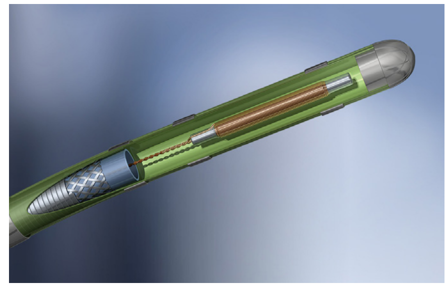
Intricon
MICROMEDICAL TECHNOLOGY

Understanding the design of electromagnetic navigation technology

As electromagnetic navigation becomes the top choice for surgical navigation, sensor and design considerations are critical.

David Bosch, Intricon



An example of an embedded electromagnetic (EM) sensor in a catheter tip [Image courtesy of Intricon]

Since its inception in the 1990s to widespread adoption by the late 2000s, electromagnetic navigation (EMN) has emerged as the clear choice for surgical navigation and has been widely adopted in the fields of interventional bronchoscopy, urology, neurosurgery and cardiology.

A properly designed EMN system has several advantages. It can localize with the precision of optical tracking without the need for a line of sight. It offers the convenience of fluoroscopy for intra-patient visualization without the application of ionizing radiation. And it does not expose the patient to energy fields that any more harmful than ultrasound.

Unlike alternative navigation technologies that rely upon backscattered radiation, EMN utilizes a passive measurement scheme. The surgically relevant region is saturated in a spatially inhomogeneous magnetic field which effectively serves as an invisible and biosafe x-y-z coordinate grid. Miniature sensors within this effective grid detect and transmit information regarding their precise location, which is then processed by an external computer system.

Since EMN only records the point locations of electromagnetic (EM) sensors, it is often used in conjunction with other visualization systems. Within clinical applications, the location of the sensor (generally placed within an interventional device) is often graphically superimposed upon 3D pre-operational scans of the patient. In this way, it's possible to realize real-time visualization of the interventional device within the anatomy of a patient.

Principles of operation

EMN relies on localizing a sensor with respect to a magnetic reference field. The magnetic field is provided by a calibrated field generator, which projects a field that is inhomogeneous in space and of known geometry. The EMN sensor must (indirectly) record the field at the location in which it is placed, which in turn can be translated into positional information.

Several kinds of EMN sensors exist—for example, fluxgate and wireless—but wired induction sensors have received the most widespread adoption in interventional clinical applications. (Fluxgate sensors have not been widely adopted into clinical applications due to the size and relative complexity of the device. And wireless sensors utilize sensors that must function simultaneously as receivers and emitters. The bulky size of these sensors coupled with the size and complexity of the external drive system limits surgical applications.)

Wired induction sensors consist of one or more windings wound around a solid or hollow core and leaded out to a twisted wire pair for signal transmission. An electrical signal can be induced by virtue of Faraday's law, which implies that an electromotive force (or voltage) will be generated in any closed path that is subjected to a varying magnetic field. In this case, the closed path

Customizable electromagnetic (EM) sensor options [Image courtesy of Intricon] is contributed by the wire wrappings of the induction sensor, which also serves as a conduit for current flow.

For the sake of logical continuity and mathematical aesthetics, the full form of

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Faraday's law is described as follows:

Faraday's law can be reduced to the following form by Stokes theorem, where Ø is the magnetic flux component that is perpendicular to windings of the induction sensor and flux is loosely defined as the product of magnetic field and cross-sectional area:

$$EMF = V = -\frac{d\text{Ø}_{\perp}}{dt}$$

Intricon manufactures sensors compatible with commercial AC magnetic field generator systems such as those from Northern Digital Inc. (NDI), Quadrant Scientific, Radwave Technologies, and Polyhemus, as well as custom systems developed by various OEM medical device companies and their designers. These systems provide an AC magnetic field map in space via arranged field coils. Whereas the specific field coil arrangements and localization methods are proprietary, all of the systems share some general principles of operation.

Because magnetic field magnitude decays by the cube of the distance from any field coil, it's possible to use the intensity of the magnetic field (and induced voltage) within a sensor as a proxy for the relative distance between the sensor and any field coil. Different methods exist for full 3D localization, generally involving multiple spatially separated field coils each running at unique frequencies to achieve triangulation. Triaxial field generators utilize at least three mutually orthogonal field coils, whereas planar designs rely on high density of parallel or near-parallel field coils to achieve uniqueness in the reference field. Intricon coils are compatible with either localization scheme and can be customized to perform within custom localization volumes.

Sensor design fundamentals

The goal of any custom EMN sensor is to provide the ultimate signal integrity within the smallest possible envelope size. For practical EM sensor applications, it is beneficial to maximize the voltage induced in the coil to maximize the signal-to-noise ratio and increase localization precision. The pertinent term is sensitivity, defined as the voltage amplitude generated by a coil when subjected to a unit AC magnetic field of standard frequency.

Sensitivity increase can be most easily achieved by either increasing the number of winds — which effectively increases the effective cross-sectional area through which the magnetic field traverses — or by directly increasing the diameter of the sensor core. However, there are limitations to these methods. An unrestricted increase of physical sensor dimensions is rarely compatible with the tight working channel of most interventional devices, so alternative methods of boosting coil sensitivity are necessary.

Full-length device design for electromagnetic compatibility

The seamless integration of EM sensors within interventional devices allows for optimal performance. Medical device manufacturers typically need to partner with a design and manufacturing expert specialized in electromagnetic and physical design who can deliver full-length devices (complete "tip-to-handle" solutions) for desired electromagnetic and clinical performance.

The design process must incorporate a keen awareness of magnetic components within the finished device. Such design acumen is critically important to device performance because magnetic components distort the reference field provided by field generators, thus reducing localization precision. The mitigation of magnetic interference is nontrivial, given the number of metallic components that exist in modern interventional devices.

While there are numerous advantages of EMN components in interventional devices, it takes careful optimization of EM sensors within a device to achieve maximal performance. One-size-fits-all solutions rarely reflect the complexities of a particular clinical application, nor do they automatically provide optimal performance within modern interventional devices. Therefore, medical device manufacturers need to carefully select a development and manufacturing partner with experience in both sensor and full-device design who understands the uniqueness of each customer, device and EMN application.

David Bosch is an electromagnetic engineering research scientist at Intricon. Focused exclusively on medical technology, Intricon is a contract development and manufacturing partner to industry-leading medical device companies around the world.

The opinions expressed in this blog post are the author's only and do not necessarily reflect those of MedicalDesignandOutsourcing.com or its employees.

SOURCE: *December 6, 2022, Medical Design & Outsourcing*

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HEADQUARTERS
1275 Grey Fox Road
St. Paul, MN 55112
651-636-9770
info@intricon.com