ANALYSIS OF STATIC STIFFNESS AND NATURAL FREQUENCY OF THE SPINDLE SYSTEM

Chao Jinsan, Ji Huawei
E-mail: 9125610@mail.dyu.edu.tw

ABSTRACT
A SPINDLE OF A MACHINE TOOL MUST BE DESIGNED TO PROVIDE THE REQUIRED PERFORMANCE FEATURES. SOME FACTORS, SUCH AS BEARING'S TYPE, BEARING SPAN, BEARING PRELOAD AND LEVEL OF TOOL HOLDER'S PULL-IN FORCE WILL AFFECT THE SPINDLE'S STATIC AND DYNAMIC CHARACTERISTICS. THE COMPLICATED RELATIONSHIPS BETWEEN THESE FACTORS ARE URGENT TOPICS TO BE STUDIED. BEARING IS ONE CRITICAL COMPONENT OF SPINDLE. SEVERAL DESIGN PARAMETERS MUST BE PROPERLY SELECTED BY THE DESIGNER. IT IS EVIDENT THAT HIGHER PRELOAD WILL PROVIDE HIGHER STIFFNESS. HOWEVER, THIS WILL LIMIT THE MAXIMUM ROTATIONAL SPEED. IN OTHER WORDS, LOW PRELOAD WILL RESULT IN AN UNACCEPTABLE DEFLECTION OF SPINDLE, OR WILL CAUSE CHATTERING AND NOISE WHEN MACHINING. NUMEROUS STUDIES HAVE BEEN PUBLISHED REGARDING TO THE DETERMINATION OF THE OPTIMUM BEARING SPAN OF MACHINE TOOL SPINDLES WITH TWO BEARINGS. HOWEVER, MOST OF THE SPINDLES OF MACHINE TOOLS ARE EQUIPPED WITH MORE THAN TWO BEARINGS. CAN SIMPLIFIED TWO-BEARINGS MODEL BE USED TO DETERMINE THE OPTIMUM SPAN OF THE FAR MORE COMPLICATED THREE OR FOUR-BEARING SYSTEM? THE PURPOSE OF THIS RESEARCH IS TO DETERMINE THE DIFFERENCE BETWEEN THE STATIC PERFORMANCE OF A REAL SPINDLE MOUNTED WITH FOUR ANGULAR CONTACT BEARINGS AND THAT OF THE SIMPLIFIED MODEL. SEVERAL DIFFERENT 7/24 TOOL HOLDERS AND DIFFERENT PULL IN FORCE OF DRAWBAR SYSTEM ARE SELECTED TO EXAM THE SPINDLE'S STATIC STIFFNESS. THE FINITE ELEMENT (FE) ANALYSIS SOFTWARE PACKAGE "I-DEAS" IS UTILIZED TO BUILD THE SPINDLE'S FINITE ELEMENT MODEL. THE SPINDLE'S STATIC AND DYNAMICS CHARACTERISTICS WERE SIMULATED WITH SEVERAL DIFFERENT BOUNDARY CONDITIONS. THE EXPERIMENTAL AND SIMULATION RESULTS WERE THEN COMPARED TO ENSURE THE FE MODEL'S ACCURACY. RESULTS SHOWED THAT THE DEFLECTION OF THE SPINDLE HOUSING IS SIGNIFICANT. THE SIMPLIFIED MODEL THAT DID NOT CONSIDER THE DEFLECTION OF THE SPINDLE HOUSING CAN NOT PREDICT THE STATIC STIFFNESS OF THE SPINDLE ACCURATELY. I WISH THAT THE CONCLUSIONS FOUND IN THIS RESEARCH IS HELPFUL TO THE MACHINE TOOL INDUSTRY.

Keywords: MACHINE TOOLS, SPINDLE, STATIC STIFFNESS, DYNAMIC CHARACTERISTIC, ANGULAR CONTACT BALL BEARING, 7/24 TOOL HOLDER, FINITE ELEMENT

Table of Contents
第一章 序論--P1
1.1 前言--P1
1.2 研究動機--P3
1.3 文獻回顧--P5
1.4 研究方法與內容--P12
第二章 主軸的構造與靜剛性試驗--P13
2.1 主軸的構造--P13
2.2 斜角滾珠軸承的特性--P14
2.2.1 軸承的接觸角--P15
2.2.2 軸承的排列方式--P17
2.2.3 軸承的預壓--P17
2.2.4 軸承的潤滑方式--P19
2.2.5 軸承的靜剛性特性--P20
2.2.6 軸承的靜剛性值--P25
2.3 軸-軸承系統的靜剛性--P33
2.4 7/24刀把介面靜剛性--P39
2.4.1 主軸拉刀力設定對軸-刀把介面剛性的影響--P42
2.4.2 制造公差對軸-刀把介面剛性的影響--P44
2.5 主軸系統靜剛性試驗架構--P48
第三章 主軸系統脈衝試驗與分析--P55
3.1 脈衝試驗(IMPULSE TESTING)--P56
3.1.1 衝擊槌與脈衝輸入訊號--P58
3.1.2 加速規的安裝方式--P62
3.1.3 訊號處理與訊號品質確認--P64
3.2 實驗設備與架構--P67
第四章 主軸有限元素模型--P73
4.1 主軸有限元素模型靜剛性分析--P73
4.1.1 選用元素種類與收斂性--P74
4.1.2 主軸靜剛性模型的建構與分析--P77
4.1.3 錯估軸承靜剛性的原因--P92
4.2 襯套變形量的影響--P94
4.3 軸承剛性及跨距對主軸靜剛性的影響--P97
4.4 自然頻率分析--P100
第五章 結論--P103

