INTEGRATION OF CHATTER AVOIDANCE AND MINIMUM QUANTITY LUBRICATION CONDITION IN MACHINING PROCESS

WAN MOHD AZLAN BIN WAN MOHD NOWALID

MASTER OF ENGINEERING

(MECHANICAL)

UNIVERSITI MALAYSIA PAHANG

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 (Mechanical).

____

(Supervisor's Signature)

Full Name : IR DR AHMAD RAZLAN YUSOFF

Position : ASSOCIATE PROFESSOR

Date :

STUDENT'S DECLARATION

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

____

(Student's Signature)

Full Name : WAN MOHD AZLAN IN WAN MOHD NOWALID

ID Number : MMM13004

Date :

INTEGRATION CHATTER AVOIDANCE AND MINIMUM QUANTITY LUBRICATION CONDITION IN MACHINING PROCESS

WAN MOHD AZLAN BIN WAN MOHD NOWALID

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical & Manufacturing Engineering

UNIVERSITI MALAYSIA PAHANG

JULY 2019

ACKNOWLEDGEMENTS

First of all, thanks to Allah the Almighty for giving me the strength to complete my project successfully. I would like to express my sincere gratitude to my supervisor Assoc. Prof Madya Ir Dr Ahmad Razlan Yusoff for his ideas, invaluable guidance, continuous encouragement and constant support in making this project possible. My deep thanks go to my dearest family, especially to my father Wan Mohd Nowalid Bin Wan Abdul Aziz and mother, Ramlah Binti Said, both of my wives who always support and pray for my success throughout this project. Their support provides me the spirit and strength that I require to endure throughout the period of my study. I would like to thank the lecturers and technicians at the Faculty of Manufacturing Engineering and other related faculties for their valuable comments and constructive criticisms. Finally, I would also like to thank my fellow colleagues for being there for me through thick and thin.

ABSTRAK

Proses pemesinan yang mempunyai kadar pengeluaran yang tinggi akan menyebabkan mata alat haus dan kerosakan bahan kerja serta dalam masa yang sama mengalami getaran yang wujud tersendiri. Kadar ricihan bahan yang tinggi ini dicapai pada kadar pemesinan berkelajuan tinggi serta melibatkan penggunaan bendalir pemotongan dengan kadar tinggi. Objektif utama projek ini adalah untuk mengimbangi antara pencegahan getaran untuk mendapatkan kualiti produk dan produktiviti yang tinggi, sementara pelinciran kuantiti minimum akan membawa kepada kos produktiviti yang rendah dan kesan yang paling minimum kepada alam sekitar. Untuk mencapai objektif ini, pekali daya perlu ditentukan dengan pemesinan dalam keadaan kering, penggunaan cecair dan pelinciran kuantiti minimum dengan kelajuan pemotongan yang berbeza. Getaran dalam proses pemotongan boleh ditentukan dengan menggunakan ramalan kestabilan pemesinan, terutama pada kesan lengkungan kestabilan. Untuk mengesahkan kestabilan pelbagai jenis pemotongan yang menggunakan cecair penyejuk secara eksperimen, kestabilan pemotongan dalam jarak kelajuan tertentu dan kedalaman pemotongan telah diperiksa. Akhir sekali, untuk menggunakan konsep gabungan tanpa getaran dan MQL, proses pemesinan digunakan untuk struktur berdinding nipis. Eksperimen ini direka untuk menilai prestasi kaedah yang digunakan pada pelbagai kelajuan spindle 1500, 3000, 4500, 6000 dan 7500 rev / min dan kadar suapan 0.025, 0.05, 0.075, 0.010 dan 0.125 mm / gigi. Hasilnya diukur dari segi nilai daya pemotongan pada kepingan kerja. Had kestabilan menggunakan cecair dan MQL dengan penetapan kelajuan dicipta dan terbukti dalam percubaan pemotongan getaran untuk mendapatkan keadaan pemotongan yang stabil dan tidak stabil pada parameter pemotongan tertentu. Akhirnya, struktur dinding nipis bentuk L, T dan poket yang menggabungkan pelinciran kuantiti minimum dan pencegahan getaran sendiri dalam lengkungan kestabilan digunakan untuk meningkatkan kedalaman pemotongan. Susulan dari objektif di atas, ia menunjukkan bahawa apabila pekali daya jejarian dikira menggunakan ketiga-tiga keadaan pelinciran yang berbeza telah menunjukkan nilai terendah dalam pelinciran kuantiti minimum diikuti oleh pemesinan tanpa pelincir dan pemesinan menggunakan pelincir penyejuk. Sebagai kesimpulan, nilai pekali daya pemotongan yang dikenal pasti berbeza bagi keadaan pemesinan yang berlainan walaupun pada daya pemesinan telah diukur dalam arah x dan y secara dinamik. Oleh itu, pencegahan getaran sendiri dengan menggunakan pelinciran kuantiti minimum dapat meningkatkan produktiviti dan kesan persekitaran dalam proses pemesinan produk berdinding nipis. Gabungan kestabilan pemotongan dan pelinciran kuantiti minimum boleh digunakan dan mencapai proses pembuatan mapan dengan produktiviti yang tinggi, kos pemesinan rendah dan produk ketepatan.

