國 立 成 功 大 學
航 空 太 空 工 程 研 究 所
碩 士 論 文

# 繞線機之纏繞路徑規劃與控制

# Winding Pattern Design and Control of Filament-Machine

研究生： 陳立璇 Li-Hsuan Chen

指導教授： 陳介力 Chieh-Li Chen

中 華 民 國 一 零 九 年 七 月

# 論文摘要

研究題目：

繞線機之纏繞路徑規劃與控制

Winding Pattern Design and Control of Filament-Machine

研究生：陳立璇

指導教授：陳介力

為了滿足航太產業質輕高強度之需求，燃料氣瓶的設計與製造成為太空發射載具提升負載能力的關鍵。目前較常採用的製程是以設計好之固定幾何金屬瓶，配合複合材料披覆來達成增強抗張能力及降低瓶重之效果。本研究結合了金屬瓶設計、複材纏繞設計、整體氣瓶應力分析並完成纏繞製程。所提出之纏繞製程以控制系統為著眼點，由機構運動學推導出繞線機台各軸馬達的運動命令，並根據耦合性決定四軸的主從關係，以進行複材纏繞實現。本論文以傳統三軸車床為基礎建構四軸繞線機台，藉由繞線機各次座標系之定義，獲得複材纏繞氣瓶程序的幾何描述。首先，以複合材料剪力模數與楊氏係數、柱面纏繞角，藉由充氣加壓氣瓶靜力平衡的關係式，計算最佳的氣瓶端蓋幾何外型。為了使纏繞過程不產生複材與金屬氣瓶間的滑動，計算複材纏繞過程側向滑脫力不超出最大靜摩擦力的纏繞角範圍，做為纏繞模式的參考。由於複材的主軸方向與副軸方向的抗張強度有極大差異，在設定柱面纏繞角下完成氣瓶表面均勻纏繞複材一次後，便可進行複材厚度計算與複材增強氣瓶之應力分析。根據分析結果，找出複材耗費長度最少且應力分布足以抵抗內部高壓氣體之纏繞角度與纏繞路徑。最後，基於所獲得之纏繞路徑，以繞線機構計算四軸驅動馬達相對之運動控制指令，並設計人機介面，實現繞線控制與即時監控功能。研究成果除可提升台灣在航太業製造能力外，對醫療、工業與民生使用之各式壓力氣瓶製造也極具產業應用價值。

**關鍵字：繞線機、路徑規劃、複材增強、壓力氣瓶、運動控制**

# ABSTRACT

In order to meet light weight and high strength needs for aerospace industries, the design and manufacture of fuel containers are critical to the increase in load capacity of space rockets. At present, the most commonly procedure is to design a metal container then winded by composite material such as carbon fiber. This study combines metal bottle design, composite winding design, cylindrical container stress analysis and the implementation of the winding process. The description of the winding process is based on the need of control motion so that it is much easier to be realized. The motion commands of the motors of each axis of the winding machine are generated from the kinematics relations and a master-slave motion control system is realized to accomplish the winding process.

In this dissertation, a four-spindle winding machine is constructed by a modification of a traditional three-spindle lathe. Through the definition of each coordinate system of the winding machine, the geometric description of the composite material winding cylindrical container was obtained. Firstly, using the composite material shear and Young's modulus in associated with the cylindrical winding angle, the optimal end cap geometry is determined using the static balance of the pressured container. In order to prevent sliding between the composite winding strip and the cylindrical container during the winding process, the winding angle range will be suggested such that the lateral slip force in between does not exceed the maximum static friction. Due to the great difference in the tensile strength between the main axis direction and the secondary axis direction of the composite material, after an uniform winding, the composite material thickness needs to be evaluated and stress analysis can be carried out to confirm the fulfillment of requirement. The length of the composite material used for a complete uniform winding will be different with respect to the winding angle to the cylinder wall. Therefore, a good choice of winding angle can be obtained accordingly. Finally, based on the obtained winding path, the winding mechanism is constructed to carry out the winding procedure. A man-machine interface is designed to realize winding control and real-time monitoring function. The proposed results will be beneficial to Taiwan’s manufacturing capabilities in the aerospace and relative industrial applications.