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WELCOME FROM THE RECTOR OF UNIVERSITAS INDONESIA

I am honoured to have the opportunity to officially welcome you to the 12th International Conference on QiR (Quality in Research) 2011. As we are all aware that the impact of globalization has resulted in a very competitive business environment; a condition that makes the fulfillment of the needs of customer/clients' ever–sophisticated project, product, or service most challenging. Without any doubt, a sustainable design and technology is the key factors in assisting our industries to enhance their contributions to the future development of humanity. Therefore, it is our hope that this conference will be able to provide an international forum for exchanging knowledge and research expertise as well as creating a prospective collaboration and networking on various fields of sustainable engineering and architecture.

In order to achieve business objectives and benefits, engineering products or projects require various resources, skills, and technology. Accordingly, we need an application of knowledge, tools, and techniques necessary to develop sustainable products or projects, which are environmentally friendly, produced through efficient processes, and adapted to local conditions. And this may be achieved by eco-technology. Eco-technology is a technology that will give consumers what they want; lower cost, convenience, save money and deliver what people everywhere needs: less waste, less pollution, and green environment. Eco-technology practices can facilitate to conserve and restore the environment through the integration of engineering and ecological principles. However, eco-technology requires multidisciplinary synthesis of knowledge and skills; and the development and application of this technology in the sector of industry and services is therefore a crucial requirement for sustainable development process. For this reason, we urgently need new technologies and practical applications to be further developed based on the current knowledge.

Accordingly, I hope this conference can be a kick-off for the strengthened action and partnerships on creating a platform for us; national and international thinkers, academics, government officials, business executives and practitioners, to present and discuss the pivotal role of engineers in creating sustainable development.

I would like to thank the Faculty of Engineering of Universitas Indonesia for organizing this meaningful and timely event, and supporting organizations for their participation and contributions. I am sure that you will all find this conference stimulating and rewarding and with this, I wish you all a fruitful conference.

Prof. Dr. der. Soz. Gumilar Rusliwa Somantri
Rector
Universitas Indonesia

WELCOME FROM THE DEAN OF FACULTY OF ENGINEERING UNIVERSITAS INDONESIA

On behalf of the Faculty of Engineering, University of Indonesia, it is my greatest pleasure to extend our warmest welcome to all of you to the 12th International Conference on QiR (Quality in Research) 2011. As we know that this conference is conducted to cover a wide range of sustainable design and technology issues, I hope this two days-conference will be spent in interesting discussions and exchange of ideas. I also hope that this conference will be able to provide a state-of-the-art information and knowledge in this challenging world of sustainable design and technology. The growing success of our institutions and expertise should urge us to develop our competitive capabilities, especially when we face certain challenges which should be overcome with hard work, cooperation, and working together hand in hand. We will work together to develop a common path and develop collaboration opportunities for future action and research on multi-disciplinary engineering areas for quality of life and humanity.

I am delighted that you have accepted our invitation to this conference in such a large numbers as indicated and that we will have many international speakers and papers from various countries to be presented and discussed in these two days. We will explore various issues on sustainable development and we must widen the scope of sustainability from a product-, system-, or an individual building-scale to the whole community-scale. At the same time, we have to widen the focus from ecological aspects to social and economic aspects. This means that environmental solutions should always be considered from the aspects of human health and well-being, safety, and economic point of view. This conference provides an excellent forum for engineering professionals, business executives, industry practitioners, and academicians to exchange ideas and to share their experience, knowledge and expertise to each other.

I would like to thank our sponsors, supported bodies, and various contributors for their generous support of this conference. I would also like to thank our distinguished speakers for agreeing to share their insights with us. To our friends from overseas and other provinces of Indonesia, I would also like to extend a warm welcome to you and wish you an enjoyable stay in Bali. Last but not least, I would invite you to join me in thanking the committed staff that made this conference happen and to make it success.

I wish us much success in the deliberations, discussions, and exchange of ideas which we will have within this conference and I wish you a very pleasant and enjoyable stay here in Bali.

