euspen's 21st International Conference &
Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Tolerance analysis for the C axis of a dual-axis rotary indexing table

Jhy-Cherng Tsai[1*], Po-Hao Huang[1], Ping-Hsuan Hsieh[1], Jia-Hong Lin[1], Yi-En Hsu[1], Yaw Zen Chang[2]

[1]*Department of Mechanical Engineering, National Chung-Hsing University*
[2]*Hiwin Technologies Co., Ltd.*

**jctsai@nchu.edu.tw*

Abstract

Rotary indexing table (RIT) is the critical module of a multi-axis machine tool as it affects the accuracy of the machine tool. While tolerancing is one the most crucial factors that affect the accuracy of the RIT, this research is aimed to tolerance analysis of the C axis of a RIT. The product hierarchy and tolerance network for the C axis are first constructed and route for tolerance stack-up is analyzed. Tolerance analysis is further conducted based on the stack-up route. The accumulated variations of the C axis center position are analyzed based on the variational kinematics method. The resultant tolerance stack-up, based on current tolerancing specifications, are ±0.039mm and ±0.174mm in radial and axial direction respectively.

Keywords: Rotary Indexing Table, Tolerance Network, Tolerance Analysis

1. Introduction

Machine tool is important foundation of industrial production and an index of industrialization of a country. Precision of such equipment is critical. The rotary indexing table (RIT), such as the dual-axis RIT shown in Figure 1, is an important module for multi-axis machine tools. The C-axis is composed of the rotary table, a mandrel that is fixed to a rotary shaft and seats on an axial bearing. The mandrel is driven by a built-in-motor with water-cooling jacket and with an encoder attached. One of the most important factors affecting the RIT accuracy is the tolerance of components. This paper analyzes assembly tolerance stack-up of the RIT as a step toward for tolerance design.

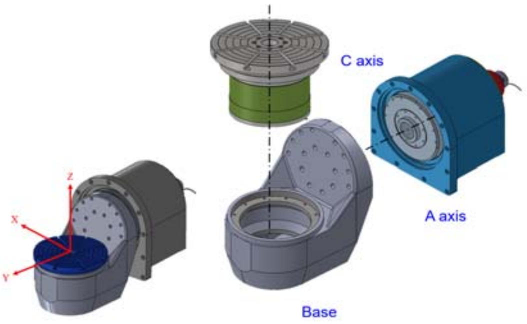

Figure 1: A dual-axis RIT for five-axis machine tools

2. Tolerance Network

The first step for tolerance stack-up analysis is to find the stack-up route. For this purpose, the assembly relationship, including tolerancing constraints, among components has to be constructed. The RIT is composed of three modules, namely the C axis, Base and the A axis. Tolerance analysis starts from product decomposition to the feature level as tolerancing are assigned to geometry and dimensions of features. Assembly conditions are also constructed among features thus form a network. Tolerances are accumulated, *i.e.* tolerance stack-up, when components are assembled.

There are various representation schemes, such as TTRS [1], constraint network [2], tolerance network (TN) [3], and T-Map[4]. They are similar in representing geometric constraints among geometric features in a product. In this work, TN is used to represent assembly relationship as TN represents geometric features and geometric constraints with variations as a graph. The graph intuitively maps features into nodes and constraints as edges of the graph thus is easier to recognize.

The RIT is decomposed into components and further decomposed into geometric features to construct the product hierarchy. Geometric constraints, such as GD&T, are applied to features to construct TN of a part/component. AS an example, Figure 2 shows the TN of the part Table of the C-axis module. Each geometric feature is shown as a black rectangle with a coordinate frame (red rectangle) associated with it. The frame is further referred to the datum reference frame (DRF, shown as rectangle filled with gray) of the part. Geometric constraints are represented as oval blocks where yellow oval represents self-reference constraint and purple oval means cross-reference constraint. Assembly relationship among components is then mapped to the TN and applied to assembled features. Figure 3 shows part of the resultant TN of the C-axis module as the full TN is too large to fit in the paper.