ABSTRACT

Machining processes with high productivity cause tool wear and materials defects even damage machine spindle and limited by self-excited vibration or chatter. Cutting operations represent the largest process of manufacturing activities in machining process. At the same time, it produces different cutting force value depends on method of cutting, geometry of the tools and speed variation. This high material removal rate can be also achieved at high speed conditions, however, it consumes very high cutting fluid utilization. The main objective of this project is to compensate between chatter avoidance as high quality of product and productivity, while minimal quantity lubrication (MQL) deals with low cost of productivity and environmental effect in machining processes. In order to achieve this objective, cutting force stiffness under dry, flood and minimal quantity lubrication with speed dependence is determined. This chatter vibration in cutting processes can suppress by using chatter stability prediction, particularly at lobbing effect where stable cutting locating at certain speed. To validate the chatter stability of various types cutting fluid conditions experimentally, stable or unstable (chatter) cutting within range of specific speed and depth of cut were checked. Finally, to apply the concept combine between the chatter avoidance and MQL, machining process was employed in machining process of thin walled structure. The experiments were designed to evaluate the performance of the method used at various spindle speed of 1500, 3000, 4500, 6000 and 7500 rev/min and feed rates of 0.025, 0.05, 0.075, 0.010 and 0.125 mm/tooth. Results showed that a slight different cutting coefficients that obtain from milling force from *x* and *y* direction using Dynamometer 9275b at different cutting speeds obtained from lubrication of dry, flood and MQL experiment compare with mechanics of cutting models. Finally, the thin wall structures shape applied the integration of MQL and chatter avoindance in stability lobe for increasing the machining depth of cut. In conclusion, with the changing lubrication conditions, the values of cutting force coefficients identified differ for different lubrication conditions despite on milling force measured by dynamometer in x and y direction. Therefore, the integration of chatter avoidance and minimal quantity lubrication can be applied and achieved the sustainable manufacturing process with high productivity, low machining cost and precision product.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

dF_t	Infinitesimal local cutting forces in the tangential direction
dF_r	Infinitesimal local cutting forces in the radial direction
dF_a	Infinitesimal local cutting forces in the axial direction
db	Infinitesimal chip width of the cutting edge segment
dl	Infinitesimal differential length of the cutting edge segment
K_{tc}	Cutting coefficients for shearing forces in tangential
K_{rc}	Cutting coefficients for shearing forces in radial
K_{ac}	Cutting coefficients for shearing forces in axial
K_{te}	Cutting coefficients for ploughing forces in tangential
K_{re}	Cutting coefficients for ploughing forces in radial
K_{ae}	Cutting coefficients for ploughing forces in axial
t_n	chip thickness
Ψ_c	axial angular position of cutting point on the cutter
V_c	cutting speed
f_t	feed per tooth
Θ	angular position of a cutting edge element
Z	axial coordinate

LIST OF ABBREVIATIONS

DOC	Deep Of Cut
AA	Aluminium Alloy
DOE	Design Of Experiment
FR	Feed Rate
MQL	Minimum Quantity Lubrication
SS	Spindle Speed
HSM	High Speed Machining
Fe	Ferrous
Mn	Manganese
Al	Aluminium
ZOD	Zeroth Order Approximation
SLD	Stability Lobe Diagram
DDE	Delay Differential Equation
ZOD	Zeroth Order Approximation
SD	Semi-discretization
MDOF	Multi Degree of Freedom
TFEA	Time Finite Element Analysis
HP	Horse Power
RPM	Revolution per minute

REFERENCES

Abolhasani, A., Zarei-Hanzaki, A., Abedi, H. R., & Rokni, M. R. (2012). The room temperature mechanical properties of hot rolled 7075 aluminum alloy. Materials and Design, 34, 631–636.