Prof. Dr. Ir. Bambang Sugiarto, M.Eng
Dean Faculty of Engineering
Universitas Indonesia

WELCOME FROM THE QiR 2011 ORGANIZING COMMITTEE

On behalf of the Organizing Committee, it is my greatest pleasure to extend our warmest welcome to all of you to the 12th International Conference on QiR (Quality in Research) 2011. The selected theme for this year's conference is "Integrated Design in Urban Eco-Technology for Quality of Life and Humanity". With this theme, the conference focuses on the scientific analysis and design of the key factors explaining the success applications of integrated design in urban eco-technology, their market perspectives, and their contributions to the existing and future development of humanity. In line with this theme, it is our utmost pleasure to hold the QiR 2011 in conjunction with the 2nd International Conference on Saving Energy in Refrigeration and Air Conditioning (ICSERA 2011).

With its continuous presence for 12 years, QiR has become an icon for Faculty of Engineering Universitas Indonesia in serving the objectives to provide engineering excellence for both national and international in all aspects of engineering, design, and architecture. For the first time, the QiR 2011 is held in a famous beautiful island of Indonesi - Bali. The QiR 2011 is supported by Universitas Udayana, in the spirit of strengthening of cooperation and mutual growth to be world class institution. I am delighted to inform you that we have such a large number of participants today, as indicated, that we will have 21 invited speaker presentation and more than 520 papers from more than 20 countries to be presented and discussed during these two days-conference. We are fortunate to have a lot of good quality papers belong to:
32 papers on ICSERA
39 papers on Chemical Engineering
115 papers on Electrical Engineering
37 papers on Mechanical and Naval Architecture Engineering
101 papers on Materials Engineering
54 papers on Architecture & Planning
75 papers on Industrial Engineering
72 papers on Civil Engineering

I would like to thank all contributors, speakers and participants for your generous support to this conference. It is my pleasant duty to thank all the members of Organizing Committee and the International Board of Reviewers for their advices and help. We are grateful to all Sponsors, Supporters, Exhibitors, Partner Universities and Professional Associations, for their spontaneous response and encouragement through committing funds and extending help in kind. I would like to sincerely thank the Rector of Universitas Indonesia and the Dean of Faculty of Engineering, for fully supporting the Committee and providing all supports to make this conference happen and to make it a success.

I wish you a very pleasant stay here in Bali; and finally, let me wish all of you a meaningful and fruitful conference. Thank you and we hope to see you again at the QiR 2013.

Prof. Dr. Ir. Bondan T. Sofyan, M.Si.
Chairman of QiR 2011 Organizing Committee

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Preliminary Kinematics Design of 5-axis Micromilling Machine

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ABSTRACT

5-axis micromilling technology is increasing since 1990's to produce 3D product in micro even nano dimension, which use in most of automotive industry, house appliance, airplane components, micro medical equipment, electronic industry, etc. Highest accuracy is the main goal of every 5-axis micromilling.
To design a 5-axis micromilling machine, the first thing to do is to determine the machine construction based on the machine requirement. Most of 5-axis machine widely used has three translation axis XYZ and two rotational axis of ABC. This paper present a conceptual mechanical design evaluation for three type of 5-axis micromiling construct with avaliable components.
Machining accuracy is depending on some factor, one of the factors is the machine geometry that related to rigidity and construction strength. So, the strength analysis of 5-axis micromilling design for the construction must be done with 5.5 N cutting force. The simulation and analysis is perform using CAE software.
To translate the command from CAM system (CL data) into machine movement is done by transforming the machine kinematic into matrices space using the kinematic engine. The kinematic engine for 5-axis micromilling is successly develop and ready to implemented in a postprocessor.

Keywords

5-axis micromilling, design evaluation, kinematic design

1. INTRODUCTION

Nowadays, the products are becoming more varies, aesthetic and futuristic. Products with complex shape and sometimes in a micro even nano dimension are found in most of automotive industries, house appliances, airplane components, micro medical equipments, electronic industry and etc. In this term, 5-axis micromilling is becoming attractive solution to achieve such product. The technology of 5-axis micromilling is increasing since 1990's and even growing in the past few years. The trend of every machining technology is to increase the accuracy of the product.

