Magnetometer (MM)

Target of Investigation

Magnetometer is an instrument mainly used to detect rebar size, rebar orientation, rebar location, rebar depth (concrete cover depth). Magnetometer is also commonly used to obtain as-built information on embedded rebar when there are no record drawings available. Though magnetometers cannot detect corrosion directly, their ability to measure cover is helpful; lower cover increases the ability for concrete to deteriorate and expose steel to oxygen and moisture.

Description

The first magnetometers, known as “covermeters,” “profometer,” or “pachometers,” were manufactured in the 1950s. Prior to the mid-1980s, magnetometers were built based on the magnetic reluctance principle.[1] More recent devices have been manufactured according to the concept of electrical conductivity to offer better system stability for detecting ferrous and nonferrous metals inside concrete.

Magnetometer is commonly used in conjunction with other NDE technologies. For example, for tests requiring a concrete core sample or contact with embedded steel reinforcement through drilling a hole, a magnetometer can help the drill miss any reinforcement. Additionally, a magnetometer can quickly and easily handle construction inspection quality control for recently-constructed bridges if, for example, there is a question about adequate cover (e.g., determining if a rebar cage floated up during the concrete pour).

Physical Principle

Magnetometers are based on an electromagnetic field and are unaffected by nonconductive materials such as concrete, composite, and timber. The eddy current principal charges a primary coil, creating a magnetic field. Eddy currents are produced on the surface of any electrically conductive material in the vicinity of the magnetic field. The eddy currents induce a magnetic field in the opposite direction of the primary coil field. This opposition affects the measured impedance in the coil. Reinforcing bars that are closer to the probe or are larger produce a stronger magnetic field. They operate at frequencies above 1 kHz. The magnetic induction principle is similar to that of a transformer. Primary coils are charged while a secondary set of coils pick up the voltage transferred by the magnetic circuit created by the primary coils and rebar. Magnetometers based on magnetic induction are less sensitive than ones using eddy current principles. Regardless of the principle used, the size, orientation, and location of the rebar (concrete cover) affect voltage measurement, in terms of amplitude and phase difference.[1,2] Magnetometers using induction operate at frequencies below 90 Hz.

When an electrically conductive material, e.g., steel rebar inside concrete, is subjected to a changing magnetic field, eddy currents are generated along the material’s surface. The eddy currents induce a magnetic field in an opposite direction of the initially introduced magnetic field that causes a voltage change in one or more coils or sensors inside the probe. The voltage change is a function of the rebar size, location, and orientation. The voltage change, in terms of amplitude and phase difference, is measured and analyzed to estimate rebar size, location (concrete cover), and orientation.

Data Acquisition

A magnetometer consists of a magnetic probe and a data processor with a display screen. In some equipment, the probe, data processor, and display screen are integrated into a single lightweight, hand-held device. The probe is moved along the surface of a concrete deck or girder. As the operator moves the probe, he/she can observe magnetic field changes on the screen in either a digital or graphical form. Rebar orientation can be determined through a planar rotation of the probe at the concrete surface. The longitudinal axis of the probe is aligned with the direction of the rebar when a maximum value of the magnetic field is indicated on the screen of the magnetometer.

Mapping rebar in concrete decks may be accomplished by scanning the concrete surface with the probe in different directions (figure 1). The operator marks the concrete surface when the location and orientation of each rebar are determined.[3] Some commercially available equipment has the capability to map rebar in concrete decks and display a rebar grid on the screen. The data may be recorded and saved for post-processing and documentation.

Figure 1. Photo. Locating a Rebar with a Magnetometer (Profometer).

Locating a Rebar with a Magnetometer (Profometer). A worker is kneeling on a concrete deck. His right hand is moving a hand-held probe on the deck. The probe is attached to a small instrument panel resting on the deck. The worker is observing the instrument panel.

Data Processing

All data processing is performed internally by the data processor component of the equipment. As such, no significant data manipulation is required by the operator. The data processor is programmed to compare detected magnetic field changes with those from known rebar sizes at different depths inside concrete to make an estimate of the rebar size and location.

Data Interpretation

Magnetometers are simple to operate, with minimal operator training required. However, experience is required to interpret the results in complex cases (e.g., dense rebar placement). To minimize the effect of the nearby ferromagnetic materials, the maximum depth of concrete cover should be limited to about two-thirds of the distance between two adjacent bars. When both the rebar size and concrete cover are unknown, the operator must assume a value for one (usually the rebar size) to estimate the other unknown parameter.

Advantages

- Provides rapid information about rebar size, orientation, or concrete cover.
- Field-worthy equipment.
- Easy to operate equipment, with minimal operator training required.
- Audible output with available headset option for working in noisy environments.
- Some systems applicable to non-ferrous metals, e.g., stainless steel bars.
- Relatively inexpensive and commercially available equipment.

Limitations

- Only effective within top 4 inches of the concrete surface.
- Only first layer of reinforcing steel may be located and sized.
- Decreased effective depth as rebar spacing decreases. For a concrete cover estimate to be accurate, the parallel rebar spacing must be 1.5 times greater than the concrete cover.
- Ineffective in regions of congested reinforcing steel.
- Difficult data interpretation when there is interference due to the presence of other magnetic materials such as adjacent parallel rebar, external magnetic field, and magnetic aggregates in concrete.
- For prestressed concrete bridge girder applications, only effective only within a depth equal to two-thirds of the parallel strand spacing.
- Time intensive for rebar mapping.

References

1. Bray, D.E., and Stanley, R.K., *Nondestructive Evaluation—A Tool in Design, Manufacturing and Service*, McGraw Hill, New York, 1989.
2. ASTM, “Standard Guide for Use of the Metal Detection Method for Subsurface Exploration,” D7046-11, ASTM International, West Conshohocken, PA, 2011.
3. Federal Highway Administration (FHWA), “Use of Magnetic Tomography Technology to Evaluate Dowel Placement,” (Website), Washington, DC, Accessed online: February 2015, http://www.fhwa.dot.gov/pavement/concrete/mitreport/mits02.cfm.