# COMSOL Modelling for Li-ion Battery Diagnostics

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**Introduction:** In today's world, Li-ion batteries are widely used power sources for various applications including the automotive industry. The performance and cycle life of Li-ion battery are gradually becoming important issues especially for dynamic power applications (EVs, HEVs). To create a better control over the performance and cycle life of a Li-ion battery, accurate battery diagnostics is required. We are investigating a non-invasive method for Li-ion battery diagnosis based upon magnetic field probing to diagnose its ageing parameters [1]. The scope of this research work is to develop a Li-ion battery model with applied magnetic field to induce battery health deteriorating parameters like deprived intercalation of insertion particle ($Li^+$), internal impedance rise, internal temperature rise, electrolyte decomposition and electrodes' cracking [2] for battery ageing and predict its future age.

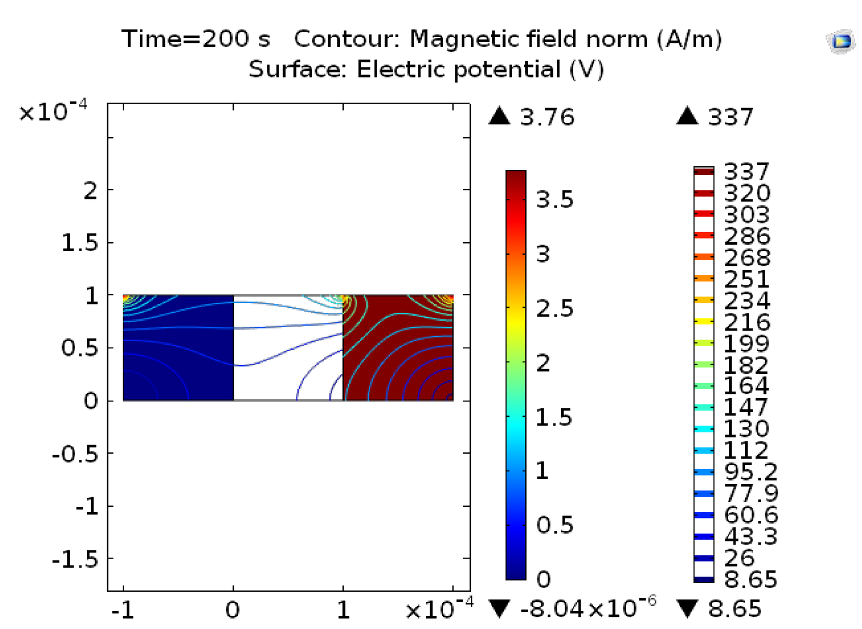


**Figure 1**. P2D Modelling of Li-ion battery with Magnetic Field

**Computational Methods:** We have designed and simulated a simple 2-D geometry model based on pseudo two dimensional (P2D) modelling which is coupled with magnetic field (mf) physics. Following equations and parameters are used for solving the model. A detailed analysis has been performed to evaluate the response of applied magnetic field on the domains of Li-ion battery [3, 4].

*Battery Electrode/Electrolyte Equations*

$$\varepsilon_l \frac{\partial c_l}{\partial t} + \nabla \cdot N_l = R_l; \quad R_l = - \frac{V_{Li^+,m} i_{v,m}}{F} + F_{l,src}$$

$$\nabla \cdot i_l = i_{v,total} + Q_l \; ; \quad \nabla \cdot i_s = -i_{v,total} + Q_s$$

$$i_s = -\sigma_{s,eff} \cdot \nabla \Phi_s \qquad N_l = -D_{l,eff} \nabla C_l + \frac{i_l t_+}{F}$$

$$i_l = -\sigma_{l,eff} \nabla \phi_l + \frac{2\sigma_{l,eff} \cdot RT}{F} \left(1 + \frac{\partial ln f_\pm}{\partial ln c_l}\right)(1 - t_+) \nabla ln c_l$$

$$D_{l,eff} = \varepsilon_l^{1.5} \cdot D_l \qquad i_{v,total} = \sum_m i_{v,m} + i_v$$

