國立臺灣大學工學院應用力學研究所

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# 利用電化學法探討鋰離子電池組穿刺安全設計與串聯溫度管理

# On the Nail Penetration Safety Design and Series Connection Thermal Management for Li-Ion Battery Pack with an Electrochemical Approach

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# 摘要

在車禍發生時，電動汽車之電池組極有可能發生穿刺的情形。透過一套標準的電池穿刺試驗方法，特定電池組在發生穿刺後的行為即可以被顯現。然而，穿刺試驗通常需要花費較高的時間與成本。因此，只要透過結合多孔電極理論與電池熱破壞方程式，電池穿刺試驗將能夠利用模擬進行相關的分析。

此篇論文針對一個由九顆電池堆疊而成的電池組進行討論。利用我們所發展的模型，電池穿刺試驗之模擬與實驗結果相當吻合。除此之外，為了增加電池組之安全性，我們亦模擬了將一種特定的防火材料(REDDEX)加入電池組中的效益。在模擬中，我們比對了三種不同 REDDEX 的成效，並且透過與實驗的結合，我們證明了加入 REDDEX 將對電池組之安全性有顯著的提升。

除了電池組之安全設計，此篇論文亦分析了其在正常工作狀態下之性能。在實際運用的情形中，為了能夠控制電動汽車電池組之溫度，常見的方式為將冷空氣直接吹入電池組當中，利用熱對流降低電池的溫度。但是基於個別電池擺放位置的不同所造成的不均勻散熱流場，電池組中的每一顆電池將難以保持在相同的溫度。雖然眾所周知電池溫度的差異會對其放電電壓與容量造成影響，但是針對其程度，目前仍然需要更進一步的定性與定量分析。此分析可以透過我們的電池組電化學模擬來達成。

我們模擬了一個由串聯十顆 26650 磷酸鋰鐵鋰離子電池所組成之電池組的循環壽命。針對每一顆電池，我們以直接給定個別電池不同溫度的方式，形成一個由十顆性能不均的電池所串聯而成的電池組。由於其放電能力的不一致，我們的模擬結果顯示此情形將會造成電池組容量的下降，並且，其下降的速度將隨溫

度差異的增加而上升。針對溫度不均對電池組壽命的影響，一個更詳細與完整的分析將會在此篇論文中呈現與討論。

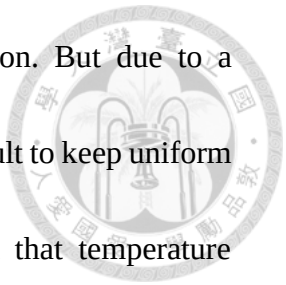
**關鍵字**：鋰離子電池、穿刺、安全設計、電池串聯、循環壽命、溫度效應、熱管理、模擬。

# Abstract

Battery pack nail penetration is likely to occur in electric car collisions. Therefore, to demonstrate the behavior of a specific battery pack when subjected to nail penetration, a standard nail penetration test has been performed. However, conducting such experiment could be time and money consuming. As a result, by combining the porous electrode theory and thermal abuse equations, the battery pack nail penetration test could be analyzed via simulation.

The case of a nine-cell battery pack nail penetration test was studied. By using the developed model, the simulation results agree well with the experiment. In addition, to improve the safety of battery packs, a specific fireproof material, REDDEX, was installed into the assembly, and a corresponding simulation was carried out. Three types of REDDEX was compared by both numerical modeling and experiment, where it is shown that an enhanced safety could be obtained by applying the material.

Other than safety designs, the performance of battery pack is also investigated. In real-life application of electric vehicles, battery packs require thermal management systems to control the temperature within. A practical method is to apply conditioned



air directly into the battery packs, cooling the cells by convection. But due to a nonuniform cooling flow caused by the layout of the cells, it is difficult to keep uniform temperature inside the battery packs. Although it is well known that temperature difference will affect the performance (discharge voltage and capacity) of the battery pack, the degree of this influence, however, requires further qualitative and quantitative analysis. This analysis can be performed by the aid of battery pack modeling.

We simulated the battery pack cycle life property of ten 26650 LFP cells connected in series. For all the cells within, we artificially assigned ten different temperature values, generating a scenario of performance imbalance for the ten series connected cells. Due to the imbalance situation, our result has shown that the capacity degradation of the battery pack increases with temperature difference, and the undesired effect accelerates with increasing pack average temperature value. A more detailed and integrated analysis of battery packs formed by imbalance performance cells will be presented and discussed in this work.

**Keywords**: lithium-ion battery, nail penetration, safety design, series connection, cycle life, temperature effect, thermal management, simulation.