Generally, there are several types of 5-axis micromilling machine that is classified according to the number of translation and rotational axis. However the most commonly used is the three translation axes XYZ with two rotary axes of AB, AC, or BC axis. The combination of those axis resulting several types of 5-axis milling machine known as table-tilting type, spindle-tilting type and table/spindle-tilting type [1,2,3,4]. Young-bong Bang, Kyung-min Lee and Seungryul Oh [5] shows that a 5-axis micromilling can be constructed at a low cost with commercially available parts and the constructed micromilling machine is capable of producing practical micro parts.

To build a 5-axis micromilling machine, the main system components which are kinematics and construction, and the control system have to be designed with respect to the specified working conditions. Dehong Huo, Kai Cheng and Frank Wardle [6, 7] explained that there are three major issues to design a 5-axis micromilling: motion accuracy, dynamic stiffness and thermal stability. So, it is important to analyze and simulate the machine construction strength which can be done using Computer Aided Engineering (CAE) software. The machine dynamic performance depending not only on the mechanical structure and components but also the control system and electronic drives.

The next step is to formulate detail of kinematics model of the machine, that translate the command from a CAM system in a form of CL (cutter location)-file, to become NC command for the movement of each axis. Bohez [1] classify the 5-axis milling according to combination of linear and rotary axes and he shows the kinematic chain of all groups that he has classified. R-S Lee and C-H She [2] proposed kinematics model of machine postprocessing for three type 5-axis machine tools using homogeneous coordinate transformation matrix. Chen-Hua She and Zaho-Tang Huang [3] also proposed proposed kinematics

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model of machine postprocessing for three type 5-axis machine tools with nutating head and table configuration. Sylvain Lavernhe et.al [8] presents a predictive model of the kinematical behavior during 5-axis machining; the model is use the inverse-time method to coordinate machine-tool axes. He also proposed a predictive model kinematical performance in 5-axis milling within the context of high-speed machining [9]; the proposed model relies on each axis displacement in the joint space of the machine tool and predicts the most limiting axis for each trajectory segment. Lamikiz et.al [10] proposed a methodology for the estimation of the geometrical accuracy using the Denavit and Hartenberg (D-H) formulation. M. Sharif Uddin et.al [11] proposed a simulator and compensation of machining errors in five-axis machining by considering the effect of kinematic errors on the three-dimensional interference of the tool and the workpiece. He found that there are three kinematic error associated with linear axes and eight kinematic errors associated with rotary axes of the machining center, are considered and identified practically by a DBB method. M.Munlin et.al [12] proposed a new algorithm designed for five-axis milling to minimize the kinematics error near the stationary points of the machined surface.

The objectives of this work are to design the mechanical geometry and construction and the kinematics of 5-axis micromilling machine. Three types of commonly used 5-axis micromilling cofiguration are evaluated.

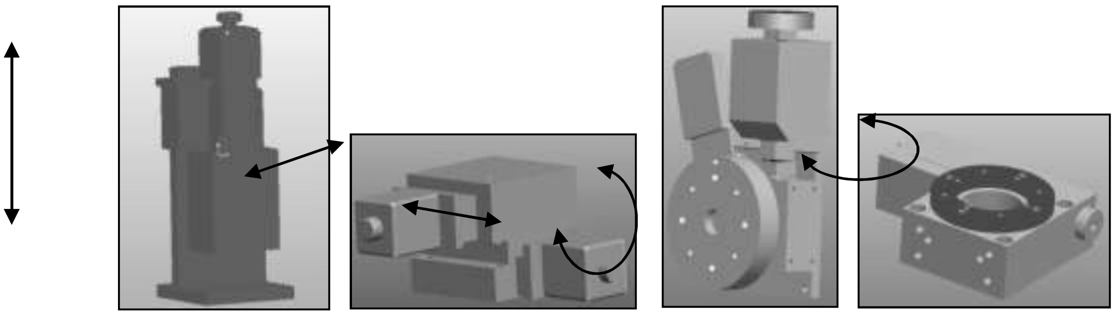
2. DESIGN OF 5-AXIS MICROMILLING

2.1 Types of 5-axis micromilling

Theoritically, there are numerous combination to yield the five-axis machine tools configuration. However as explained above, in practice, the configuration can be classified into three basic types according to the distribution of the two rotational movement units :

1. Table-tilting with two rotation on the table.
2. Spindle-tilting with two rotation on the spindle.
3. Table/spindle tilting with one rotation each on the table and spindle.

