Modeling of Lorenz Force Flowmeter for Molten Metal Flow Application

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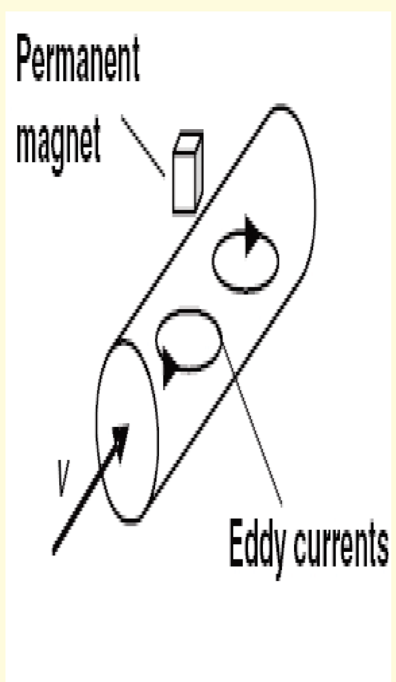
Introduction



Principle sketch of Lorenz force velocimetry

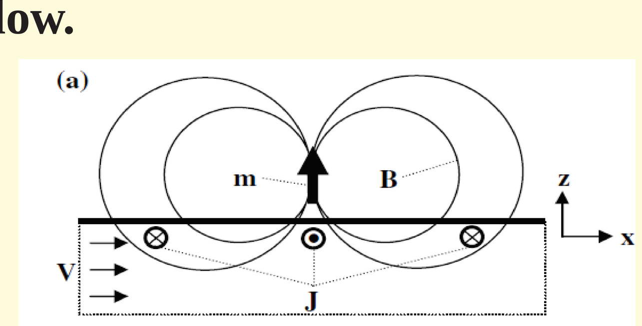
Lorenz force velocimetry is a non contact technique for velocity measurement of electrically conducting fluids. It is based on exposing the fluid to a magnetic field and measuring the drag force acting upon the magnetic field lines. Two methods can be employed for measurement of this force 1) one in which the force is determined through the angular velocity of a rotary magnet system and 2) the other one in which the force on a fixed magnet system is measured directly. LFV has a wide range of potential applications in compact high temperature reactors, metallurgy, semiconductor crystal growth, and glass manufacturing.

Philosophy of Detection

A small permanent magnet with dipole moment *m* is located at a distance *L* above a semi-infinite fluid moving with uniform velocity *v* parallel to its free surface. The magnetic field of the dipole which we refer to as the primary field is of the order

$B \sim \mu_0 m L^{-3}$ at the surface of the fluid.

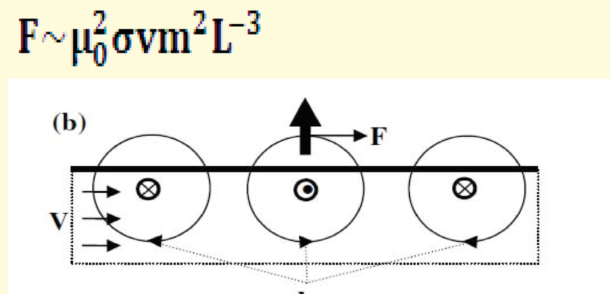
By virtue of the fluid's motion, eddy currents with amplitude $J \sim \sigma v B \sim \mu_0 \sigma v m L^{-3}$ are induced which are horizontal and concentrated below the surface as shown in figure below.

