雙膜式壓電合成致動器產生之合成噴流研析

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摘 要

壓電合成噴流致動器(Piezoelectrically Actuated Synthetic Jet Generator)因具有質量輕、低耗能、作動靈敏，構造簡單優點，故極具應用於航空載具、電子裝置散熱、以及提升燃料混合效果等主動式氣流控制範疇之潛力。本論文主要探究合成噴流複雜的流場結構及特性，進而建立壓電合成噴流致動器關鍵設計、分析技術。為檢測壓電致動器片作動特性，研究中以有限元素法(Finite Element Analysis, FEA)與Polytec??D 都普勒雷射干涉儀，分析、並量測壓電片承受電壓驅動波型後產生之位移及體積變量。致動器氣室之壓電片持續作動而由噴口形成穩定噴流，實驗上即藉由熱絲式流速計與雷射螢光顆粒激發顯像技術擷取質點影像，以量測/觀察低頻率驅動條件下合成噴流暫態流場結構週期時變特性及速度分佈；同時以計算流體力學方法，模擬壓電合成噴流隨時間週期變化之瞬時流場行為，並與量測結果相互比較，以驗證理論模型數值計算準確度。本文亦延伸探討實際工作自然頻率驅動條件下壓電合成噴流週期時變流場結構及速度分佈，推展運用數值模擬方法，研析其最大振動幅度狀況下噴口寬度、氣室厚度、驅動電壓/頻率、壓電片相對相位延遲等關鍵設計參數對致動器效能影響，以期達成致動器效能最佳化調控以提昇其操作效率。

關鍵詞 : 合成噴流 ; 壓電致動器 ; 數值模擬

目錄

參考文獻

[1].Ingard, U. and Labate, S.,“ Acoustic generation of circulation currents and jet effects, ’ ’ Journal of the Acoustical Society of America, Vol. 22, Issue 1, 1950, p. 87.

[2].Dore, B. D.,“ Double boundary layers in standing surface waves, ’ ’ Pure and Applied Geophysics, Vol. 24, No. 4, 1976, pp. 629-637.

[3].Coles, D.,“ Prospects for useful research on coherent structure in turbulent shear flow, ’ ’ Indian Academy of Sciences, Proceedings (Engineering Sciences), Vol. 4, 1981, pp.111-127.

[4].Savas, O.,“ On flow visualization using reflective flakes, ’ ’ Journal of Fluid Mechanics, Vol. 152, 1985, pp.235-248.

[5].Makarov S. N., Semenova N. G. and Smirnov V. E.,“ Acoustic streaming model for an intense sound beam in free space, ’ ’ Fluid Dynamics, Vol. 24, No. 6, 1989, pp.823-826.

[6].Kral, P., Sheard, F. W., Ouali, F.F. and Challis, L. J.,“ Theory of electron resonant tunnelling through localized states in the presence of hot