3. Tolerance Stack-up Analysis

The constraint in the TN is a relationship and can be represents as a homogenous transformation. In the ideal case, without tolerancing, the ideal geometry or fitting condition of the design is expressed as $\mathbf{T}_{ideal}\mathbf{(i)}$ where i means the ith constraint. Tolerance attached to it can be expressed as $\mathbf{\Delta T(i)}$ that is the variational kinematics or differential transformation due to the tolerance[5]. As a result, the real constraint that considers the effects of tolerance is $\mathbf{T}_{real}\mathbf{(i)}=\mathbf{T}_{ideal}\mathbf{(i)}\cdot\mathbf{\Delta T(i)}$. This representation has been widely employed in literatures and used in tolerance analysis of various electromechanical products[5-9].

In conjunction with the TN shown in Figure 3, the error accumulated along a path P is calculated as $\mathbf{T}_{real}\mathbf{(P)}=\Pi\ \mathbf{T}_{real}\mathbf{(i)}$; $\mathbf{T}_{ideal}\mathbf{(P)}=\Pi\ \mathbf{T}_{ideal}\mathbf{(i)}$ where P is the path of tolerance stack-up. The resultant error is the difference between $\mathbf{T}_{real}\mathbf{(P)}$ and $\mathbf{T}_{ideal}\mathbf{(P)}$ and cab be shown as a bonding box that represents the stack-up error in each axial direction. The resultant tolerance stack-up, based on current tolerancing specifications, by statistical analysis are ±0.039mm in radial direction and ±0.174mm in axial direction. The results suggest further tolerance adjustment is needed to achieve higher assembly precision of the C-axis module of the RIT.