Adetoro, O. B., & Wen, P. H. (2010). Prediction of mechanistic cutting force coefficients using ALE formulation. International Journal of Advanced Manufacturing Technology, 46(1–4), 79–90.

Afazov, S. M., Zdebski, D., Ratchev, S. M., Segal, J., & Liu, S. (2013). Effects of micro-milling conditions on the cutting forces and process stability. Journal of Materials Processing Technology, 213(5), 671–684.

Ahmadi, K., & Ismail, F. (2012). Modeling chatter in peripheral milling using the Semi Discretization Method. CIRP Journal of Manufacturing Science and Technology, 5(2), 77–86.

Alauddin, M., Mazid, M. A., El Baradi, M. A., & Hashmi, M. S. J. (1998). Cutting forces in the end milling of Inconel 718. Journal of Materials Processing Technology, 77, 153–159.

Altintas, Y. (1999). Electro-mechanical design engineering: a formal education program\nin mechatronics. 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (Cat. No.99TH8399).

Altintas, Y. (2001). Analytical Prediction of Three Dimensional Chatter Stability in Milling. JSME International Journal Series C.

Altintas, Y. (2011). Research on metal cutting, machine tool vibrations and control. Seimitsu Kogaku Kaishi/Journal of the Japan Society for Precision Engineering.

Altintaş, Y., & Budak, E. (1995). Analytical Prediction of Stability Lobes in Milling. CIRP Annals - Manufacturing Technology, 44(1), 357–362.

Altintas, Y., Eynian, M., & Onozuka, H. (2008). Identification of dynamic cutting force coefficients and chatter stability with process damping. CIRP Annals - Manufacturing Technology, 57(1), 371–374.

Altintaş, Y., & Lee, P. (1996). A General Mechanics and Dynamics Model for Helical End Mills. CIRP Annals - Manufacturing Technology, 45(1), 59–64.

Armarego, E. J. A., & Deshpande, N. P. (1991). Computerized End-Milling Force Predictions with Cutting Models Allowing for Eccentricity and Cutter Deflections. CIRP Annals - Manufacturing Technology, 40(1), 25–29.

Aronson, J. (1994). A pragmatic view of thematic analysis. The Qualitative Report, 2(1), 3.

Azeem, A., Feng, H. Y., & Wang, L. (2004). Simplified and efficient calibration of a mechanistic cutting force model for ball-end milling. International Journal of Machine Tools and Manufacture, 44(2–3), 291–298.

Branham, D. C. (2004). Oil mist lubrication. Fuels and Lubes International.

Campa, F. J., Lopez de Lacalle, L. N., & Celaya, a. (2011). Chatter avoidance in the milling of thin floors with bull-nose end mills: Model and stability diagrams. International Journal of Machine Tools and Manufacture, 51(1), 43–53.

Campatelli, G., & Scippa, A. (2012). Prediction of milling cutting force coefficients for Aluminum 6082-, 1, 563–568.

Cao, H., Li, B., & He, Z. (2012). Chatter stability of milling with speed-varying dynamics of spindles. International Journal of Machine Tools and Manufacture, 52(1), 50–58.

Chen, W. (2000). Cutting forces and surface finish when machining medium hardness steel using CBN tools. International Journal of Machine Tools and Manufacture, 40, 455–466.

Chetan, Ghosh, S., & Venkateswara Rao, P. (2015). Application of sustainable techniques in metal cutting for enhanced machinability: A review. Journal of Cleaner Production.

Childs, T. (2000). Metal Machining Theory and Applications. Materials Technology, 416.

Cornwell, P., Doebling, S. W., & Farrar, C. R. (1999). Application of the strain energy damage detection method to plate-like structures. Journal of Sound and Vibration, 224(2), 359–374.

De Chiffre, L. (1977). Mechanics of metal cutting and cutting fluid action. International Journal of Machine Tool Design and Research, 17, 225–234.