REFERENCES
[1]. Huang Joonhong, "綜合加工機用各種7/24刀把介紹", 機械工業雜誌, 三月號, 168期, 中華民國86年。
[2].黃俊宏, "綜合加工機的刀把", 機械工業雜誌, 四月號, 中華民國82年, PP. 301~314。


[5].王文瑞, "主軸性能檢測方法", 機械工業雜誌, 三月號, 中華民國86年, PP.223~233。

[6].N. URMAZE, "CHATTER-FREE MILLING AND OPTIMIZED MATERIAL REMOVAL RATES: ANALYSIS OF CH -ATTER IN MILLING", HTTP://WWW.MMSONLINE/ARTICLES/。

[7].台中精機集團, "工具機主軸靜剛性分析與測試之整合", HTTP://WWW.OR.COM.TW/MZ。


[10].T. TERMAN, J. G. BOLLINGER, "GRAPHICAL METHOD FOR FINDING OPTIMUM BEARING SPAN", MACHINE DESIGN, MAY, 27, 1965, PP. 159~162。


[12].H. R. EL-SAYED, "DYNAMIC BEHAVIOUR OF MACHINE TOOL SPINDLES MOUNTED IN THREE BEARINGS", MACHINERY AND PRODUCTION ENGINEERING, FEBRUARY, 6, 1974, PP. 139~144。

[13].W. POPOLI, "HIGH SPEED SPINDLE DESIGN AND CONSTRUCTION", HTTP://WWW.MMSONLINE/ARTICLES/。


[16].黃俊弘, "工具機主軸的專利回顧", 機械工業雜誌, 四月號, 中華民國83年, PP.197~206。
407~415。


[32]. 郭慶祥, 吳政憲, "工具機高速主軸之性能測試與分析", 碩士論文, 大葉大學機械工程研究所, 中華民國89年7月。


[34]. Z. M. LEVINA, "STIFFNESS CALCULATIONS FOR CYLINDRICAL AND TAPER JOINTS", MACHINES & TOOLING, VOL. 41, NO. 3, 1970, PP. 5~11。


[38]. J. H. WANG, "INVESTIGATION OF THE TOOL HOLDER SYSTEM WITH A TAPER ANGLE 7:24", INTERNATIONAL JOURNAL OF MACHINE TOOLS AND MANUFACTURE, VOL. 34, NO. 8, 1994, PP. 1163~1176。

[39]. D. J. EWINS, "MODAL TESTING-THEORY, PRACTICE AND APPLICATION 2ND ED.", RESEARCH STUDIES PRESS, 2000。

[40]. R. J. ALLEMANG, "VIBRATIONS: ANALYSIS AND EXPERIMENTAL MODAL ANALYSIS", COURSE NOTES: UC-SDRL-CN-263-662, UNIVERSITY OF CINCINNATI, FEBRUARY, 1999。

[41]. D. J. INMAN, "ENGINEERING VIBRATION", PRENTICE HALL, 1994。

[42]. HP, "THE FUNDAMENTALS OF MODAL TESTING-APPLICATION NOTE 243-3", HTTP://WWW.AGILENT.COM。

[43]. P. AVITABILE, "EXPERIMENTAL MODAL ANALYSIS-A SIMPLE NON-MATHEMATICAL PRESENTATION", HTTP://WWW.SANDVMAG.COM。

[44]. PCB, "INTRODUCTION TO PIEZOELECTRIC ACCELEROMETERS", HTTP://WWW.PCB.COM/TECH_ACCEL.HTM。


[46]. J. MATHEWS, "GUIDE TO ADHESIVELY MOUNTING ACCELEROMETERS", ENDEVCO, TECHNICAL PAPER 312, HTTP://WWW.ENDEVCO.COM/TEST/LITERATURE_TECH.HTM。

[47]. R. D. SILL, "MINIMIZING MEASUREMENT UNCERTAINTY IN CALIBRATION AND USE OF ACCELEROMETERS", ENDEVCO, TECHNICAL PAPER 299, HTTP://WWW.ENDEVCO.COM/TEST/LITERATURE_TECH.HTM。


[49]. SKF, "PRECISION BEARINGS", SKF, 1987。


[51]. 黃俊弘, "高速主軸之技術發展與應用", 機械工業雜誌, NO. 204, 三月號, 中華民國89年。

[52]. 王敬勝, "氣浮高速主軸拉刀機構之拉刀力有限元素分析", 碩士論文, 高雄第一科技大學機械與自動化工程所, 中華民國90年7月。


[54]. MTS SYSTEMS CORPORATION, "SIBLAB USER GUIDE, V. 3.2.4"。

[55]. V. ADAMS, A. ASKENAZI, "BUILDING BETTER PRODUCTS WITH FINITE ELEMENT ANALYSIS", ONWARD PRESS, 1999。

[56]. 田子奇, 吳政憲, "高速化工具機動態特性分析與改善", 碩士論文, 大葉大學機械工程研究所, 中華民國90年1月。

[57]. STRUCTURAL DYNAMICS RESEARCH CORPORATION, "I-DEAS ONLINE HELP LIBRARY", MTS SYSTEMS CORPORATION。

[58]. R. ZEILLINGER, H. KOTTRITSCH, "DAMPING IN A ROLLING BEARING ARRANGEMENT", SKF, HTTP://EVOLUTION.SKF.COM。