高轉速無感測驅控直流無刷薄型馬達技術探討

~以智慧吸塵器嵌入式鼓風機驅動設計為例

The High Speed Sensorless Brushless DC Slim Motor ~ for the embedded drive application of the blower inside the smart vacuum cleaner

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關鍵詞(Keywords)

- 高轉速鼓風機馬達 High speed blower motor
- 軸向磁通 Axial Flux
- 無感測驅控器 Sensorless driver
- 模糊邏輯控制法 Fuzzy Logic Controller, FLC

摘要(Abstract)

永磁直流無刷薄型馬達可嵌入於高轉速流機，除了簡化軸承與端蓋等優點，甚至降低系統轉動慣量，降低加減速電流，實現高效直驅的節能效果。現有市面流通的無感測驅控 IC 能提供的額定電流規格多在 1 A 以內，且可匹配之電氣頻率偏低限制了與高轉速流機之多極薄型馬達結合的應用性。鼓風機的薄化、節能、智慧化是現有清潔機器人之智慧吸塵模組的重要技術趨勢，本研究開發兩款不同構形之多極薄型馬達，包括其磁路分析模擬與特性預估，實體雛形分別與智慧吸塵器高轉速鼓風機嵌入結合測試，馬達整體尺寸在直徑 52 mm 及高度 10 mm 以下，搭配無感測器設計架構，簡化馬達零件與組裝工序，以智慧化模糊邏輯控制驅控技術，改善高轉速之下的能耗，並縮短整定時間，使得依照灰塵量大小即時調整轉速變得可能。實際驗證發現，徑向磁通薄型馬達設計在空載測試時，12 V 與 0.32 A 電流可達額定 14,000 rpm；與離心 Blower 模組直接負載測試時，平均電流在 2.3 A 以內，驗證其無感測驅控法在高轉速(14,000 rpm)應用下換相時機與電流控制強健性，對於依賴充電電池驅動的智慧吸塵器，與原有直流有刷馬達驅動鼓風機方案比較(電流>4.5 A)，平均耗電量下降達 50%，可有效降低回站充電頻率。此外，對照組之軸向磁通薄型

馬達因為採取無鐵芯設計，氣隙較大，整體馬達效率表現不如有鐵芯的徑向磁通設計，但是其較低的頓矩(cogging)可以獲得較平順的加速曲線，且線圈發熱可直接均勻傳遞至電路底板外，未來結合低鐵損 SMC 鐵芯，較易實現中空軸設計，仍具薄化嵌入應用之可能性。

The slim brushless DC motor could be embedded inside the high speed fluidic machinery to simplify the bearing or housing design. Besides, the total rotor inertial is decreased to eliminate the surge current demand during the acceleration command. The currently existing integrated sensorless driver IC usually limits the current output of 1A. Besides, the microprocessor bandwidth could not cope with the higher electric frequency of the multi-pole motor for the high speed fluidic machinery. The compactness of the blower, power-efficiency and intelligence are the main product genes of the new smart vacuum cleaner. This study investigates the feasibility of two type multi-pole slim motors for embedding application of the high speed blower in the robot cleaner. The magnetic analysis and the performance estimation are conducted and the prototypes are tested with the high speed blower. The sensorless scheme is adopted so the motor parts and assembly process are simplified to achieve a motor diameter size of 52 mm and 10mm in height. Together with the smart fuzzy logic control driver technology, the motor power efficiency at high speed range is regulated. Since the settling time is much decreased, the dynamic response for speed adjusting due to different dust level becomes quite better.

The experimental results show that the radial flux design consumes 0.32 A and 2.3 A separately at the free-load and full-load mode at 14,000rpm with 12 V DC bus input. This proves the phase switching control robustness of the three-phase current. To compare with the original DC motor for the blower of the battery-driven robot cleaner, the highly efficient direct-drive saves at least 50 % power consumption to effectively lessen the recharge demand. Although the axial flux design consumes more power mostly due to its coreless design, it delivers smoother acceleration curve since the cogging is negligible and the heat generated from the stator coil could be more easily transferred to the base board. In the future, the SMC stator will be adopted for the axial flux design to further evaluate the application potential of the hollow type slim motor.

1. 前言

根據 Winter Green 研究機構於 2010 的市調報告書指出[1]，清掃機器(cleaning robot)已是大眾化商品，具備輕巧與便宜的特性，在全球市場方面，2009 年時總值達 5.06 億美元，並預估 2016 年將成長到 20 億美元。供應此一全球市場的廠商一覽表如表 1 所示，其中 iRobot®市佔率最高。另一市調網站 Asia Bizz(asiabizz.com)於 2011 年底時

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