In order to build and evaluate the above designs, the following components, which are available in the market, are selected :



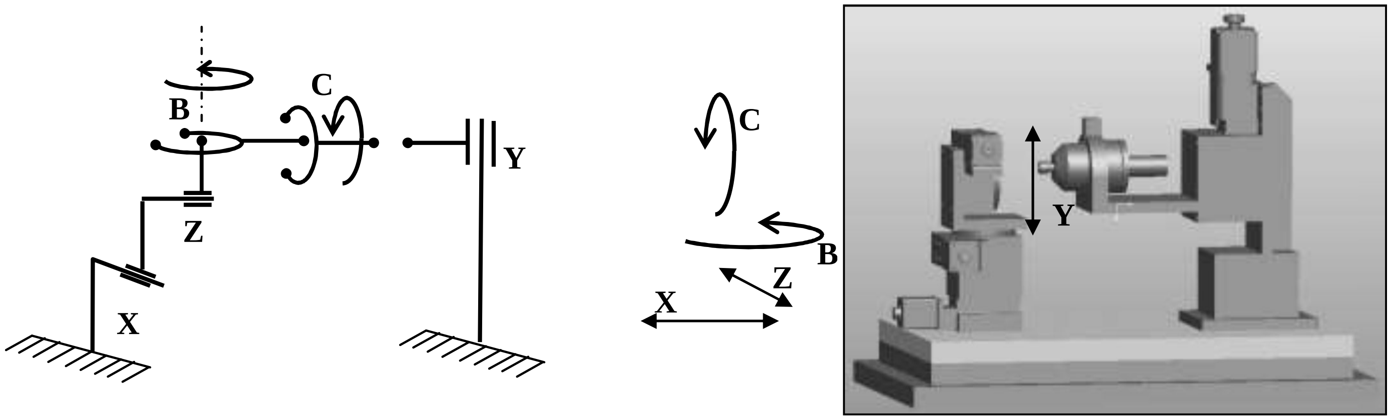
(a) (b) (c) (d)

Fig.1 (a) Single Linear Stage, (b) Two Linear Stages which are attached to each other, (c) and (d) Rotary Stage

The specification of the selected components has been verified against the predefiened accuracy (1 μm) and possible maximum load (< = 3 kgf).

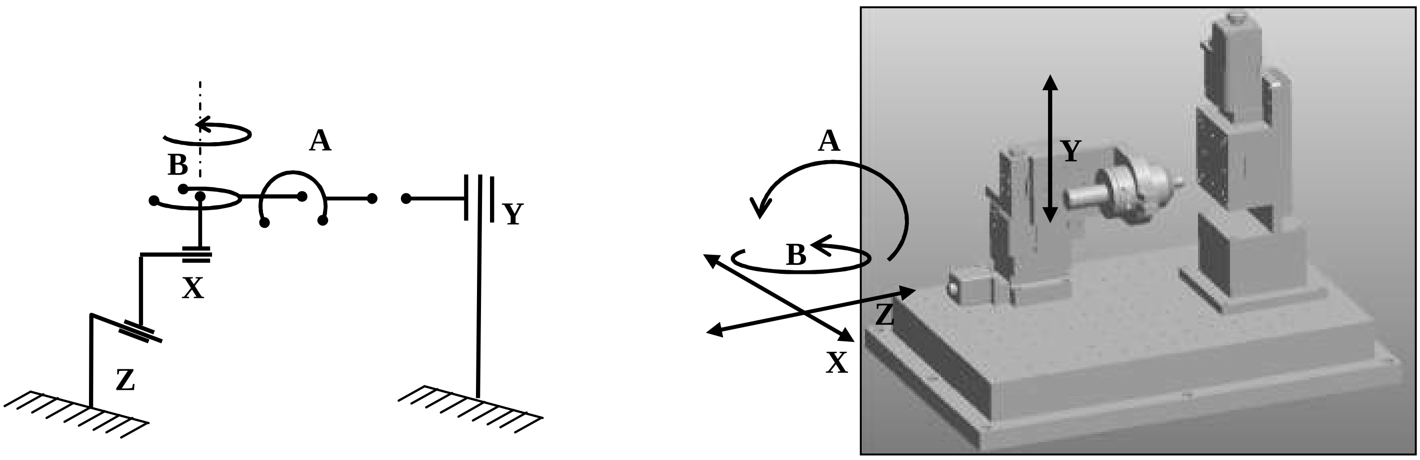
2.2 Possible Kinematics and Construction Design of 5-axis micromilling

The designs of three types of machine mentioned above, using avaliable components is shown in the Fig.2, Fig 3 and Fig.4 .



