item in a MD with U-shaped coil flux guide and field-neutralizing coil (Fig. 1a) to a specified value of flux Φ in the system, for example, down to zero [8, 9]. Coercive force in this case is estimated from the magnitude of current of the field-neutralizing device. Disadvantages of coercimeters with self-compensation system are slow measurement progress limited by performance of automatic compensation circuit, presence of additional measurement errors associated with possible overshoot in the automatic compensation system, as well as inability of repeated measurement of H_c along the same trajectory of MD movement due to changes in residual magnetization in the demagnetization during self-compensation.

2. Direct measurement of field intensity over a test strip (Fig. 1c), by the tangential component of this field H_τ, close in value to the "internal field" H_i in the item. The latter, in turn, in the case of residual magnetization of ferromagnetic bodies with a high magnetic susceptibility at the back of the hysteresis loop having in the direction of reversal of magnetization a high demagnetization coefficient, is practically equal to the coercive force of the item on the given hysteresis loop [10–12]. This method is free from the above drawback associated with electrical signal conversion in self-compensation circuits, since it provides performance limited only by the speed of signal conversion in the magnetic field meter.

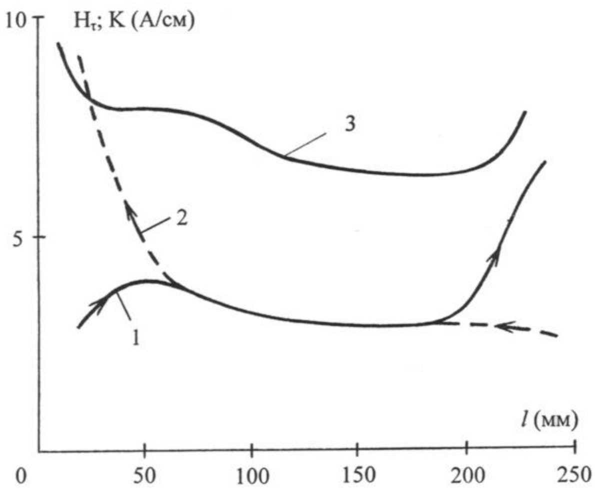

Figure 2

As an example, Fig. 2 shows distribution of the tangential component H_τ of magnetic field intensity over a sheet of structural steel (sheet 4 mm thick, size in plan view 250 x 250 mm) having coercive force of 3–3.5 A/cm, magnetized with a mobile U-shaped electromagnet (poles 28 × 12 mm), distance between inner edges of the poles 32 mm), along the midline of the sheet with a gap between the poles of the electromagnet and the sheet δ = 1.5 mm (Fig. 1a). The current (ampere-windings) of magnetization was chosen to satisfy the condition of technical saturation of the sheet material in the interpolar space of the electromagnet. The field strength was measured with a Hall transducer (size of active element 0.35 x 0.35 mm) at a distance of 1 mm from the surface of the sheet in a plane perpendicular to the direction of movement of the electromagnet. Curve 1 is obtained when moving the electromagnet along the length *l* from the proximal edge of the sheet (left to right), while curve 2 (dotted line) – from the far edge to the proximal one (right to left), as shown by arrows in Fig. 2. For comparison, here is also shown curve 3 for distribution along the length *l* of K readings (in A/cm) of digital coercimeter KRM-Ts, whose transposable MD has similar to the described electromagnet testing area dimensions.

