

DEVELOPMENT AND ANALYSIS OF
DIRECT CURRENT LOW ENERGY
MICRO-SHEET-FORMING MACHINE

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Master of Engineering(Mechanical)

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Engineering in Mechanical

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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LIST OF SYMBOLS

Ra	Average roughness
Ah	Charge
I	Current
Ω	Electrical resistance measured in Ohms
F	Force
Hz	Frequency measured in hertz
k	Kilo
L	Length
Rz	Mean roughness depth
μm	Micrometer
V_m	Min. Volts
N	Newton
A_p	Peak Amps
W_p	Peak Watts
P	Power rating
V_o	Tapped density
T	Thickness
t	Time consumed measured in seconds
V	Voltage measured in volts
W	Watt
Wh	Watt-hour

LIST OF ABBREVIATION

AC	Alternative current
AFM	Atomic force microscopy
CNC	Computer numerical control
CVD	Chemical vapour deposition
DAQ	Data acquisition
DC	Direct current
ECM	Electrochemical machining
EDM	Electrical discharge machining
EMF	Electro-magnetic filter
FEM	Finite element method
FFT	Fast fourier transform
FRF	Frequency response function
FSR	Force sensitive resistor
LIGA	Lithographie, Galvanoformung, Abformung
MEL	Mechanical engineering laboratory
MEMS	Micro-electro-mechanical systems
NSOM	Near-field scanning optical microscopy

SEM	Scanning electron microscopy
STM	Scanning tunnelling microscopy
PVD	Physical vapour deposition
PZT	Lead zirconate titanate
UTS	Ultimate tensile strength
TEM	Tunnelling electron microscopy

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ABSTRAK

Permintaan yang meningkat terhadap mikro-produk telah mendorong perkembangan pesat dalam teknologi pembuatan mikro bagi bahagian-bahagian individu dan sistem, yang merangkumi pembangunan baru proses pembuatan, peralatan dan jentera. Banyak usaha yang telah dilakukan hingga kini untuk meningkatkan kecekapan teknologi pembuatan miniatur/ mikro. Walau bagaimanapun, tidak banyak kajian yang dilakukan terhadap penjimatan tenaga semasa pemprosesan bahan. Pengurangan saiz bahan yang diproses dijangka akan turut mengurangkan penggunaan tenaga secara berkadar dengan skala miniatur. Fokus kajian ini adalah untuk merekabentuk mesin penghasil kepingan mikro yang menggunakan tenaga dalam kuantiti yang rendah bagi tujuan aplikasi pembentukan kepingan logam yang nipis, dan membina mesin penghasil kepingan mikro yang menggunakan arus terus dengan kuasa yang rendah. Di samping itu, kajian ini bertujuan mengukur dan menganalisis keupayaan dan kualiti mesin yang dibina. Beberapa konsep telah dihasilkan dan dinilai dengan melakukan analisis Kaedah Unsur Terhingga (Finite Element Method) dan perbandingan bahan-bahan. Konsep optimum telah dipilih untuk membangunkan reka bentuk yang terperinci. Pembinaan dan pemasangan mesin dilakukan berdasarkan reka bentuk konsep yang telah dipilih. Satu prototaip yang mempunyai sistem penggunaan tenaga yang rendah bagi mesin penghasil kepingan mikro merangkumi elemen-elemen mekanikal dan elektronik telah dibangunkan. Prestasi mesin ini telah diuji dari segi frekuensi asli, daya tebusan, kelajuan dan keupayaan penebukan, penggunaan tenaga (tebusan tunggal dan berdasarkan kekerapan masa). Mesin ini didapati mampu melakukan proses penghasilan kepingan mikro dalam satu peringkat tunggal untuk membentuk bahagian-bahagian kepingan logam yang nipis dengan ketebalan kurang daripada 100 mikron. Selain itu, mesin ini juga berkeupayaan menghasilkan sehingga 600 lejang seminit, dengan kapasiti daya sebanyak 320 N. Sejumlah 0.0038 Wh tenaga telah digunakan oleh mesin ini untuk menghasilkan satu bahagian tunggal. Oleh yang demikian, dapatlah dirumuskan bahawa kajian ini telah berjaya membangunkan sebuah mesin penghasil kepingan mikro yang menggunakan tenaga yang rendah bagi aplikasi pembentukan kepingan logam yang nipis.