$$\frac{\partial c_s}{\partial t} = \nabla \cdot (D_s \nabla c_s) \qquad \frac{\partial c_s}{\partial t}|_{r=0} = 0$$

$$-D_s \frac{\partial c_s}{\partial r}|_{r=R_p} = \sum_m \frac{V_{Li,m} i_{v,m} r_p}{F 3 \varepsilon_s}$$

$$\frac{\partial C_1}{\partial t} + \nabla . N_l = R_l$$

$$\nabla . i_l = Q_l$$

$$\nabla . i_s = Q_s, i_s = -\sigma_s \nabla \phi_s$$

$$i_l = -\sigma_l \nabla \phi_l + \frac{2\sigma_l RT}{F}\left(1 + \frac{\partial nf}{\partial \ln C_1}\right)(1 - t_+) \nabla \ln C_1$$

$$N_l = -D_l \nabla C_1 + \frac{i_l t_+}{F}$$

$$\phi_l = phil, \phi_s = phis, C_1 = cl$$

*Applied Magnetic Field Equations*

$$\sigma \frac{\partial A}{\partial t} + \nabla \times \left(\mu_0^{-1} \mu_r^{-1} B\right) - \sigma V \times B = J_e$$

$$\sigma \frac{\partial A}{\partial t} + \nabla \times H = J_e$$

$$B = \nabla \times A$$

**Results:** The simulation results provide behaviour of battery under the applied magnetic field. Under battery diagnosis, we get the magnetic field response in each domain and determine the behaviour pattern of each domain. The figures 2 (a, b) show that the electric potential (phis) in domain 3 increases with magnetic flux density (B) during discharging and vice-versa. The figure 3 shows the magnetic field response with insertion particle concentration (liion.cs_average). Magnetic field intensity (H) increases with the insertion particles concentration. During diagnosis process, we will investigate the impact of magnetic field on following ageing parameters like:

- The MFR (Magnetic Field Response) vs. loss of capacity due to the ageing
- MFR with respect to charging/discharging behaviour of the Li-ion battery
- MFR with respect to change in internal impedance of the Li-ion battery