(a) (b)

Fig.2: a) Schematic of Kinematics model and b) possible Table-tilting design/construction with XYZ and BC axis movement as 1st Alternative.



(a) (b)

Fig.3: a) Schematic of Kinematics model and b) possible Spindle-tilting design with XYZ and AB axis movement as 2nd Alternative.

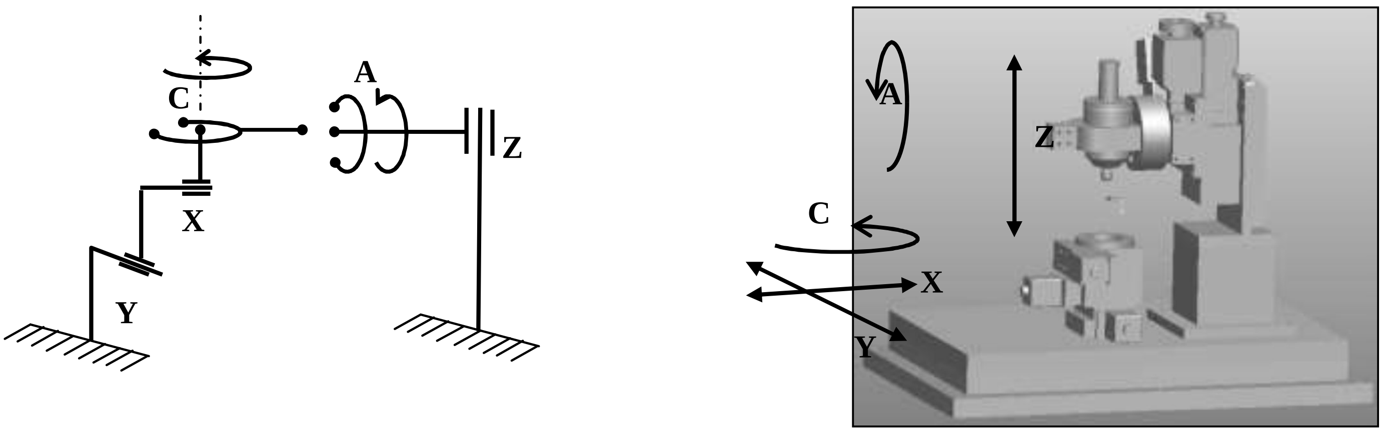


Fig. 4: a) Schematic of Kinematics model and b) possible Table/spindle-tilting with XYZ and AC movement as 3th Alternative.

2.3 Design Evaluation

To evaluate the design alternative, this paper use an Advanced Decision Matrix based on the Robust Decision Making, explained by Ulman [13]. By using this method,it able to compare all the alternative and decide the most satisfaction alternative.

The weightings or scoring to evaluate the design by using the word equation as follow :

Satisfaction = belief that an alternative meets the criteria

Belief = knowledge + confidence.

This virtual sum of knowledge and confidence can be expressed on a Belief Map as a tool to picture and undertand evaluation, see Fig.5. To qualitatively measuring knowledge and confidence is using the scale as shown in Fig.6. The advance

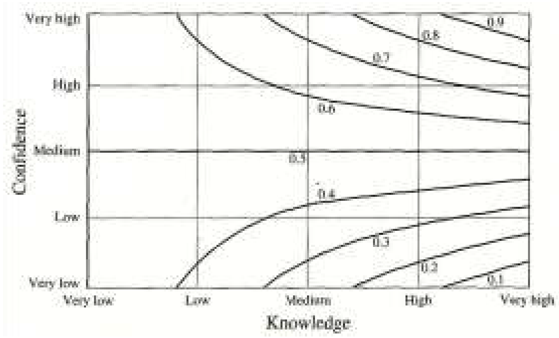


Fig 5: Belief map to weight the design alternative [13]

