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Integrated ultrasonic driven balancer for ultra precision high speed machine tools

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Abstract

Ultra precision machining -in particular milling and drilling- is a flexible way to produce parts with optical surface quality. Due to the tight tolerances of the process parameters, air bearing spindles are necessary for ultra precision machining. The low axial and radial stiffness of the air bearing spindle requires a much better balance state than the ISO balancing grade G1 that is applied to conventional spindles in order to avoid damage to the air bearings. State of the art balancing of an ultra precision spindle is manually done and hence a time consuming and error prone procedure. Due to the human interaction and uncertainties in the unbalance detection multiple iterations are necessary in order to achieve a sufficient balancing state. In this paper a experimental setup that evaluates the capability of an autonomous, in-spindle balancing system based on angular redistribution of masses is presented. The necessary angular torque to change the angle of the balancing mass is provided by a ring-shaped ultrasonic traveling wave motor. The properties of this system are investigated in regards to the smallest possible step of the drive. Particular attention is paid to the influence of different drive parameter values on the behavior of the ultrasonic motor. It is shown that the balance mass can be rotationally shifted with a resolution better than 0.05°, -fully adequate for ultra precision balancing.

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Keywords: balancing, ultrasonic motor, ultra precision, high speed

1. Introduction

Ultra precision machining is a process which is used to create free form surfaces in optical quality. Like any other process which utilizes rotating tools, the fly cutter in ultra precision cutting needs to be balanced as well [1]. A balance process comprises multiple balance iterations. Each iteration consists of multiple steps. First the spindle is run up and the unbalance induced vibrations are measured. If the desired balance state is not reached, the spindle is run down and the balance state is adjusted, e.g. by adding, removing or redistribution of masses. This procedure is repeated until the desired balance state is reached, see Fig. 1. Due to the low axial and radial stiffness of the air bearing spindles in ultra precision machining, the balance process is even more time-consuming in order to avoid damaging

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the air bearings. One possibility to reduce the secondary process time is to enhance the unbalance detection and thus reducing the necessary balancing steps, since the compensation mass and position can be determined more accurately [2]. Alternatively the balancing process can be drastically shortened up if the balance state can be adjusted during the operation of the spindle, eliminating the need for the time-consuming spindle runups, rundowns and manipulation of the balance mass.

In this paper a system is presented which is able to adjust the balance state of a running spindle by means of rotational redistribution of mass. The balance mass is moved by a ring-shaped ultrasonic traveling wave motor (USM) which is driven by the integrated electronics. The communication with the operator is established by 2.4 GHz based radio transmission. It is shown that rotary position increments smaller than 0.05° can be achieved and the system is able to operate when mounted on a running spindle.

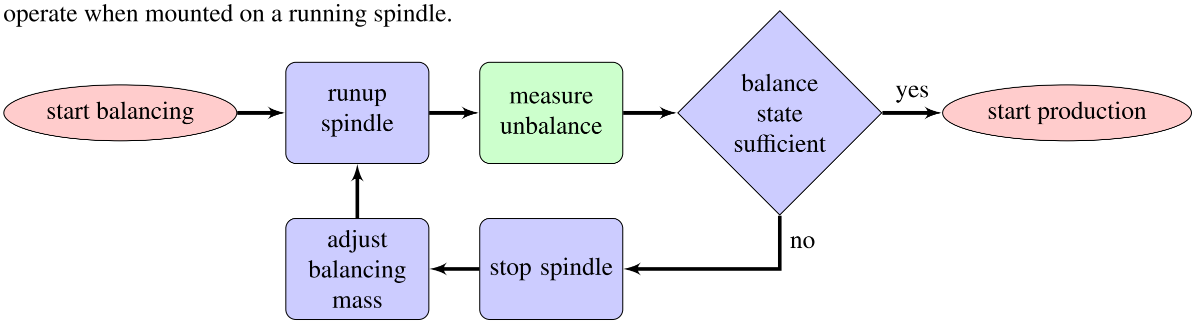

Fig. 1. Balancing process of an ultra precision spindle.

Nomenclature

α	angle of balance mass 1
β	angle of balance mass 2
γ	step size of the USM
φ_{AB}	phase shift between signal A and B
φ_b	phase of the balance ring
φ_e	phase of the experimental setup
ω	angular velocity of the spindle
c	propagation velocity of the radio signal
f_c	commutating frequency of the USM
$\vec{f_n}$	force of the unbalance n
f_D	frequency of Doppler shift
f_0	carrier frequency
fs	sampling rate
$\vec{F_u}$	balance force
$\vec{l_n}$	vector to the balance mass n
m_{un}	mass of the balance mass n
M_u	torque generated by the the USM
P_n	number of commutating pules send to the USM
r	distance between RFM73 and rotation axis
v	velocity between transmitter and receiver
V_s	supply voltage of the USM

2. Balance principle

In this paper the method of mass redistribution, in particular the rotary mass redistribution, is used to balance the rotor. Therefore two balance rings with different radii located in the same plane are mounted on the spindle. The idea