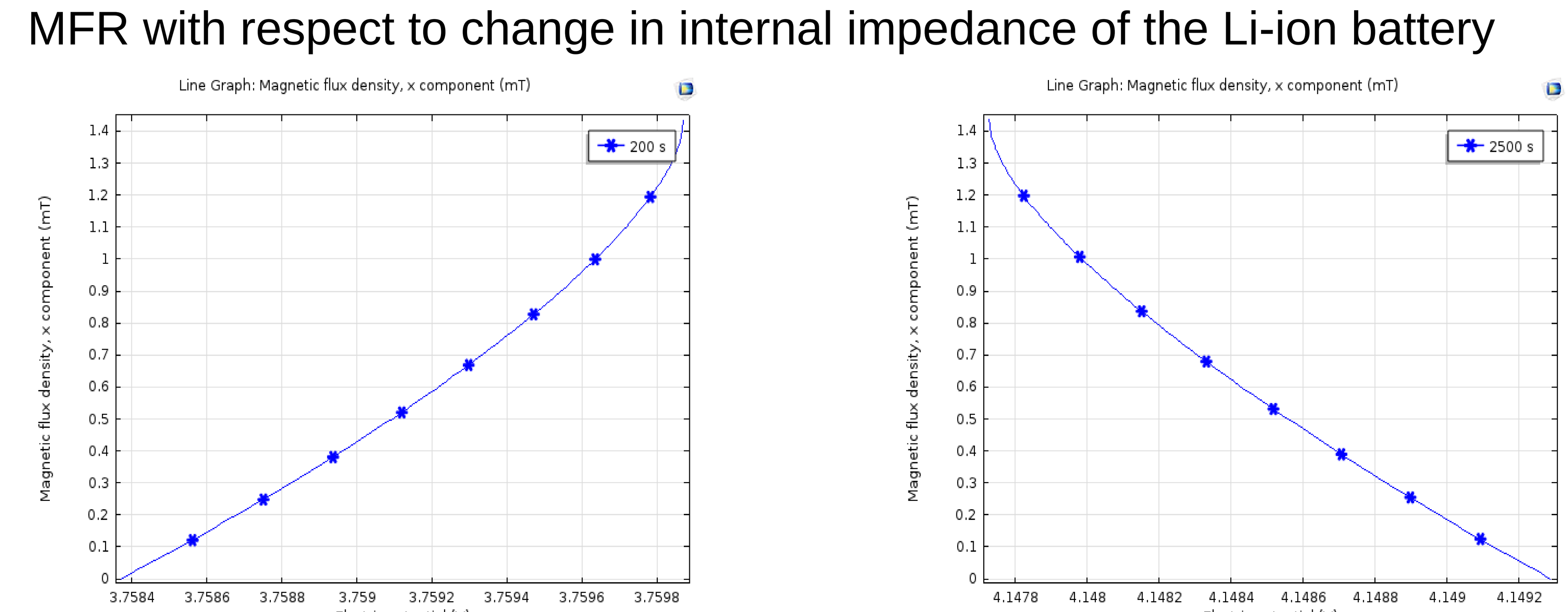


**Figure 2.** Electric potential of Li-ion battery Vs. Magnetic field response
(a) During Discharging (b) During Charging

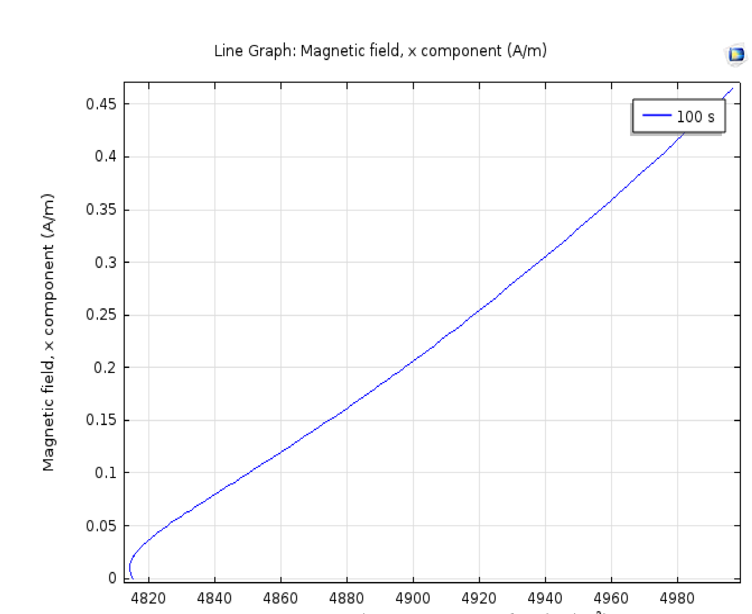


**Figure 3.** Insertion Li-ion particle concentration Vs. Magnetic field response

**Conclusion:** Promising results during simulation indicate that *COMSOL Multiphysics®* has potential to support this study and help in modelling MFP interfaced with Li-ion battery to diagnose the battery as well as predict ageing phenomena inside the battery. This model will also help to design a prototype for real time diagnostics for Li-ion Battery.

**References:**

1. N. Khare, P. Singh, and J. K. Vassiliou, "A novel magnetic field probing technique for determining state of health of sealed lead-acid batteries," J. Power Sources, vol. 218, pp. 462–473, 2012.

2. Rashid, M. and Gupta, A., 2015, "Effect of relaxation periods over cycling performance of a Li-ion battery", Journal of the Electrochemical Society, vol. 162(2), pp. A3145-A3153, 2015

3. Zhou, Lina, et al. "Paramagnetic electrodes and bulk magnetic susceptibility effects in the< in situ NMR studies of batteries: Application to Li< sub> 1.08</sub> Mn< sub> 1.92</sub> O< sub> 4</sub> spinels." Journal of Magnetic Resonance 234, pp. 44-57, 2013.

4. N. Taniguchi, K. Hatoh, J. Niikura, T. Gamo, M. Doyle, and J. Newman, "Comparison of Modeling Predictions with Experimental Data from Plastic Lithium Ion Cells," vol. 143, no. 6, pp. 1890–1903, 1996.

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