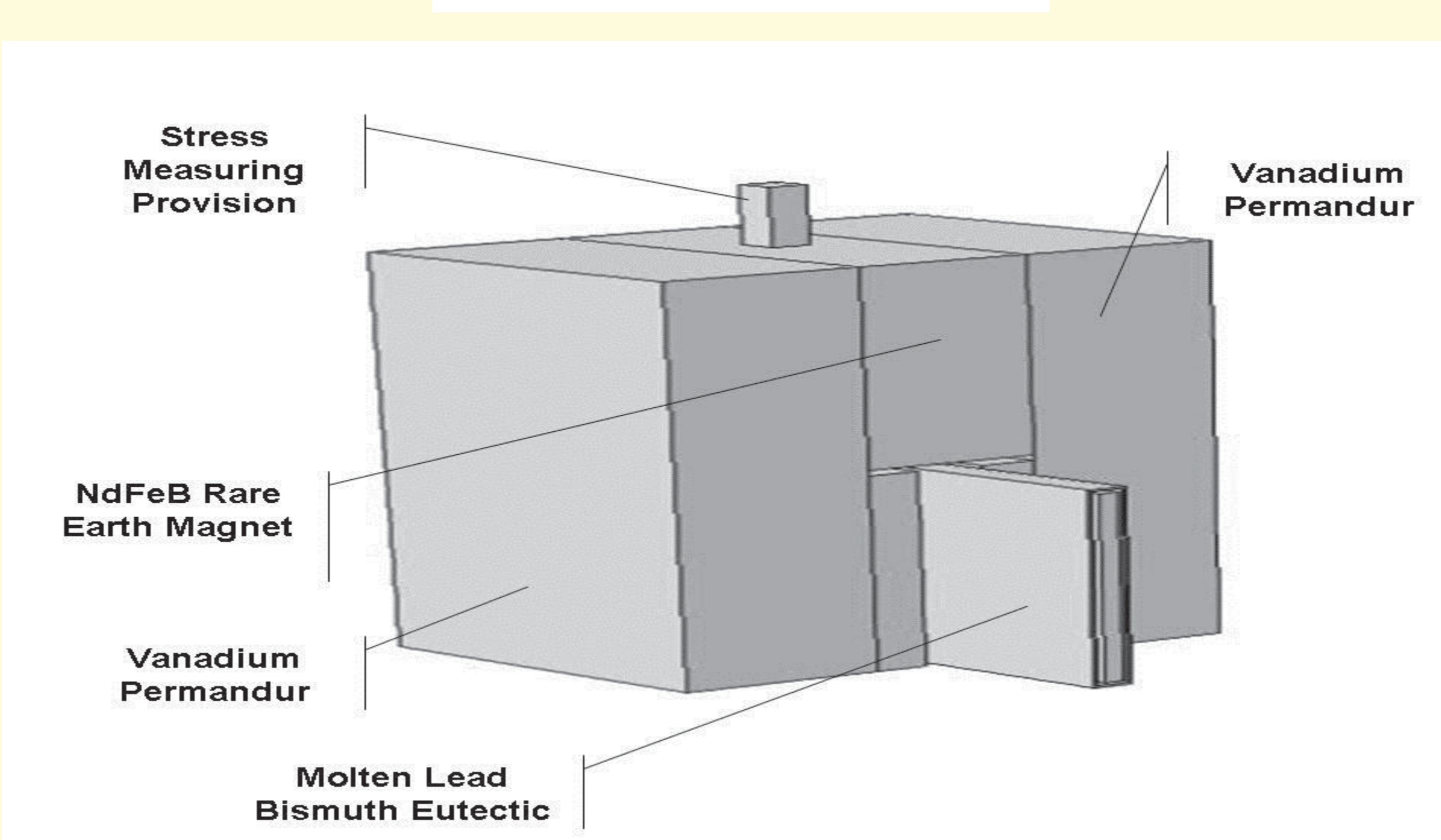


The eddy currents interact with the primary field to produce the Lorenz force which breaks the flow. The eddy currents surround themselves with a magnetic field *b*, This magnetic field extends to the location of the dipole, and its magnitude there is $\sim \mu_0 J L \sim \mu_0^2 \sigma v m L^{-2}$

