APPLICATION OF THE VERSATILE PF-01 FLUX-GATE MAGNETIC POLE LOCATOR IN MEDICINE


UDC 615.47.03:616-003.6-07-08

Roentgenological and ultrasonic methods are the main approaches presently used in medicine for location of foreign bodies. However, in practice these methods are not always sufficient for location and surgical removal of a foreign body.

For more successful, rapid, and nontraumatic location of ferromagnetic foreign objects it seems reasonable to use flux-gate magnetic pole locators [4-7].

Although the prototype flux-gate magnetic pole locators FP-2, PFT-1, and PF-1 (sensitivities to permanent magnetic field gradients of 13, 10, and 10 mOe/cm full scale and diameters of sensing elements of 7-10, 7, and 4 mm, respectively) developed at the Institute of Metal Physics (Ekaterinburg) have been successfully tested in clinics in Ekaterinburg and Moscow [2, 3] and recommended for serial production, they are not yet widely used in medicine.

Limitations on the use of these devices were imposed by technological difficulties in the large-scale production of flux-gate sensors, the development of more technologically advanced and versatile flux-gate sensors (suitable both for general and for ophthalmic surgery), and the small number of available devices (only 10 units were produced in the experimental series).

The recently-developed versatile flux-gate magnetic pole locator model PF-01 (Fig. 1) provides the opportunity for broadening the application of magnetic pole locators in different branches of medicine.

The PF-01 flux-gate magnetic pole locator has the following specifications: diameter of the working part of the sensing element, 2.6 mm; overall sensor length, 95 mm; maximal sensitivity to permanent magnetic field gradient, 4 mOe/cm full scale; sensitivity to nonuniformity of permanent magnetic field affecting the flux-gate sensor, over a range of gradients from 0.4 mOe/cm to 3 Oe/cm; pointer-type center-zero indicator indicates sign of gradient; range of sensitivity divided into ten smoothly-varying subranges; spurious deviation of pointer caused by the spontaneous rotation of the sensor in the Earth’s magnetic field at maximal sensitivity, not more than ±2 mOe/cm; accuracy of location of magnetic poles of sought object at 6 mm distance, ±2 mm; powered from 220 V 50 Hz AC power line or optional 12 V battery pack; power consumption, not more than 0.6 W; dimensions, 220 x 160 x 90 mm; mass, not more than 2.6 kg.

The block diagram of the PF-01 magnetic pole locator is shown in Fig. 2.

The excitation generator (EG) is made of two logical elements which generate an alternating voltage of rectangular shape with frequency 200 kHz. This frequency is twice divided in two. The output signal generated after the first division is used to control the synchronous detector (SD). After the second division a rectangular step voltage is generated that is used for excitation of the flux-gate sensor.

Flux-gate sensor (FS) is designed for measuring magnetic field gradients (Fig. 3). This sensor consists of two ferroelements coaxially arranged inside a nonmagnetic metal tube at a distance of 15 mm from each other. The ferroelements are shifted from the center of the longitudinal axis of the sensor [1]. Each ferroelement is a section (coil) with the core made from the 80 NKhs permalloy wire fired in vacuum. The length of the core is 5 mm, its diameter 0.1 mm. The connection of the sections provides their simultaneous functioning as both exciting and measuring windings (see Fig. 3b).

The flux-gate sensor functions on the basis of nonlinearity of the remagnetization curve of ferromagnetic material.

Alternating current of 50 Hz frequency from generator EG flows through the exciting windings of FS. An alternating magnetic field with amplitude of 60 Oe is generated, which periodically induces magnetic saturation inside the cores. In the absence of external magnetic field the electromotive forces induced in the sections of the measuring windings compensate each other, and the resulting signal at the output of the windings will be equal to zero. If a nonuniform external magnetic field appears (for example, if the sensor approaches a magnetic particle), then one of the cores will be affected by this field to a greater extent than the other. The electromotive forces generated in the sections of the measuring windings in this case are not equivalent and a nonzero signal appears at the output of the windings.
This signal passes to gyrator filter $F$, where the second harmonic (100 kHz) is selected. Then this harmonic is amplified by amplifier $A$ and passes to synchronous detector $SD$.

The signal after synchronous detection passes to a pointer-type indicator $I$, the amplitude of the readings being proportional to the gradient of the permanent magnetic field.

To evaluate the sensitivity of the PF-01 magnetic pole locator some experiments were performed with objects of different shape and size specially manufactured from different alloys. These objects were premagnetized by a strong magnet (uniform magnetic field of about 500 Oe), their residual magnetization appearing as a result.

The sensitivity of the device was determined for the most characteristic relative positions of the sensor and a ferromagnetic foreign body. In the first position the sensor of the magnetic pole locator was oriented along the line connecting it with one of the magnetic poles of the examined foreign object (i.e. to one of its ends, see Fig. 4a). In the second position the sensor was oriented at right angles to the magnetic poles of this object (Fig. 4b) and in the third case it was oriented at a sharp angle to the magnetic pole of this object (Fig. 4c).

The data obtained on the sensitivity of the magnetic pole locator are given in Table 1. The object was considered as detected if the indicator pointer of the device at maximal sensitivity deviated at least 5% of full scale.

Analysis of these data shows that the sensitivity of the PF-01 locator is 15-70% higher than that of the previous models. It is seen from Table 1 that the distance from which the foreign object can be distinguished depends on the length, magnetic properties, and orientation of the object.

The first and the second cases of relative orientation of sensor and foreign object were discussed in [7]. It was concluded from the curves obtained that the maximal deviation of the indicator pointer is observed when the sensor and the foreign object are positioned along the same straight line. In the first case one maximum was found, while the second case was characterized by the presence of two maxima having equal amplitudes but opposite signs. The maxima are located near the ends (magnetic poles) of the foreign object.