Devillez, A., Le Coz, G., Dominiak, S., & Dudzinski, D. (2011). Dry machining of Inconel 718, workpiece surface integrity. Journal of Materials Processing Technology, 211(10), 1590–1598.

Devillez, A., Schneider, F., Dominiak, S., Dudzinski, D., & Larrouquere, D. (2007). Cutting forces and wear in dry machining of Inconel 718 with coated carbide tools. Wear, 262, 931–942.

Dhar, N. R., Ahmed, M. T., & Islam, S. (2007). An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel. International Journal of Machine Tools and Manufacture, 47(5 SPEC. ISS.), 748–753.

Dhar, N. R., Islam, M. W., Islam, S., & Mithu, M. A. H. (2006). The influence of minimum quantity of lubrication (MQL) on cutting temperature, chip and dimensional accuracy in turning AISI-1040 steel. Journal of Materials Processing Technology, 171(1), 93–99.

Engin, S., & Altintas, Y. (2001). Mechanics and dynamics of general milling cutters. International Journal of Machine Tools and Manufacture, 41(15), 2195–2212.

Ewins, D. J. (2000). Modal Testing: Theory, Practice and Application. book.

Fontaine, M., Devillez, A., Moufki, A., & Dudzinski, D. (2006). Predictive force model for ball-end milling and experimental validation with a wavelike form machining test. International Journal of Machine Tools and Manufacture, 46(3–4), 367–380.

Fox-Rabinovich, G., Dasch, J. M., Wagg, T., Yamamoto, K., Veldhuis, S., Dosbaeva, G. K., & Tauhiduzzaman, M. (2011). Cutting performance of different coatings during minimum quantity lubrication drilling of aluminum silicon B319 cast alloy. Surface and Coatings Technology, 205(16), 4107–4116.

Fratila, D. (2010). Macro-level environmental comparison of near-dry machining and flood machining. Journal of Cleaner Production, 18(10–11), 1031–1039.

Fratila, D., & Caizar, C. (2011). Application of Taguchi method to selection of optimal lubrication and cutting conditions in face milling of AlMg3. Journal of Cleaner Production, 19(6–7), 640–645.

Gao, G., Wu, B., Zhang, D., & Luo, M. (2013). Mechanistic identification of cutting force coefficients in bull-nose milling process. Chinese Journal of Aeronautics, 26(3), 823–830.

Gonzalo, O., Beristain, J., Jauregi, H., & Sanz, C. (2010a). A method for the identification of the specific force coefficients for mechanistic milling simulation. International Journal of Machine Tools and Manufacture, 50(9), 765–774.

Gonzalo, O., Beristain, J., Jauregi, H., & Sanz, C. (2010b). International Journal of Machine Tools & Manufacture A method for the identification of the specific force coefficients for mechanistic milling simulation. International Journal of Machine Tools and Manufacture, 50(9), 765–774.

Grossi, N., Sallese, L., Scippa, A., & Campatelli, G. (2014). Chatter stability prediction in milling using speed-varying cutting force coefficients. In Procedia CIRP (Vol. 14, pp. 170–175).

Hayasaka, T., Ito, A., & Shamoto, E. (2017). Generalized design method of highly-varied-helix end mills for suppression of regenerative chatter in peripheral milling. Precision Engineering, 48, 45–59.

He, J., & Fu, Z.-F. (2001). Modal Analysis. Modal Analysis, 117(10), 291.

Insperger, T., Mann, B. P., Surmann, T., & Stépán, G. (2008). On the chatter frequencies of milling processes with runout. International Journal of Machine Tools and Manufacture, 48(10), 1081–1089.

Insperger, T., & Stépán, G. (2002). Semi-discretization method for delayed systems. International Journal for Numerical Methods in Engineering, 55(5), 503–518.

Insperger, T., Stépán, G., & Turi, J. (2008). On the higher-order semi-discretizations for periodic delayed systems. Journal of Sound and Vibration, 313(1–2), 334–341.

Insperger, T., & Stépán, G. (2002). Semi-discretization method for delayed systems. International Journal for Numerical Methods in Engineering, 55(5), 503–518.