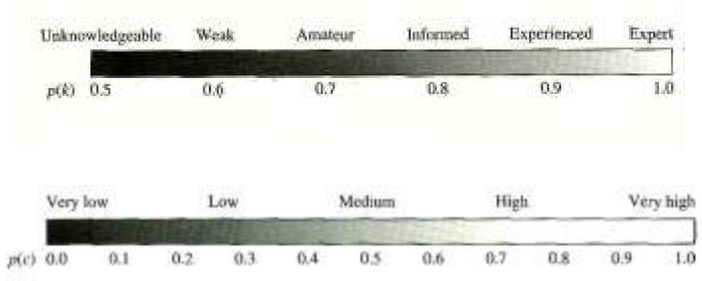


Fig. 6: Scale for qualitatively measuring (a) Knowledge and (b) Confidence [13]

Table 1.Advance decision matrix for 5-axis micromilling design.

Criteria		Importance	Alternatives		
			1st	2nd	3th
1	Position Accuracy within 0,5 nm	15	0,6	0,5	0,6
2	Good construction rigidity	15	0,5	0,3	0,6
3	Low vibration	12	0,4	0,3	0,4
4	Less critical parameter	12	0,3	0,3	0,5
5	Flexibility in movement	12	0,5	0,5	0,5
6	Wide range of working envelop	12	0,3	0,4	0,5
7	Less component	8	0,2	0,2	0,4
8	Easy to assembly	6	0,2	0,3	0,4
9	Easy to maintain	8	0,2	0,3	0,4
		Satisfaction	38,9 %	35,8 %	49,6 %

According to the highest score of satisfaction, the 3th alternative will be the appropriate design for 5-axis micromilling machine. To have a better analysis, the strength of the design construction is simulated using a CAE software, as shown in Fig. 7. The critical point of the whole machine tool is on the component Z axis, about 6.26 x 10^{-2} N/mm^2, the magnitude is still in safe for the operation with 5,5 N of cutting force [14].

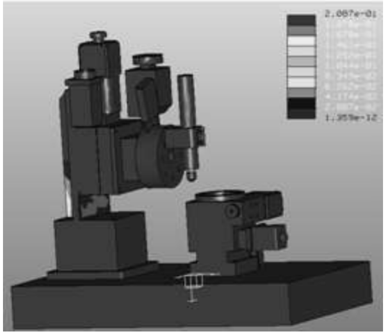


Fig.7: Strength analysis of the 3th alternative design

3. DETAIL KINEMATICS FOR POSTPROCESSING

The kinematic of a machine is a transformation from a point in machine coordinate system (MCS) into the tool coordinate system (TCS) and the workpiece coordinate system (WCS), where the point is move along the coordinate system as an axis vector. The intersection betwen TCS and WCS will caused the machining process, this called Cutter Contact (CC) point. To control the movement of the tool, a set of CC point will computed as a set of Cutter Location (CL) point. Nowdays, the CAM system able to generate the CL file and simulating the cutting process.

But to transform and calculate the CL point to become the axis movement of the machine tools XYZ axis and AC axis, the kinematic engine for each machine tool must be designed. The CL data consist of the position and orientation of the cutter with respect to the workpiece coordinate system as shown in Fig. 8. The point vector is written as $[Q_x\ Q_y\ Q_z\ 1]^T$ as the cutter tip center and vector of form $[K_x\ K_y\ K_z\ 0]^T$ are used to represent direction for homogeneous coordinate notation. The supercript "T" denotes the transposed matrix. The four fundamental transformation matrice used in this paper are as follows :

$$Trans\ a,b,c = \begin{matrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{matrix} \quad (1) \qquad Rot(X,\varphi) = \begin{matrix} 1 & 0 & 0 & 0 \\ 0 & C\varphi & -S\varphi & 0 \\ 0 & S\varphi & C\varphi & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \quad (2)$$

$$Rot(Y,\varphi) = \begin{matrix} C\varphi & 0 & S\varphi & 0 \\ 0 & 1 & 0 & 0 \\ -S\varphi & 0 & C\varphi & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \quad (3) \qquad Rot(Y,\varphi) = \begin{matrix} C\varphi & S\varphi & 0 & 0 \\ S\varphi & C\varphi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \quad (4)$$