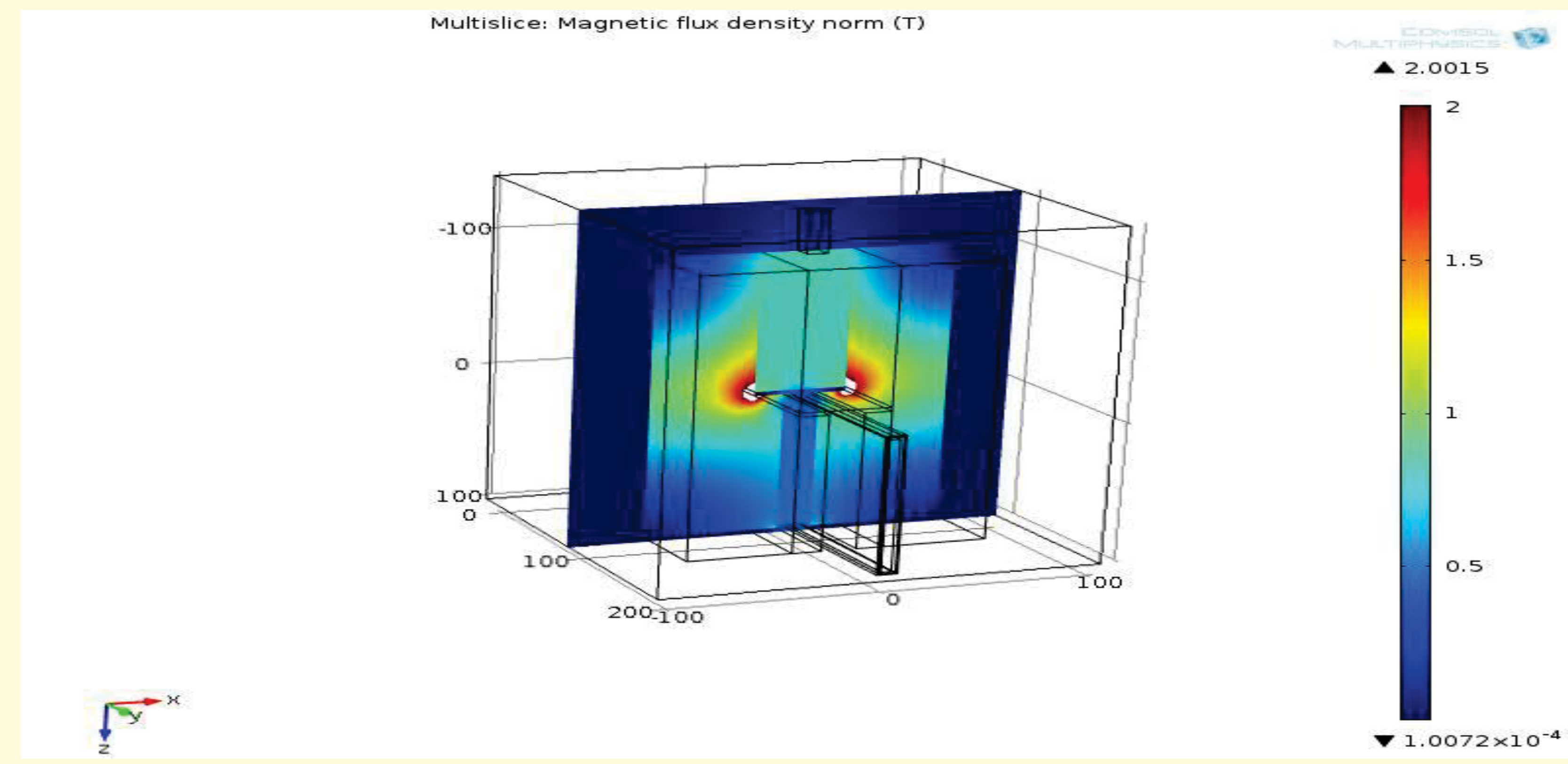
As known from classical electrodynamics, a magnetic dipole experiences a force of the order $F \sim m b L^{-1}$

when subjected to a magnetic field gradient b/L. This provides us with the estimate $F \sim \mu_0^2 \sigma v m^2 L^{-3}$