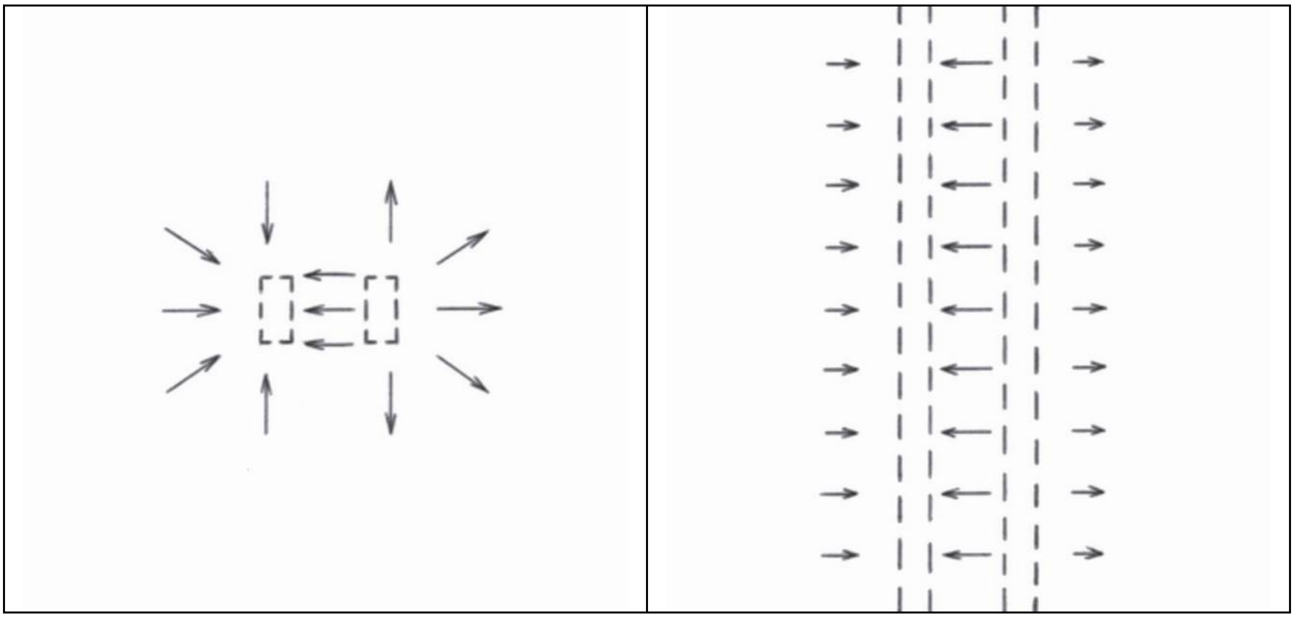

Figure 3a Figure 3b

Figure 3 shows arrangement of electromagnet poles in the case of "stationary" magnetization (Fig. 3a) and when moving it from one end of sheet to another (Fig. 3b). Arrows in the figures show the direction of the magnetic field lines during magnetization.

Figure 2 shows that in magnetizing the sheet material, a pronounced edge effect is in evidence. It manifests itself in that the residual magnetization field strength H_τ in the proximal part of the sheet is smaller, while in the far part it is much higher than the coercive force H_c of the material. The remaining part of the sheet (60–70 mm from the proximal and far edges, i.e. between l = 60 and l = 190 mm), the H_τ parameter adequately reflects the distribution of coercive force of the item along the length l and is close in value to H_c. With regard to the readings of coercimeter K**,** they appear to be significantly (almost twice) higher than corresponding H_c values. The cause of significant increase in H_τ in the far end of the sheet in magnetizing with mobile MD, and too high coercimeters readings in the case of "static" magnetization is the following.

During magnetization with "stationary" MD (Fig. 3a) a magnetic material is magnetized not only in the tested area (median part of interpolar space), but also from the outside, as well as at two sides of the lateral surfaces of the MD. As a result, after magnetization (switching off current in the electromagnet), the tested zone is demagnetized by those parts of the sheet, which are located outside of the poles and on each side of the MD, with all the magnetized areas of those parts operating concordantly. Under the influence of these areas the magnetic flux in the tested zone of the sheet after removal of MD changes its sign to the opposite, i.e. the material is subjected to hysteresis loop reversal to the values of "internal field" intensity greater (in absolute magnitude) than coercive force of the material.

A similar process is taking place in the terminal section of the sheet after magnetizing by the mobile device (Fig. 3b). Here the terminal section is affected by previously magnetized areas, resulting in "internal field" in this place becoming higher than H_c.

Thus, coercimeter with a mobile MD, in addition to the above advantages (continuous measurement of the test parameter, ease of documenting of test results on elongated items and items with a complex surface, etc.), has another advantage compared to traditional-design coercimeters with MD (at least for items such as sheets), namely, the ability to measure residual magnetization of the tested item that is close to the coercive force of the material and not dependent on the dimensions of items in plan view. In this case, it is possible by introducing a small constant correction factor H_τ, to directly measure coercive force value of the material almost along the entire trajectory of MD movement on the item.

Proposed technical solutions allow to significantly expand the scope of application of coercimeters with movable MD, especially for diagnostic robots, because they ensure continuous highly efficient measurement of coercive force in the elongated items (pipelines, rails, bridges, tanks, etc.). This simplifies the process of documenting the results of measurements, their lock-on (in the course of movement of the device) to specific parts of the tested item, the construction of the topography of distribution of coercive force values on the surface of the item. In addition, use of permanent magnet as magnetizing component of the device can provide a significant reduction in energy consumption of the kit; it allows designing self-contained power supply coercimeters, which further extends the functionality of the device due to access to sites located far from industrial power supply sources.
For more details visit our web-site www.snr-ndt.com.

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