ABSTRACT

Increased demands for micro-products have led to rapid development of micro-manufacturing technologies in the manufacture of individual parts and systems, which includes development of new manufacturing processes, tools and machinery. Tremendous efforts have been made, to date, to improve the efficiency of miniature-/micro-manufacturing technologies. However, there has been lack of research on energy saving during which materials are being processed. It is expected that with the miniaturization of materials being processed, energy consumption is also being 'miniaturized' proportionally. The focus of this study was to design a low energy micro-sheet-forming machine for thin sheet metal application and fabricate a low direct current powered micro-sheet-forming machine. In addition, the research aimed to quantify and analyze the capability and quality of the fabricated machine. Several concepts were generated and these were evaluated by performing Finite Element Method (FEM) analysis and materials comparison. An optimal concept was selected to develop a detailed design. Fabrication and assembly of the machine was made according to the selected conceptual design. A prototype of low energy system for a micro-sheet-forming machine that included mechanical and electronic elements was developed. The machine was tested for its performance in terms of natural frequency, punching forces, punching speed and capability, energy consumption (single punch and frequency-time based). The machine was capable of single stage of micro-sheet-forming processes for thin sheet metal parts with thickness of less than 100 μm . Furthermore, it was also capable of producing up to 600 strokes per minute, with force capacity of 320 N. The energy consumption for the machine to produce a single part was 0.0038 Wh. Thus, it can be concluded that this research has successfully resulted in the development of a low energy micro-sheet-forming machine for thin sheet metal forming application.

REFERENCES

- Arai, F. & Fukuda, T. (1997) A new pick up and release method by heating for micromanipulation. *IEEE*. 383-388.
- Arai, F., Ando, D., Fukuda, T., Nonoda, Y. and Oota, T. (1995) Micro manipulation based on micro physics - Strategy based on attractive force reduction and stress measurement. *Proc. IEEE/RSJ*. 236-241.
- Aronson, R. B. (2003) The new world of micromanufacturing. *Manufacturing Engineering*. 140, 4.
- Aronson, R. B. (2004) Micromanufacturing is Growing. *Manufacturing Engineering. Manufacturing Engineering*. 132, 4
- Boljanovic, V. (2005). *Die Design Fundamentals*. Industrial Press.
- Bowling, R. A. (1986) Detection, Adhesion and Removal. Proceedings of the Symposium on particles on surfaces 1. Plenum Press. San Francisco.
- Bowling, R. A. (1988) A theoretical review of particle adhesion. Particles on Surfaces I - Detection, Adhesion, and Removal. Plenum Press. New York.
- Brussel, H. V., J. Peirs, Reynaerts, D., Delchambre, A., Reinhart, G., Roth, N., Weck, M. and Zussman, E. (2000) Assembly of microsystems. *Annals of the CIRP*, 49, 451-472.
- Byung, Y. J., Rhim, S.H. and Oh, S.L. (2005). Micro-hole fabrication by mechanical punching process. *J. Mats. Proc. Tech.*, 170, 593.
- Chern, G.L. and Renn, J.C. (2004). Development of a novel micro-punching machine using proportional solenoid. *J. Mats. Proc. Tech.*, 25, 89-93.
- Chern, G.L., Wu, Y.J. E. and Liu, S.F. (2006) Development of a micro-punching machine and study on the influence of vibration machining in micro-EDM. *J. Mats. Proc. Tech.*, 180, 102-109.
- Claessen, U. and Codourey, A. (2002). Microfactory. *Section Head CSEM CH 6055 Alpnach Switzerlan*. Switzerland.
- Davim, J. P., Vilarinho, C., Soares, D., Castro, F. and Barbosa, J. (2005) Influence of the chemical composition on the machinability of brasses. *J. Mats. Proc. Tech.*, 170, 441-447.
- Dietmair, A., and Verl, A. (2009). Energy consumption forecasting and optimisation for tool machines. *Energy*, 62, 63.
- Feddema, J. T., Xavier, P., and Brown, R. (1999) Micro-Assembly Planning with Van Der Waals Force. Proceedings of the 1999 IEEE International Symposium on Assembly and Task Planning. Porto, Portugal, IEEE. 32-38.