acoustic phonons, ’ ’ Physica Status Solidi (B), Applied Research, Vol. 204, Issue 1, 1997, pp.438-441.
[7].McCormick, D. C., “ Boundary layer separation control with directed synthetic jets, ’ ’ AIAA Paper No. 2000-519, 2000.
[8].Bertelsen, A. F., “ An experimental investigation of high Reynolds number steady streaming generated by oscillating cylinders, ’ ’ Journal of Fluid Mechanics, Vol. 64, Issue 03, 1974, pp.589-598.
[9].Gopalkrishnan, R., Triantafyllou, M. S., Triantafyllou, G. S. and Barrett, D., “ Active vorticity control in a shear flow using a flapping foil, ” Journal of Fluid Mechanics, Vol. 274, 1994, pp. 1-21.
[10].James, R. D., Jacobs. J. W. and Glezer, A., “ A round turbulent jet produced by an oscillating diaphragm, ” Phys. Fluids, Vol. 8, 1996. pp. 2484-2495.
[11].Smith, B. L. and Glezer, A., “ The formation and evolution of synthetic jets, ” Physics of Fluids, Vol. 10, No. 9, 1998, pp. 2281-2297.
[12].Smith, B. L., “ Synthetic Jets and their Interaction with Adjacent Jets, ” PhD Thesis, Georgia Institute of Technology, Atlanta, GA, 2000.
[13].Lee, C., Ha, Q.P., Hong, G. and Mallinson, S., “ A piezoelectrically actuated micro synthetic jet for active flow control, ” Sensors and Actuators A, Vol. 108, 2003, pp. 168-174.
[14].Karla, M., Robert, B., and Poorna, M., “ Piezoelectric composites as bender actuators, ” Integrated Ferroelectrics, Vol. 71, 2005, pp. 221 – 232.
[15].Chen, F. J., Yao, C., Beeler, G. B., Bryant, R. G., and Fox, R. L., “ Development of Synthetic Jet Actuators for Active Flow Control at NASA Langley, ” AIAA Paper No. 2000-2405, 2000.
[16].Bryant, R. G., Fox., Lachowizc, J. T. and Chen, F.J., “ Piezoelectric Synthetic Jets for Aircraft Control Surfaces, ” Proceedings of the SPIE Conference on Industrial and Commercial Applications of Smart Structures, SPIE Vol. 3674, Newport Beach, CA, March, 1999.
[17].Rathnasingham, R. and Breuer, K. S., “ Characteristics of Resonant Actuators for Flow Control, ” 34th Aerospace Sciences Meeting and Exhibit, Reno, NV, AIAA Paper No. 96-0311, 1996.
[18].Amitay, M. and Cannelle, F., “ Evolution of finite span synthetic jets, ” Physics of Fluids, Vol. 18, 054101, 2006, (16 pages).
[19].Liang., Y. C., Kuga, Y. and Taya, M., “ Design of membrane actuator based on ferromagnetic shape memory alloy composite for synthetic jet applications, ’ ’ Sensors and Actuators A, Vol. 125, 2006, pp. 512 – 518.
[20].Rediniotis O., Ko J, Yue, X, Kurdila, A., “ Synthetic jets, their reduced order modeling and applications to flow control, ” 37th Aerospace Sciences Meeting and Exhibit, Reno, NV, AIAA Paper No. 99-1000, 1999.
[21].Crook, A. and Wood, N. J., “ Measurements and visualization of synthetic jets, ” 39th Aerospace Sciences Meeting and Exhibit, Reno, NV, AIAA Paper No. 2001-0145, 2001.
[22].Shuster, J. M. and Smith, D. R., “ Experimental study of the formation and scaling of a round synthetic jet, ” Physics of Fluids, Vol. 19, 045109, 2007, (21 pages).
[23].Crook, A., Sadri, M., and Wood, N. J., “ The development and implementation of synthetic jets for control of separated flow, ” AIAA Paper No. 99-3176, June 1999.
[24].Cater, J. E. and Soria, J., “ The evolution of round zero-net-mass-flux jets, ” J. Fluid Mech., Vol. 472, 2002, p. 167.
[25].Smith, B. L. and Swift, G. W., “ A comparison between synthetic jets and continuous jets, ” Exp. Fluids, Vol. 34, 2003, p. 467.
[26].Smith, B. L. and Swift, G. W., “ Power dissipation and time-averaged pressure in oscillating flow through a sudden area change, ” J. Acoust. Soc. Am., Vol. 113, 2003, p. 2455.
[27].Rizzetta, D. P., Visbal, M. R. and Stanek, M. J., “ Numerical investigation of synthetic jet flowfields, ” AIAA Journal, Vol. 37, No. 8, 1999, pp. 919 – 927.
[28].Wang, Y., “ Microfluidic technology for integrated thermal management: micromachined synthetic jet, ” Ph. D. thesis, Georgia Inst. Technology, Atlanta, GA, November 2003.
[29].Lee, C. Y., and Goldstein, D. B., “ Two Dimensional Synthetic Jet Simulation, ” AIAA Journal, Vol. 40, No. 3, 2002, pp. 510-516.
[30].Fugal, S. R., Smith, B. L. and Spall, R. E., “ Displacement amplitude scaling of a two-dimensional synthetic jet, ” Physics of Fluids, Vol. 17, 045103 , 2005, (10 pages).
[31].Calkins, F. T., Mabe, J. H., Smith, J. P. and Arbogast, D. J., “ Low frequency multilayer piezopolymer synthetic jets for active flow control, ” AIAA Paper No. 98-0201, 1998.
[32].Smith, B. L., and Glezer, A., “ Vectoring and small-scale motions effected in free shear flows using synthetic jet actuators, ” AIAA Paper No. 97-0213, 1997.
[33].Smith, B. L., Trautman, M. A., and Glezer, A., “ Controlled interactions of adjacent synthetic jets, ” AIAA Paper No. 99-0669, 1999.
[34].Pack, L., and Seifert, A., “ Periodic excitation for jet vectoring and enhanced spreading, ” AIAA Paper No. 99-0672, 1999.
[35].Parekh, D. E., and Glezer, A., “ AVIA: Adaptive virtual aerosurface, ” AIAA Paper, No. 2000-2474, 2000.
[36].Seifert, A., Bachar, T., Koss, D., Shepshelovich, M., and Wygnanski, I., “ Oscillatory Blowing:A tool to delay boundary-layer separation, ” AIAA Journal, Vol. 31, No. 11, 1993, pp. 2052-2060.
[37].Amitay, M., Hohan, A., Trautman, M., and Glezer, A., “ Modification of the aerodynamics characteristics of bluff bodies, ” AIAA 97-2004, 1997.