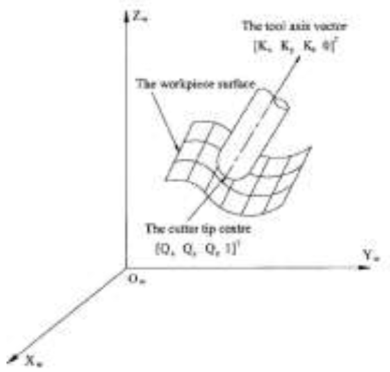


Fig. 8 : Geometric definition of CL data [2]

In this paper, the kinematics engine will design based on a method proposed by R-S Lee and C-H She [2]. The method is using inverse kinematic to establish a mathematical description. They shows three types of 5-axis machine tool of table tilting XYAC-Z, spindle tilting XY-ABZ and table/spindle-tilting XYA-BZ. Since, the 5-axis micromilling design axis is XYC-AZ, then calculating the kinematic equation for NC data is very neccecary.

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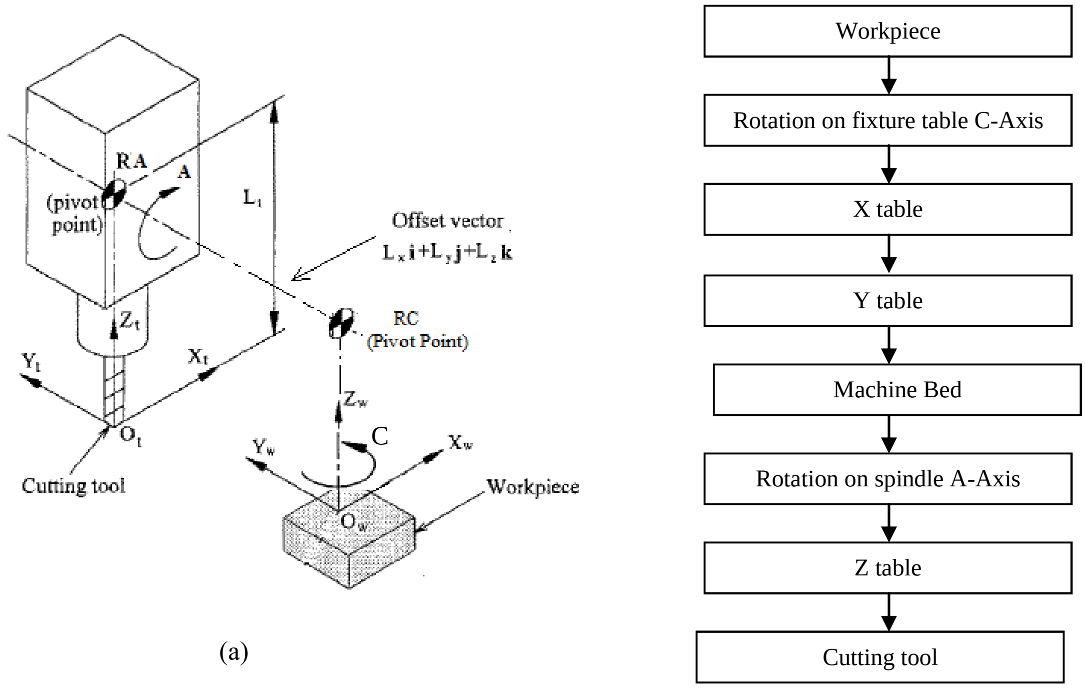
For the 5-axis micromilling table/spindle-tilting type present in this paper, the coordinate system of $O_wX_wY_wZ_w$ and $O_tX_tY_tZ_t$ are attached to the workpice and the cutting tool, respectively. The coordinate system and the relationship of structural elements of table/spindle-tilting type is shown in Fig 8.



(a) (b)

Fig. 9: (a) Coordinate system and (b) relationship of structural elements of table/spindle-tilting type configuration

The pivot point R_A is located on the A axis arbitrarily and the pivot point RC is the intersection of workpiece rotation and the spindle tilting. The offset vector $L_xi+L_yj+L_zk$ is calculated from the origin O_w to the point RC and the effective tool length, L_t, is the distance between the pivot point RA and the cutter tip center, O_t.

