Measurement of a One-dimensional Axisymmetric Flow Profile with Eddy Current Flow Meters and Deep Neural Networks

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Eddy Current Flow Meters (ECFMs) have been used to measure flows of conductive fluids for decades. Recently, interest in ECFMs has increased due to applications in advanced fission reactors and fusion reactors. ECFMs are well suited for such applications, as they can provide simple, compact, and external measurements of flow in fluids that are often high-temperature, corrosive and may contain radioisotopes. Traditionally, ECFMs are operated using an AC current at a single frequency. This has limited ECFMs to measuring average fluid velocities, blockages, or voids. In this project, we set out to expand the capabilities of ECFMs by measuring the one-dimensional fluid velocity profile of liquid mercury in a pipe. To accomplish this, we made several ECFM sensitivity measurements at a range of frequencies. Different frequencies vary the electromagnetic skin depth of the device. By adjusting frequencies, we could probe the fluid velocity at various radial locations in the pipe and construct a radial flow-velocity profile.. However, the relationship between the ECFM sensitivity measurements and the inferred velocity profile is highly nonlinear and requires solving an inverse problem. Traditional numerical methods for solving inverse problems are inefficient, numerically unstable, and require a unique solution for each ECFM frequency sweep. However, using electromagnetic finite-element simulations to train a Deep Neural Network, we created a model that provides a general relationship between the sensitivity measurements of an ECFM and the fluid velocity profile with greater stability, for laminar, turbulent and monotonically decreasing flows in a pipe. Using the measured sensitivity in liquid mercury, our Deep Neural Network model calculates a flow profile that agrees well with computational fluid dynamic simulations of the flow profile. This technique has potential to improve real time flow monitoring for optimizing performance, ensuring safe operation of conductive fluid loops, and/or validating complex computational fluid dynamic models.