- Gaugel, T., Dobler, H., Malthan, D., Bengel, M. and Weis, C. (2001), Minifabrik für Laserdioden und Biochips. 1-7.
- Geiger, M., Kleiner, M., Eckstein, R., Tiesler, N. and Engel, U. (2001) Microforming. *CIRP Annals - Manufacturing Technology*, 50, 445-462.
- Geiger, M., Vollertsen, F. and Kals, R. (1996) Fundamentals on the manufacturing of sheet metal microparts. *Annals of the CIRP*, 45(1), 227-282.
- Hedrick, A., (2006), Die basics 101 starts with eight basic components. Thefabricator.com (online). Retrieved from <http://www.thefabricator.com/article/stamping/die-basics-101-starts-with-eight-basic-components>
- Hess, A. (2000) Piezoelectric driven press for production of metallic microparts by forming. *7th International Conference on New Actuators*. Bremen.
- Hu, Z., Vollertsen, F., Niehoff, H. S. and Theiler, C. (2004) State of the art in micro forming and investigations into micro deep drawing. *J. Mats. Proc. Tech.*, 151, 70-79.
- Jeong, H.-W., Hata, S. and Shimokohbe, A. (2003) Microforming of three-dimensional microstructures from thin-film metallic glass. *J. of Microelectromechanical Systems*, 12(1), 42-52.
- Joo, B. Y., Rhim, S. H., and Oh, S. I. (2005). Micro-hole fabrication by mechanical punching process. *Journal of Materials Processing Technology*, 170(3), 593-601.
- Kalpakjian, S. and Schmid, S. R. (2006) *Manufacturing Engineering and Technology*, Prentice Hall.
- Kalpakjian, S. and Schmid, S.R. 2001. *Manufacturing Engineering and Technology*. 4th ed. London: Prentice-Hall, Inc..
- Kibe, Y., Okada, Y. and Mitsui, K. (2007) Machining accuracy for shearing process of thin-sheet metals-Development of initial tool position adjustment system. *International Journal of Machine Tools & Manufacture*, 47, 1728-1737.
- Kima, S. S., Hana, C. S. and Lee, Y.-S. (2005) Development of a new burr-free hydro-mechanical punching. *J. Mats. Proc. Tech.*, 162-163, 524-529.
- Klocke, V. and Gesang, T. (2003), Nanorobotics for Micro Production Technology. *Klocke Nanotechnik, Pascalstr.* Proceedings of the SPIE, 4943, 132-141.
- Kolesar, E. S., Moncrief, W. A., Lewis, F. L. and Moncrief-O'donnell (2000), Introduction to Microelectromechanical Systems (MEMS). University of Texas at Arlington.
- Kumar, N. S., Shetty, A., Shetty, A., Ananth, K., and Shetty, H. (2012). Effect of spindle speed and feed rate on surface roughness of Carbon Steels in CNC turning. *Procedia Engineering*, 38, 691-697.

- Matsushita, N. (2003) Laser Micro-Bending for precise micro-fabrication of magnetic disk-drive components. *Int. Sympo. on Laser Precision Microfabrication*. No4, Munich.
- Messner, A., Engel, U., Kals, R., and Vollertsen, F. (1994) Size effect in the FE-simulation of micro-forming processes. *J. Mats. Proc. Tech.*, 45, 371-376.
- Mishima, N., Ashida, K., Tanikawa, T., and Maekawa, H. (2002), Design of a microfactory, *Proceedings of the ASME Design Engineering Technical Conference — 7th Design for Manufacturing Conference*. Montreal, Que., Canada.
- Mori, K., Abe, Y., Kidoma, Y., and Kadarno, P. (2013). Slight clearance punching of ultra-high strength steel sheets using punch having small round edge. *International Journal of Machine Tools and Manufacture*, 65, 41-46.
- Mrad, R. B. and Tenzer, P. E. (2004) On amplification in inchworm(tm) precision positioners. *Mechatronics*, 14, 515-531.
- Neugebauer, R., Drossel, W., Ihlenfeldt, S., and Rentzsch, H., (2011). Machining with redundant kinematics. *Proc. ASME Des. Eng. Tech. Conf. 6 (Parts A and B)*, 871-882.
- Oh, S. I., Rhim, S. H., Joo, B. Y., Yoon, S. M., Park, H. J., and Choi, T. H. (2005) Forming of micro channels with ultra thin metal foil by cold isostatic pressing. *5th Japan-Korea Joint Symposium on Micro-Fabrication*.
- Okazaki, Y., Mishima, N., and Ashida, K. (2002) Microfactory and micro machine tool. The 1st Korea-Japan Conference on Positioning Technology. Daejeon, Korea.
- Okazaki, Y., Mishima, N., and Ashida, K. (2004) Microfactory – Concept, History, and Developments. *Journal of Manufacturing Science and Processing*, 126, 837-844.
- Park, J. H., Yoshida, K., Nakasu, Y., and Yokota, S. (2002) A resonantly-driven piezoelectric micropump for microfactory. *Proc. ICMT20002*. Kitakyushu
- Qin, Y., Brockett, A., Ma, Y., Razali, A., Zhao, J., Harrison, C., and Loziak, D. (2010). Micro-manufacturing: research, technology outcomes and development issues. *The International Journal of Advanced Manufacturing Technology*, 47(9-12), 821-837.
- Qin, Y. (2009) Overview on Micro-Manufacturing. IN QIN, Y. (Ed.) *Micro-manufacturing Engineering and Technology*. Glasgow, Elsevier.
- Qin, Y. (2007) Advances in micro-manufacturing research and technological development and challenges/opportunities for micro-mechanical-machining. *Cutting Tools Congress*. Milano, Italy.
- Qin, Y. (2010). *Micro-Manufacturing Engineering and Technology*. UK: Elsevier.

