Standard Practices for Usage of Inductive Magnetic Field Probes with Application to Electric Propulsion Testing

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Inductive magnetic field probes (also known as B-dot probes and sometimes as B-probes or magnetic probes) are useful for performing measurements in electric space thrusters and various plasma accelerator applications where a time-varying magnetic field is present. Magnetic field probes have proven to be a mainstay in diagnosing plasma thrusters where changes occur rapidly with respect to time, providing the means to measure the magnetic fields produced by time-varying currents and even an indirect measure of the plasma current density through the application of Ampère's law. Examples of applications where this measurement technique has been employed include pulsed plasma thrusters and quasi-steady magnetoplasmadynamic thrusters.

The Electric Propulsion Technical Committee (EPTC) of the American Institute of Aeronautics and Astronautics (AIAA) was asked to assemble a Committee on Standards (CoS) for Electric Propulsion Testing. The assembled CoS was tasked with developing Standards and Recommended Practices for various diagnostic techniques used in the evaluation of plasma thrusters. These include measurements that can yield either global information related to a thruster and its performance or detailed, local data related to the specific physical processes occurring in the plasma.

This paper presents a summary of the standard, describing the preferred methods for fabrication, calibration, and usage of inductive magnetic field probes for use in diagnosing plasma thrusters. Inductive magnetic field probes (also called B-dot probes throughout this document) are commonly used in electric propulsion (EP) research and testing to measure unsteady magnetic fields produced by time-varying currents [1,2]. The B-dot probe is relatively simple in construction, and requires minimal cost, making it a low-cost technique that is readily accessible to most researchers. While relatively simple, the design of a B-dot probe is not trivial and there are many opportunities for errors in probe construction, calibration, and usage, and in the post-processing of data that is produced by the probe. There are typically several ways in which each of these steps can be approached, and different applications may require more or less vigorous attention to various issues.

B-dot probes self-generate an output voltage when immersed in a time-changing magnetic field and typically the output does not require amplification, making *B*-dot probes both robust and simple to use. The raw dB/dt-generated probe signal can be time-integrated to provide a local measurement. Several other attractive features of *B*-dot probes include design flexibility, relative noise-immunity, and the fact that fabrication is relatively straightforward and inexpensive.

A *B*-dot probe consists of a small inductive loop of 1 or more turns of light-gauge wire that is inserted into a time-varying plasma discharge, oriented so that the *B*-field of the discharge passes through the loop. The loop must be electrically insulated from the discharge, commonly accomplished by enclosing the loop and its leads in a thin-walled sealed insulating tube (Pyrex, for example). A schematic showing a notional *B*-dot probe is presented in Fig. 1.

The operation is based on Faraday's Law in which time-varying magnetic fields perpendicular to and linking the inductive coil windings induce a voltage that is proportional to the time derivative of the magnetic field. The voltage output by the probe head is conveyed through a coaxial cable or similar transmission line and measured as voltage V_p across a load impedance Z_p, which is typically 50Ω. The signal can be integrated prior to digitization using an analog integrating circuit (not shown), or it can be recorded directly and integrated in post-processing. Frequency-dependent transmission line effects can cause differences between the voltage output by loops of wire comprising the probe coil (V_c) and the measured voltage (V_p), and in general $V_p \neq V_c$. In these cases, the measured signal must be corrected to account for the differences between the two voltages.

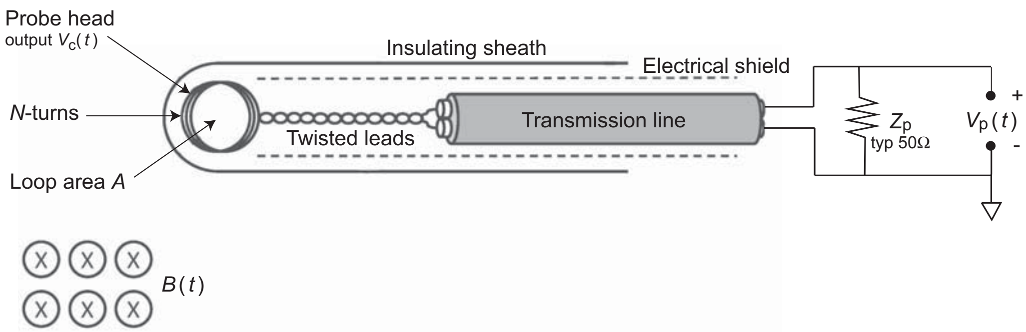

Figure 1: Schematic illustration of a *B*-dot probe (shown with an optional electrical shield) with the probe head connected through a transmission line (either a coaxial cable or a twisted-shielded pair of wires) to a load impedance Z_p (typically 50Ω) on the right hand side, where the output V_p is measured.

References

[1] R.H. Lovberg, "Investigation of Current-sheet Microstructure," *AIAA J.*, Vol. 4, No. 7, 1215-1222 (July 1966).

[2] R.L. Burton and R.G. Jahn, "Acceleration of Plasma by a Propagating Current Sheet," *Phys. Fluids*, Vol. 11, No. 6, pp. 1231-1237 (June 1968).