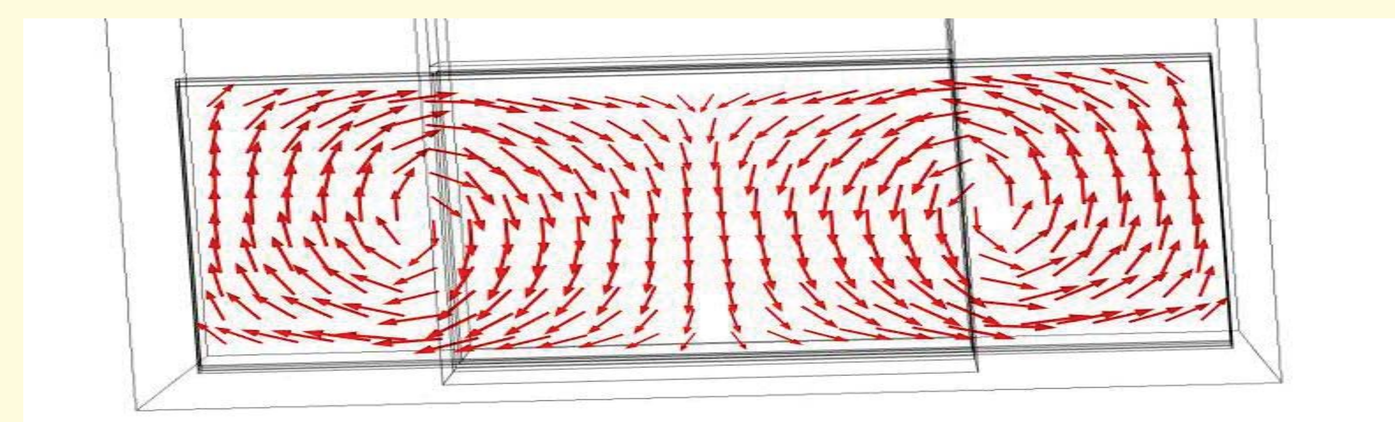




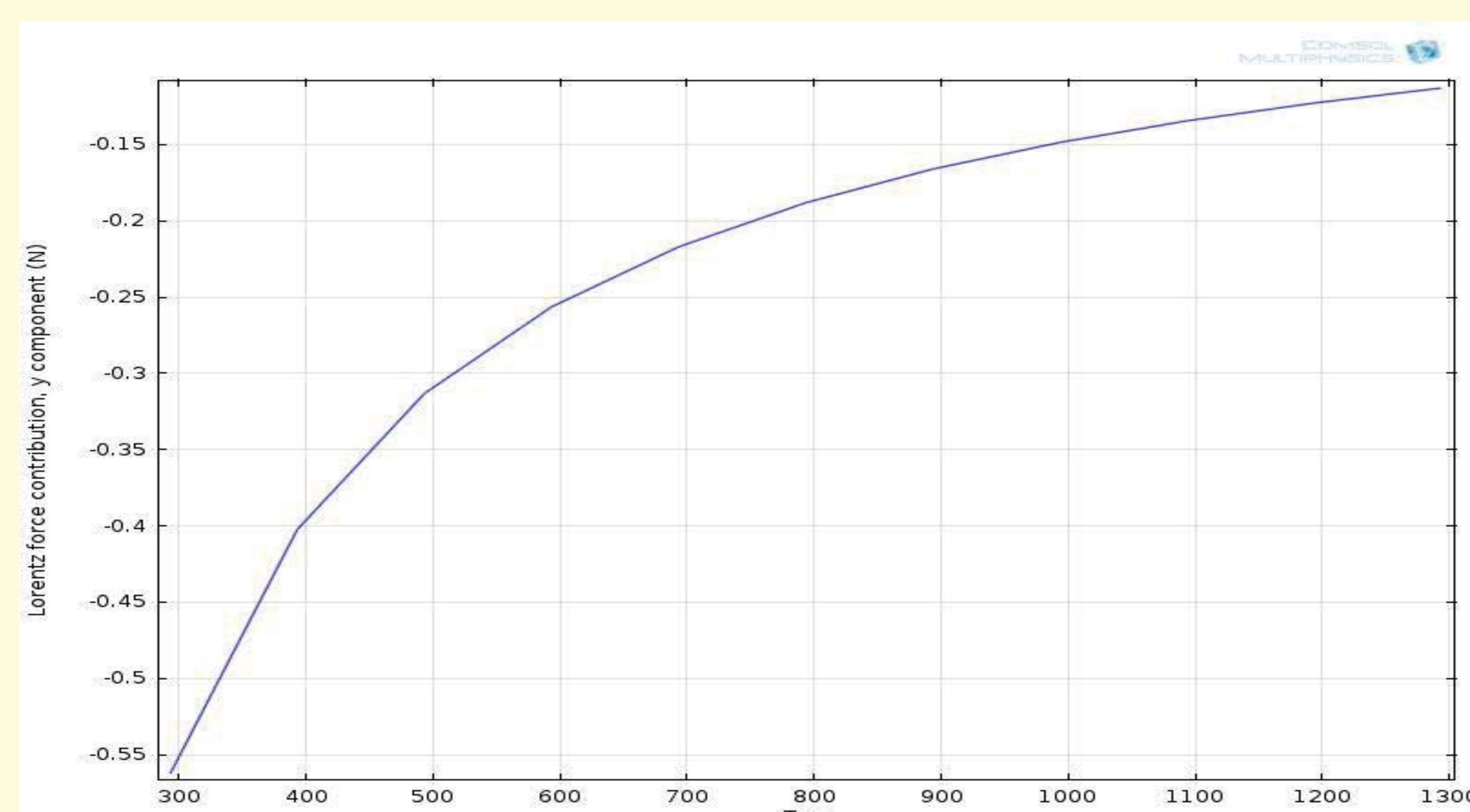
Schematic of Lorenz Force Flow Meter



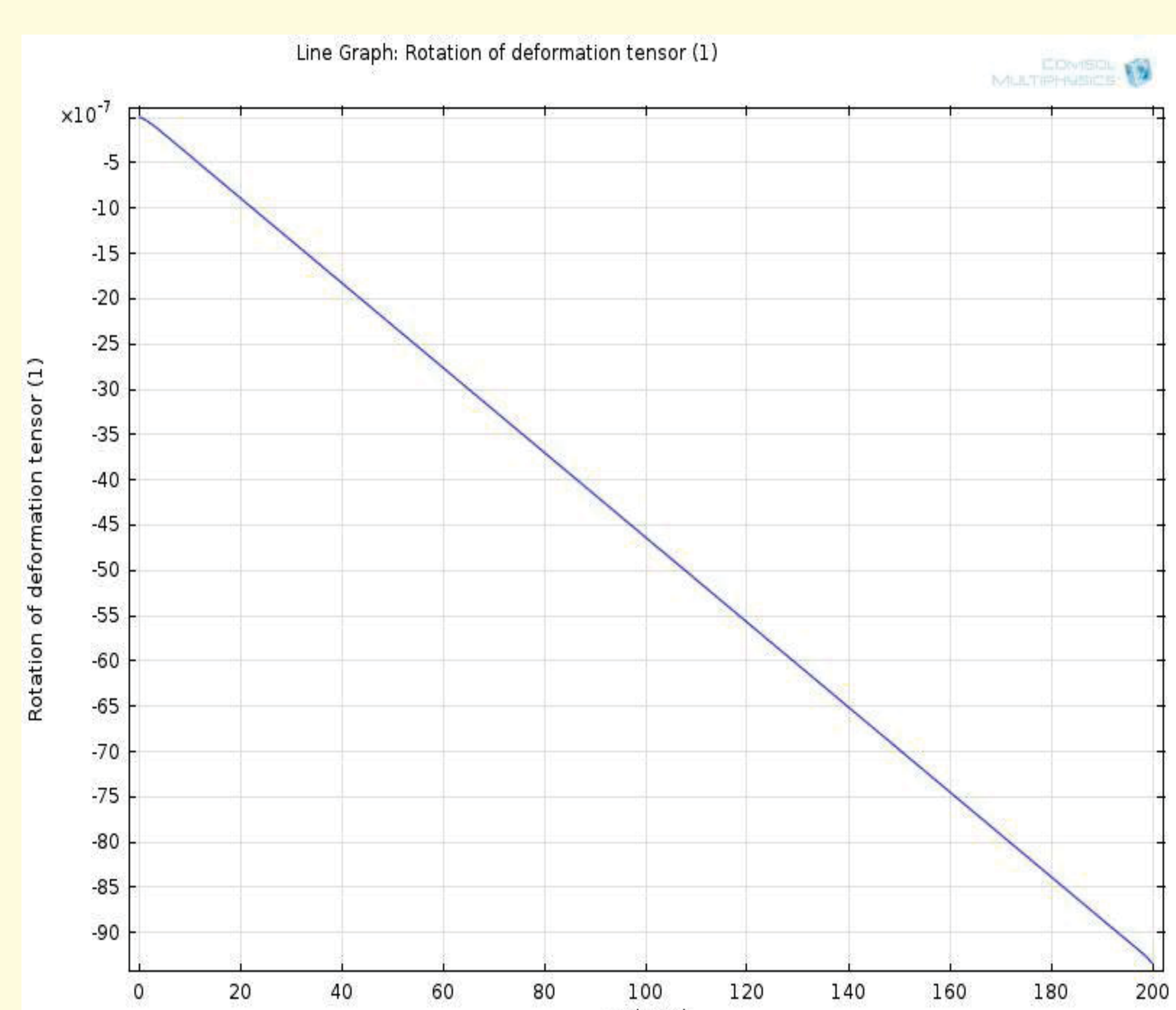
Magnetic Flux Density Simulation of the Lorenz Force Flow meter



Pattern of eddy currents induced in Lead-Bismuth Eutectic coolant in the vicinity of Lorenz Force Flow meter



Lorenz Force (N) variation with Temperature (K) of the Lead –Bismuth Eutectic



Plot of Strain in the force measurement element

Velocity (cm/s)	Strain (10^{-6})
1	1.2
2.5	3
3	3.6
4	4.8
5	6
6	7.2
7	8.4
8	9.6
9	10.8
20	24
30	36
40	48
50	60

Table showing Strain Vs Velocity

The Lorenz force flow meter are non intrusive type of flow meter for molten metal flow and are suitable for high temperature applications like Compact High Temperature Reactors (CHTR). They have salient features like ease of maintainability due to no contact with the high temperature flow medium and further permanent magnet can be maintained at lower temperature than that of the flow medium by use of high permeability ferromagnetic shunts . The sensitivity of the Lorenz force flow meter can be improved by use of high temperature superconducting magnets.

References
[1] P A Davidson, An introduction to Magnetohydrodynamics (Cambridge University Press, Cambridge, 2001)