Itoigawa, F., Childs, T. H. C., Nakamura, T., & Belluco, W. (2006). Effects and mechanisms in minimal quantity lubrication machining of an aluminum alloy. Wear, 260(3), 339–344.

Kaufman, J. G. (2000). Introduction to Aluminum Alloys and Tempers. USA: ASM International.

Koenigsberger, F., & Sabberwal, A. J. P. (1961). An investigation into the cutting force pulsations during milling operations. International Journal of Machine Tool Design and Research, 1, 15.

Korkut, I., & Donertas, M. A. (2007). The influence of feed rate and cutting speed on the cutting forces, surface roughness and tool-chip contact length during face milling. Materials and Design, 28(1), 308–312.

Lacerda, H. B., & Lima, V. T. (2004). Evaluation of cutting forces and prediction of chatter vibrations in milling. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26(1).

Lamikiz, A., De Lacalle, L. N. L., Sánchez, J. A., & Salgado, M. A. (2004). Cutting force estimation in sculptured surface milling. International Journal of Machine Tools and Manufacture, 44(14), 1511–1526.

Lee, P., & Altintaş, Y. (1996). Prediction of ball-end milling forces from orthogonal cutting data. International Journal of Machine Tools and Manufacture, 36(9), 1059–1072.

Liao, Y. S., & Lin, H. M. (2007). Mechanism of minimum quantity lubrication in high-speed milling of hardened steel. International Journal of Machine Tools and Manufacture, 47(11), 1660–1666.

Liu, X., & Cheng, K. (2005). Modelling the machining dynamics of peripheral milling. International Journal of Machine Tools and Manufacture, 45(11), 1301–1320.

Marksberry, P. W., & Jawahir, I. S. (2008). A comprehensive tool-wear/tool-life performance model in the evaluation of NDM (near dry machining) for sustainable manufacturing. International Journal of Machine Tools and Manufacture, 48(7–8), 878–886.

Mehta, A., Hemakumar, S., Patil, A., Khandke, S. P., Kuppan, P., Oyyaravelu, R., & Balan, A. S. S. (2018). Influence of sustainable cutting environments on cutting forces, surface roughness and tool wear in turning of Inconel 718. In Materials Today: Proceedings (Vol. 5, pp. 6746–6754).

Merritt, H. (1965). Theory of Self-Excited Machine-Tool Clatter. Transactions of ASME Journal of Engineering for Industry, 87, 447–454. http://doi.org/10.1115/1.3670861

Methods, F. E., Methods, F. E., Problems, F., & Problems, F. (2003). Finite Element Methods for Flow Problems. Library.

Minis, I., Yanushevsky, R., Tembo, A., & Hocken, R. (1990). Analysis of Linear and Nonlinear Chatter in Milling. CIRP Annals - Manufacturing Technology, 39(1), 459–462.

Nakano, Y., Takahara, H., & Kondo, E. (2013). Countermeasure against chatter in end milling operations using multiple dynamic absorbers. Journal of Sound and Vibration, 332(6), 1626–1638.

Palpandian, P., Raja, P., & Babu, S. (2013). Stability Lobe Diagram for High Speed Machining Processes:Comparison of Experimental and Analytical Methods – A Review. International Journal of Innovative Research in Science, Engineering and Technology, 2(3).

Patel, B. R., Mann, B. P., & Young, K. A. (2008). Uncharted islands of chatter instability in milling. International Journal of Machine Tools and Manufacture, 48(1), 124–134.

Pleta, A., Niaki, F. A., & Mears, L. (2018). A comparative study on the cutting force coefficient identification between trochoidal and slot milling. In Procedia Manufacturing (Vol. 26, pp. 570–579).

Pusavec, F., Hamdi, H., Kopac, J., & Jawahir, I. S. (2011). Surface integrity in cryogenic machining of nickel based alloy—Inconel 718. Journal of Materials Processing Technology, 211(4), 773–783.

Pusavec, F., Krajnik, P., & Kopac, J. (2010). Transitioning to sustainable production – Part I: application on machining technologies. Journal of Cleaner Production, 18(2), 174–184.

Quintana, G., & Ciurana, J. (2011). Chatter in machining processes: A review. International Journal of Machine Tools and Manufacture, 51(5), 363–376.

Ragheb, M. (2013). Vertical axis wind turbines. Wind Turbine Technology, 40.

