Repeatability of a Chucking System Based on Centralizing With a Sphere and Locating Axially on a Flange

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Abstract

Results are shown for a uniquely accurate and rigid chucking system. Radial control is by means of a light interference fit between a sphere and a cylindrical bore. Axial and tilt control is based on flat flanges. Performance relies on form control of the mating surfaces and size control of the sphere and the bore, both of which require interchangeability. The design is kinematic in the sense that radial and axial properties are strictly separated and overconstrained in that area contact is made at the flange and full circular contact is made at the equator of a sphere as shown in Figure 1. Chucking accuracy is demonstrated by removing and replacing a target and charting repeatability. Axial force can be provided by a central screw or drawbar; in this implementation six screws are used.

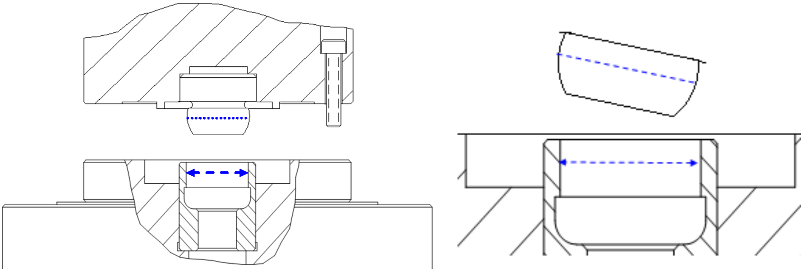

Figure 1: Spherical pilot (contact lines shown) with cylindrical bore and flat flanges

1 Introduction

Professional Instruments Company developed this system for applications requiring maximum radial, axial, and tilt accuracy, under load and at speed. Introduced in the 1980’s for the disk drive industry, *spherical-pilot chucks* later found other applications such as truing and dressing diamond wheels on one machine and using them on another. This report describes a radial repeatability test and gives a mechanistic explanation for why the system repeats so well.

2 Motivation

Tapers, collets, and other types of workholders can offer quick and easy chucking but at the expense of accuracy and stiffness [1]. Imperfect workholders can limit the performance of ultra-precision spindles, thus the need for a better system.

3 Design

Radial location is established by line contact of a carbide sphere with a one micrometer interference fit in a cylindrical carbide bore whose wall thickness is thin enough to expand slightly and uniform enough to stay centered. Roto-ground flanges establish axial and tilt location. This combination is an interesting study in kinematics, overconstraint, and elastic averaging. Particulate contamination is a concern when flat surfaces are to be assembled in an imperfect environment, but a ground texture with stoned-off peaks provides a place for microscopic particles to be displaced where they don't interfere with full contact at the flange interface [2]. Six #10-32 socket head cap screws provide axial and tilt stiffness, and for best results a repeatable sequence is used to produce uniform clamping force. Unlike a tapered joint, clamping force does not diminish with increasing speed.

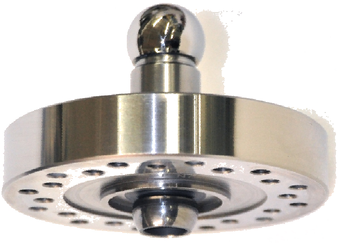

Figure 2: Test ball and spherical pilot

Figure 3: Receiver

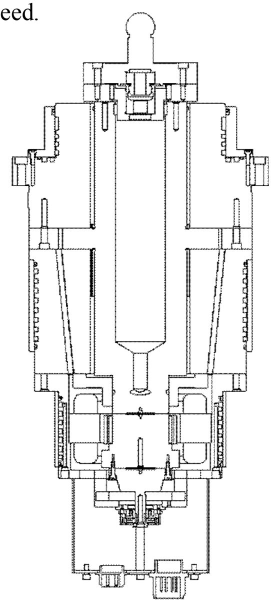

Figure 4: Spherical pilot system on a Model 5.5 ISO motorized air bearing spindle

Overconstraint (preload) provides stiffness but kinematic correctness is also desired so that the mechanism is not in conflict with itself [3]. In practice this means that the radial guide is independent from the axial-and-tilt location feature. Both features must be made to close tolerances but unlike HSK tapers, radial contact can be positioned anywhere in a wide axial zone [4]. Tilt control is provided by large-diameter flanges.

4 Approach

A test ball (Figure 2) is repeatedly installed in a receiver (Figure 3) attached to a spindle rotor (Figure 4) and TIR is recorded after each re-installation. Radial displacement is measured with a non-contact probe having sub-nanometer resolution and angular orientation and triggering is provided by a 1024-count encoder. Knapp et al described the calibrator, which incorporates an air bearing slide with a Sony Laserscale® having mimimal Abbé offset [5]. A repeatability test resulted in a 1 nanometer range over six trials without touching the ball. The structural loop is short and stiff so that external influences are not a factor. Error motion software extracts numerical values for once-per-revolution variation. Test-to-test variation is shown as a polar plot in Figure 5. The test ball is removed and reinstalled at the same orientation angle and the screws are sequentially tightened; just snug at first, then to 20 pound-inches (2.2 Nm), and finally to 40 pound-inches (4.5 Nm). Between cycles, the flange surfaces are cleaned and stoned per PI shop practice (Figure 6).

5 The measurand

The definition of the measurand is variation of the eccentricity of the target after removal and replacement at the same nominal angular orientation, clamped with a specific procedure. The target was a 25.4 mm diameter 440C hardened and lapped test ball with an integral flange. The measurement plane was 55 mm above the interface of the flanges. The structural loop was close-coupled and robust. Radial displacement variation was measured with a capacitive probe and amplifier having sub-nanometer resolution (Lion Precision C23-C probe with CPL290 driver). 10 revolutions were acquired at 5,000 rpm with 1024 samples per revolution filtered to 150 Undulations Per Revolution. A skilled operator performed the 12 chuckings, including cleaning, stoning, and re-installation.

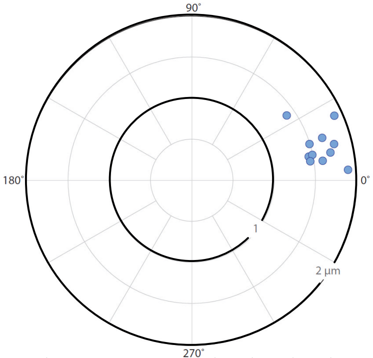

Figure 5: Test results showing less than 1 micrometer repeatability of the chucking system.

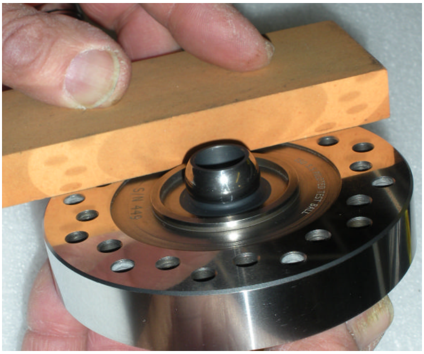

Figure 6: Flatstoning a flange

The radial repeatability of the chucking system shown in Figure 5 was less than one micrometer. The eccentricity angle varied about 30 degrees. Since the ball was only slightly eccentric, the exact angle for maximum displacement will vary quite a lot with only a slight variation in the radial location.

Conclusion and future work

Radial repeatability was within one micrometer measured 55 mm above the flange. The limiting factor appears to be tilt variations due to flange imperfections so we will study strategies for improving clamping force repeatability, the influence of particulates, and the effects of variation in circular flatness and surface finish.

References:

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