[38].Roos, F. W.,“ Synthetic-jet microblowing for forebody flow asymmetry management, ” AIAA 98- 0212, 1998.
[39].Honohan, A. M., Amitay, M., and Glezer, A.,“ Aerodynamic control using synthetic jets, ” AIAA Paper, No. 2000-2401, 2000.
[40].Gilarranz, L. J., Traub, L. W. and Rediniotis, O. K.,“ A new class of synthetic jet actuators-Part I: Design, fabrication and bench top characterization, ” Journal of Fluids Engineering, ASME, Vol. 127, 2005, pp. 367-376.
[41].Gilarranz, L. J., Traub, L. W. and Rediniotis, O. K.,“ A new class of synthetic jet actuators-Part II: Application to flow separation control, ” Journal of Fluids Engineering, ASME, Vol. 127, 2005, pp. 377-387.
[42].Greenblatt, D., Paschal, K. B., Yao, C. S., Harris, J., Schaefler, N. W., and. Washburn, A. E.,“ Experimental investigation of separation control Part 1: baseline and steady suction, ” AIAA Journal, Vol. 44, No. 12, 2006, pp. 2820-2830.
[43].Greenblatt, D., Paschal, K. B., Yao, C. S., Harris, J.,“ Experimental investigation of separation control Part 2: zero mass-efflux oscillatory blowing, ” AIAA Journal, Vol. 44, No. 12, 2006, pp. 2831-2845.
[44].Madhira, V. P. K.,“ Interaction of synthetic jets with boundary layers, ” Fluid Sciences, Department of Mechanical Engineering, UNM, Albuquerque, NM., USA.
[45].Duraisamy, K. and Baeder, J.,“ Active flow control concepts for rotor airfoils using synthetic jets, ” AIAA Paper No. 2002-2823, 2002.
[46].Gilarranz, L. J., Traub, L. W. and Rediniotis, O. K.,“ Characterization of a compact, high-power synthetic jet actuator for flow separation control, ’ ’ AIAA Paper No. 2002-0127, 2002.
[47].Bales, K., Khoo, P., and Jefferies, R.,“ Flow control of a NACA 0015 airfoil using a chordwise array of synthetic jets, ” AIAA Paper No. 2003-0061, 2003.
[48].Yao, C., Chen, F. J., Neuhart, D., and Harris, J.,“ Synthetic jet flow field database for CFD validation, ” AIAA Paper No. 2004-2218, 2004.
[49].Cui J. and Agarwal, R. K.,“ 3D CFD validation of a synthetic jet in quiescent air (NASA Langley workshop validation: Case 1), ” AIAA Paper No. 2004-2222, 2004.
[50].Umemura, A., Miura, K. and Takada, K.,“ Suppression of embedded shocks in supersonic free-shear-layer structures, ” Shock Waves, Vol. 6, No. 3, 1996, pp. 167-175.
[51].Chen, Y., Liang, S., Aung, K., Glezer, A. and Jagoda, J.,“ Enhanced mixing in a simulated combustor using synthetic jet actuators, ” AIAA Paper No. 99-0449, 1999.