Salguero, J., Batista, M., Calamaz, M., Girot, F., & Marcos, M. (2013). Cutting forces parametric model for the dry high speed contour milling of aerospace aluminium alloys. In Procedia Engineering (Vol. 63, pp. 735–742).

Shin, Y. C., & Waters, A. J. (1997). A new procedure to determine instantaneous cutting force coefficients for machining force prediction. International Journal of Machine Tools and Manufacture.

Sim, C., & Yang, M. (1993). The prediction of the cutting force in ball-end milling with a flexible cutter. International Journal of Machine Tools and Manufacture, 33(2), 267–284.

Sims, N. D., Mann, B., & Huyanan, S. (2008). Analytical prediction of chatter stability for variable pitch and variable helix milling tools. Journal of Sound and Vibration, 317(3–5), 664–686.

Smith, S., & Tlusty, J. (1990). Update on High-Speed Milling Dynamics. Journal of Engineering for Industry, 112(May 1990), 142. http://doi.org/10.1115/1.2899557

Sreejith, P. ., & Ngoi, B. K. . (2000a). Dry machining: Machining of the future. Journal of Materials Processing Technology, 101(1–3), 287–291.

Sreejith, P. S. (2008). Machining of 6061 aluminium alloy with MQL , dry and flooded lubricant conditions, 62, 276–278.

Sreejith, P. S., & Ngoi, B. K. A. (2000b). Dry machining: Machining of the future. Journal of Materials Processing Technology, 101, 287–291.

Suzuki, N., Nishimura, K., Watanabe, R., Kato, T., & Shamoto, E. (2012). Development of Novel Anisotropic Boring Tool for Chatter Suppression. Procedia CIRP, 1, 56–59.

Tang, W. X., Song, Q. H., Yu, S. Q., Sun, S. S., Li, B. B., Du, B., & Ai, X. (2009). Prediction of chatter stability in high-speed finishing end milling considering multi-mode dynamics. Journal of Materials Processing Technology, 209(5), 2585–2591.

Tlusty, J. (2000). Manufacturing Process and equipment. Prentice-Hall International Editions.

Tlusty, J., & Ismail, F. (1983). Special Aspects of Chatter in Milling. Journal of Vibration and Acoustics, 105(81), 24–32.

Totis, G. (2009). RCPM—A new method for robust chatter prediction in milling. International Journal of Machine Tools and Manufacture, 49(3–4), 273–284.

Trent, E. M., & Wright, P. K. (2000). Metal Cutting. Metal Cutting.

Wang, G., Peng, D., Qin, X., & Cui, Y. (2012). An improved dynamic milling force coefficients identification method considering edge force. Journal of Mechanical Science and Technology, 26(5), 1585–1590.

Wang, J. J., & Zheng, C. M. (2002). Identification of shearing and ploughing cutting constants from average forces in ball-end milling. *International Journal of Machine Tools and Manufacture*, *42*(6), 695–705.

Wang, M., Gao, L., & Zheng, Y. (2014). An examination of the fundamental mechanics of cutting force coefficients. *International Journal of Machine Tools and Manufacture*, *78*, 1–7.

Wang, Z. G., Rahman, M., Wong, Y. S., Neo, K. S., Sun, J., Tan, C. H., & Onozuka, H. (2009). Study on orthogonal turning of titanium alloys with different coolant supply strategies. *International Journal of Advanced Manufacturing Technology*, *42*, 621–632.

Yang, M., & Park, H. (1991). The prediction of cutting force in ball-end milling. *International Journal of Machine Tools and Manufacture*, *31*(1), 45–54.

Yang, Y., Li, X., Gao, L., & Shao, X. (2013). A new approach for predicting and collaborative evaluating the cutting force in face milling based on gene expression programming. *Journal of Network and Computer Applications*, 1–11.

Yusoff, A. R., & Sims, N. D. (2011). Optimisation of variable helix tool geometry for regenerative chatter mitigation. *International Journal of Machine Tools and Manufacture*, *51*(2), 133–141.

Zuki, N. M. N. M., Rahman, M. M., Noor, M. M., & Hafizuddin, M. (2008). Regenerative Chatter in End Milling on Mould Aluminum Alloys. In *7th UMT International Symposium on Sustainability Science and Management (UMTAS)* (pp. 1–9).