- Qin, Y., Ma, Y., Harrison, C., Brockett, A., Zhou, M., Zhao, J., and Eguia, J. (2008). Development of a new machine system for the forming of micro-sheet-products. *International Journal of Material Forming*, 1(1), 475-478.
- Qin, Y., Razali, A., Zhou, M., Zhao, J., Harrison, C., and Wan Nawang, W.A. (2012). Dynamic Characteristics of a Micro-Sheet-Forming Machine System. *Key Engineering Materials*, Vols. 504-506, pp. 599-604.
- Razali, A. and Qin, Y. (2010). FE Simulation of Sheet-Metal Feeding in Micro-Forming, 21st International Computer-Aided Production Engineering Conference. CAPE 2010 Edinburgh.
- Razali, A., Qin, Y., Zhao, J., Harrison, C., and Smith, R. (2011). Development of a new high-precision feeder for micro-sheet-forming. *Journal of Manufacturing Science and Engineering*, 133(6), 061025.
- Razali, A., Qin, Y., Harrison C. and Brockett A., (2009). Investigation of feeding devices and development of design considerations for a new feeder for micro-sheet-forming, *Int. J. Nanomanufacturing*, Vol. 3, No. 1/2, 40-54.
- Razali, A., Qin, Y., Harrison, C., Zhou, J. and Brockett, A. (2009). Non-optimized performance of newly developed linear motor gripper feeder for micro-sheet-forming application, *International Conference on Manufacturing Research (ICMR 2009)*, 24-30.
- Rollot, Y. and Régnier, S. (2000) Micromanipulation par adhésion, *Nano et micro technologies*. 653-658.
- Rougeot, P., Regnier, S. and Chaillet, N. (2005) Forces analysis for micro-manipulation. *Computational Intelligence in Robotics and Automation, IEEE*. 105-110.
- Saotome, Y. and Okamoto, T. (2001) An in-situ incremental microforming system for three-dimensional shell structures of foil materials. *J. Mats. Proc. Tech.*, 113, 636-640.
- Schneider, R. and Groche, P. (2004) Method for the optimization of forming presses for the manufacturing of micro-parts. *CIRP Annals*. 53, 1, 281-284.
- Schuler, (1998), *Metal Forming Handbook*, Springer-Verlag Berlin Heidelberg New York
- Schwarz, B. J., and Richardson, M. H. (1999). Experimental modal analysis. *CSI Reliability week*, 35(1), 1-12.
- Shanahan, J. (2006) Trend in Micro Machining Technologies. (online). Retrieved from <https://www.makino.com/about/news/trends-in-micro-machining-technologies/315/>
- Sharma, P. C. (2007). *A Textbook of Production Technology: Manufacturing Processes*. S. Chand.

- Strano, M., Monno, M., and Rossi, A., (2013). Optimized design of press frames with respect to energy efficiency. *J. Clean. Prod.* 41, 140-149.
- Suda, M., Furata, K., Sakuhara, T. and Ataka, T. (2000), *The Microfactory System Using Electrochemical Machining*. Chiba, Japan.
- Tomas, J. (2007) Adhesion of ultrafine particles—A micromechanical approach. *Chemical Engineering Science*, 62, 1997-2010.
- Vollertsen, F., Hu, Z., Niehoff, H. S. and Theiler, C. (2004) State of the art in micro forming and investigations into micro deep drawing. *J. Mats. Proc. Tech.*, 70-79.
- Vollertsen, F., Niehoff, H. S. and Hu, Z. (2006) State of the art in micro forming. *International Journal of Machine Tools & Manufacture*, 46, 1172-1179.
- Wang, C., Guo, B., Shan, D., and Bai, X. (2015). Effects of interfacial contact states on tribological behaviour in micro-sheet forming. *International Journal of Mechanical Sciences*, 101, 81-88.
- Wood, L. (2005, March 29). Research and Markets: Move to Digital Shakes Up Telecommunications and Communications Markets. PR Newswire.
- Zhou, L., Li, J., Li, F., Meng, Q., Li, J., and Xu, X. (2016). Energy consumption model and energy efficiency of machine tools: a comprehensive literature review. *Journal of Cleaner Production*, 112, 3721-3734