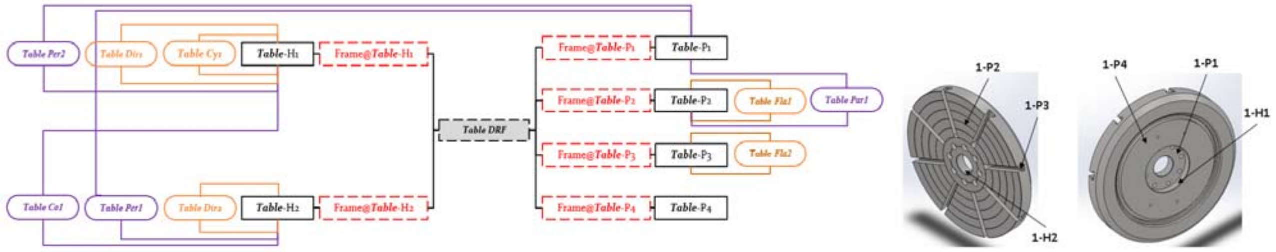

Figure 2: TN of the Table of the C-axis module

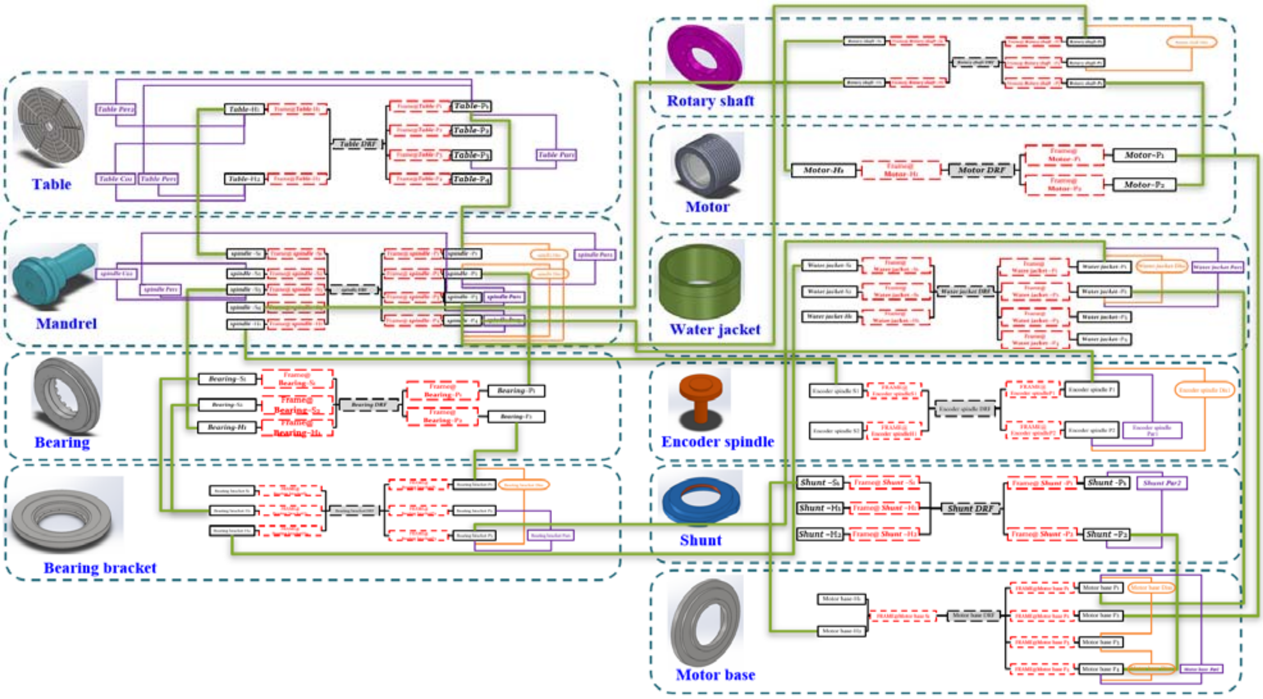

Figure 3: TN of the C-axis

4. Conclusions and Discussion

While precision of RIT is critical for multi-axis machine tool and tolerancing is one the most crucial factors that affect the accuracy of the RIT, this research is aimed on tolerance analysis of the C-axis module of a RIT. The product hierarchy and TN of the C-axis module are first constructed and then route for tolerance stack-up is analyzed. Tolerance stack-up analysis in each axial direction of the C-axis center position is then conducted along the route based on the variational kinematics method. The method treats tolerance as a differential transformation that associated with the ideal geometric constrain, represented as an ideal transformation. The resultant tolerance stack-up, based on current tolerancing specifications, are ±0.039mm in radial direction and ±0.174mm in axial direction. The results show that tolerance assignment needs further adjustment to achieve higher precision. This analysis, however, provides a systematic approach for tolerance stack-up analysis in a product. Further tolerance adjustment can be conducted based on sensitivity analysis with this approach.

Acknowledgement

This project is supported by the Hiwin Technology Co. Ltd. and the Ministry of Science and Technology, Taiwan under grant number MOST 107-2221-E-005-053-MY3.

References

[1] Clement A, Desrochers A and Riviere A 1991 *Proc. 2nd CIRP Int'l Seminar on CAT*, 325
[2] Lu S C Y and Wilhelm R G 1991 *J. of Mfg. Systems,* **10**(4) 279
[3] Tsai J C and Cutkosky M R 1997 Artificial Intelligence in Engg Design, Analysis, and Mfg, **11**(4) 325
[4] Davidson J K and Shah J J 2002, *ImechE(C): J. of Mechanical Engg. Science*, **216** 95.
[5] Tsai J C 1996 *Proc. 1996 ASME DETC/DAC* 96-DETC/DAC-1053
[6] Whitney D E and Gilbert O L 1993, Proc. IEEE Int'l Conf. on Robotics and Auto. **2** 314
[7] Chase J B and Guo B, 1999, *J. of Forklift Truck Tech. ,* **1** 5.
[8] Tsai J C, Hsiao M and Chen J L 2007, *Proc. 12th IFToMM World Congress*, mm-734
[9] Cai Z, Zhu Y and Chen D 2008, *Machinery Industry*, **300** 23.