The Design of Heat Transfer Enhancement and Experimental Study of Thermal Characteristics for Rotating Machines

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Abstract

An experimental study of heat transfer and fluid flow for three different kinds of rotating machines: the radially rotating channel, the co-axis rotating cylinders and the rotating disk under forced convection is reported. To simulate the operation conditions of high-temperature parts of these rotating machines, the specified electric power was provided to the test section to generate heat by using the D.C. power supply. The experiment results demonstrate that interaction among the centrifugal, coriolis, and inertial forces of the coolant air strongly affected heat transfer and fluid flow in rotating machines: in radially rotating channel, the coriolis force caused secondary flow result in different cooling efficiency of the leading and trailing surface; also, in co-axis rotating system, temperature difference was found between outer and inner surface; while in impinging cooling of rotating heat sink or rotating circular cylinder, rotating effect was not obvious until the rotation number（Re_r/Re_j）exceed a critical number. Different thermal results exist among various rotating machines, therefore different designs of heat transfer enhancement should be adopted: open-cell metal porous media was chosen for the radially rotating channel and optimal dimensionless nozzle-to surface distance or rotation number（Re_r/Re_j）were evaluated for the

impinging cooling of rotating surface. This study can provide useful data for the cooling design of the relevant rotating systems.

Keywords: Rotating machine, forced convection, centrifugal force, coriolis force.

一、前言

現代機械中包含了大量的旋轉部件，係因絕大部分的動力機械都以旋轉的方式達成動力的轉換。而其往往在高溫的環境下工作或自身將產生大量熱量，因此將針對具體情形設計不同散熱構型及時將熱量移除，從而避免其因高溫而失效。相比於一般的散熱設計，由於機構的旋轉，其熱流特性將發生很大的改變。因此，對於旋轉機械的熱流特性研究，無論是工程實際應用或自然科學研究都是人們關注的焦點。

本研究所探討之旋轉機構實驗模型分別來自渦輪引擎之高壓渦輪葉片、高速五軸加工機之旋轉軸、車輛之制動盤、電子裝備散熱座以及旋轉針織機。實驗研究的構型分別爲徑向旋轉單通道及 180 度轉彎雙通道之強制對流、兩同心軸向旋轉圓柱間通道之強制對流、旋轉散熱座上表面之衝擊冷卻以及旋轉圓柱體側面之衝擊冷卻等 5 種模型。實驗分別採用熱電偶測溫、紅外線熱影像等實驗手段。並進一步針對不同旋轉模型提出了增強熱傳之設計，並利用實驗驗證其可行性。通過同時展示不同實驗的結果，從而具體表現了旋轉對熱傳與流動的影響。本文針對不同旋轉機械採用之簡化模型、實驗方法以及熱傳優化之設計都將對今後旋轉機械之熱流特性研究或增強散熱之設計提供參考與啓發。

二、國內外相關研究

（一）單一與 U 型徑向旋轉通道

Morris [1]、Morie 與 Nakayama [2]對平行軸旋轉之加熱圓管內熱傳研究中顯示：在層流情況下，由於旋轉將產生一對與主流場方向垂直之二次流，造成速度及溫度場成非對稱性分佈達到提昇熱傳效果，而且在管內流速不變時，科氏力效應隨旋轉半徑減少而增加，進而降低壓降量 (Pressure Drop) 與熱傳率。Ito 與 Nanbu [3]量測徑向旋轉圓形管道內全展流摩擦 (Friction) 係數，發現旋轉會使壁面摩擦增加。Harasgama 與 Morris [4]旋轉管道在不同截面形狀（圓形、方形、三角形）之熱傳實驗中得知，在徑向向外流情況下，增加浮力將減少平均熱傳量，在徑向向內流情況下則反之。Morris 與 Ghavami-Naser [5]於徑向旋轉矩形管道熱