The relative orientation and position of the cutting tool with respect to the workpiece coordinate system can be determine by multiplying the corresponding fundamental transformation matrices in series, and should be equal to the known CL data, $[K_x\ K_y\ K_z\ 0]^T$ and $[Q_x\ Q_y\ Q_z\ 1]^T$. The mathematical expression is described as follows :

$$[K_x\ K_y\ K_z\ 0]^T = Trans\ (L_x, L_y, L_z)\ Rot(Z,-\varphi_C)\ Trans\ (P_x, P_y, P_z)\ Rot(X,-\varphi_A)[0\ 0\ 1\ 0]^T \quad (5)$$

$$[Q_x\ Q_y\ Q_z\ 1]^T = Trans\ (L_x, L_y, L_z)\ Rot(Z,-\varphi_C)\ Trans\ (P_x, P_y, P_z)\ Rot(X,-\varphi_A)[0\ 0\ -L_t\ 1]^T \quad (6)$$

where φ_A and φ_C are the rotation angles about the X, and Z axes, respectively, and positive rotation is in the direction to advance a right-hand screw in the +X and +Z axis directions. P_x, P_y, P_z are the relative translation distances of the X, Y, and Z tables, respectively. Multiplying equations (5) and (6), yields:

$$\begin{matrix} K_x \\ K_y \\ K_z \\ 0 \end{matrix} = \begin{matrix} S\varphi_A \cdot S\varphi_C \\ -S\varphi_A \cdot C\varphi_C \\ C\varphi_A \\ 0 \end{matrix} \quad (7)$$

$$\begin{matrix} Q_x \\ Q_y \\ Q_z \\ 1 \end{matrix} = \begin{matrix} -S\varphi_A \cdot S\varphi_C.L_t - P_x.C\varphi_C + P_y.S\varphi_C + L_x \\ S\varphi_A \cdot C\varphi_C.L_t - P_x.S\varphi_C - P_y.C\varphi_C + L_y \\ C\varphi_A.L_t + P_z - L_t \\ 1 \end{matrix} \quad (8)$$

From the above equations, the rotation angles (φA, φC) and the relative translation distances (Px, Py, Pz) can be solved. On the other hand, the X, Y, Z values of the NC data in programming are obtained using equation (6) under the condition $\varphi A = \varphi C = 0$, and $[Q_x\ Q_y\ Q_z\ 1]$ T = [X Y Z 1] T since the program coordinate system is coincident with the workpiece coordinate system. This leads to:

$[X\ Y\ Z\ 1]^T = [L_x + P_x, L_y + P_y, L_z + P_z - L_t]^T$

Thus, the desired equations for NC data of this configuration can be expressed as follows:

$$A = \varphi_A = \arccos(K_Z) \qquad (-\pi/2 \le \varphi_A \le \pi/2) \qquad (9)$$

$$C = \varphi_C = \arctan(K_x, K_y) \qquad (-\pi \le \varphi_C \le \pi) \qquad (10)$$

$$X = Q_x + L_x \; C\varphi_C - Q_y - L_y \; S\varphi_C + L_x \qquad (11)$$

$$Y = - Q_x - L_x \; S\varphi_C + Q_y - L_y \; C\varphi_C - S\varphi_A . L_t + L_y \qquad (12)$$

$$Z = Q_z - C\varphi_A . L_t + L_t + L_z \qquad (13)$$

The kinematic engine is succesly develop and will be then implemented into a software, known as the postprocessor.

4. CONCLUSION

The conceptual mechanical design for three types alternative of 5-axis micromilling machine with avaliable component is perform using Advanced Decision Matrix Method based on the Robust Decision Making. The highest Satisfaction score indicate that the third alternative, table/spindle-tilting of XYC-AZ axis, is the appropriate design for 5-axis micromilling.

The strength analysis of the design using a CAE software indicate that the construction is safe for 5,5 N of cutting force prediction [14].

To transform the CL data from a CAM system, it is necessary to calculate the kinematic of the machine tools into a mathematical equation that will be implemented in a postprocessor. There are many method to generate the kinematic engine. This paper succesfully develope a kinematic engine for table/spindle-tiling of XYC-AZ using a method proposed by Lee and She [2].
Further research will step on into mechanical prototyping and modelling the postprocessor of kinematic engine.

ACKNOWLEDGMENT
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