[52].Chen, Y., Scarborough, D., Liang, S., Aung, K. and Jagoda, J.,“ Manipulating pattern factor using synthetic jet actuators, ” AIAA Paper No. 2000-1023, 2000.
[53].Ritchie, B. D. and Seitzman, J. M.,“ Acetone mixing control of fuel jets using synthetic technology: scalar field measurements, ” AIAA Paper No. 99-0448, 1999.
[54].Ritchie, B. D. and Seitzman, J. M.,“ Controlled fuel-air mixing using a synthetic jet array, ” AIAA Paper No. 2000-3465, 2000.
[55].Parekh, D. E., Kibens, V., Glezer, A, Wiltse, J. M., and Smith, D. M.,“ Innovative jet flow control: mixing enhancement experiments, ” AIAA Paper No. 96-0308, 1996.
[56].Davis, S. A. and Glezer, A.,“ Mixing control of fuel jets using synthetic jet technology: velocity field measurement, ” AIAA Paper No. 99-0447, 1999.
[57].Ritchie, B. D. and Seitzman, J. M.,“ Mixing control of fuel jets using synthetic jet technology - Scalar field measurements, ” AIAA Paper No. 99-0448, 1999.
[58].Thomas M.,“ Application of the synthetic jet concept to low Reynolds number biosensor microfluidic flows for enhanced mixing: a numerical study using the lattice Boltzmann method, ” Biosensors and Bioelectronics, Vol. 19, 2004, pp. 1409-1419.
[59].Coe, D. J.,“ Fabrication Technology Approaches to Micromachined Synthetic Jets, ” Ph.D. Dissertation, Georgia Institute of Technology, 2002.
[60].Kercher, D. S., Lee, J. B., Brand, O., Allen, M. G. and Glezer, A.,“ Microjet cooling devices for thermal management of electronics, ” IEEE Transactions on Components and Packaging Technologies, Vol. 26, No. 2, 2003, pp. 359- 366.
[61].羅正忠。壓電噴射氣流器的實驗評估。中華民國航太學會/中華民用航空學會學術研討會。中華民國八十九年十二月。
[62].羅正忠，吳坤城。合成噴射氣流器的有限元素分析和效能實驗評估。第二十六屆力學會議學術研討會。中華民國九十一年十二月。
[63].羅正忠，陳華斌。壓電噴射氣流器設計參數的實驗評估。中國航太學會/中華民航學會學術研討會。中華民國九十二年。
[64].羅正忠，楊育彰。壓電噴射氣流器設計參數效能評估。中國航太學會/中華民航學會聯合學術研討會。中華民國九十三年十二月。
[65].王安邦、周志成。複動式合成噴流之流場顯影及特性探討，國立台灣大學應用力學研究所碩士論文，民國九十五年。
[66].Travnicek, Z., Fedorchenko, A., Wang, A. B.,“ Enhancement of synthetic jets by means of an integrated valve-less pump, Part I: Design of the actuator, ” Sensors and Actuators A, Vol. 120, No.1, 2005, pp. 232-240.
[67].Travnicek, Z., Vaclav T., Wang, A. B.,“ Enhancement of synthetic jets by means of an integrated valve-less pump, Part II: numerical and experimental study, ” Sensors and Actuators A, Vol. 125, 2005, pp. 50-58.
[68].顏瑞和、李奇霖。複動式與獨立式合成噴流場之數值模擬分析，國立台灣大學機械工程研究所碩士論文，民國九十五年。
[69].Van Doormaal, J. P. and Raithby, G. D.,“ Enhancements of the SIMPLE method for predicting incompressible fluid flows, ” Numerical Heat Transfer, Vol. 7, 1984, pp. 147-163.