Position Stability of a Kinematic Mounted Target designed for the High-Resolution Accelerator Alignment Technique Using X-ray Optics

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Abstract

The basic concept of the high-resolution accelerator alignment technique using x-ray optics rests on two highly stable and repeatable beam line defining pinholes. This point to point definition of the x-ray beam axis (XBA) circumvents many of the stability problems encountered with the point and line definition used in laser alignment systems. The angular stability of the light source is not critical in this concept due to the use of pinholes. However, the repeatability and position stability of each of the XBA defining pinholes is very important. Therefore we created a test setup of an actuated pinhole that is kinematic supported in its final resting position. The instrument setup and results of these tests are presented.

1. Introduction

We recently introduced a novel alignment technique utilizing the x-ray beam of a dedicated alignment undulator in conjunction with pinholes and position-sensitive detectors for positioning accelerator components in an x-ray free-electron laser. In this concept two retractable pinholes at each end of the main undulator line define a stable and reproducible x-ray beam axis (XBA). Targets are precisely positioned on the XBA using the pinhole camera technique. Position-sensitive detectors responding to both x-ray and electron beams enable the direct transfer of the position setting from the XBA to the electron beam. This system has the potential to deliver superior alignment accuracy in the micron range for target pinholes in the transverse directions over long distances. It defines the beam axis for the electron-beam–based alignment (EBA) with high reproducibility. This concept complements the existing electron-beam–based alignment and the existing survey methods advancing the alignment accuracy of long accelerators to an unprecedented level [1].

2. Position Stability of a Kinematic Mounted Target

The concept of the high-resolution accelerator alignment technique using x-ray optics requires highly reproducible actuated pinholes. Fortunately, much progress has been made in the past decades in the field of precision machining technology with micron and submicron reproducibility [2]. Applying kinematic mounting technology the semiconductor industry developed submicron wafer positioning systems in clean rooms. Subsequently insertion mechanisms with 1 to 3 micron reproducibility should be within reach for a temperature-controlled accelerator tunnel. In order to proof this assumption we created a test setup for measuring the repeatability of a kinematic mount system.

2.1 Experiment Setup

As shown in figures 1 and 2 the setup uses a 12” x 12” platform mounted 12” above the surface of a Newport support table. A controllable MDC ALM-275-1 pneumatic linear actuator with 1” travel is mounted underneath this platform. On top a 7” flange is mounted that contains the appropriate fasteners for attaching the three Vee blocks in a 120° radial configuration (Fig. 3) and the attachment for the LK-G32/G37 Keyence sensor measuring the horizontal deviations with an accuracy of $\pm$ 50 nm.

Two stainless steel mounting posts are used with an Aluminum bridge to provide a mounting structure for a second Keyence sensor that measures the vertical displacements. The Keyence sensors can be adjusted to provide the proper measuring range to a polished 1” cube that is attached to the top of the 3.5” stainless steel flange moving with the actuator. At the bottom of that flange three half spheres have been mounted matching the Vee block configuration. Upon actuation the plunger moves the platform up and on reverse pulls against a spring to force the three spheres into the lowest equilibrium state in the Vee blocks. The weight of the moving flange is 1.1Kg while the hold down force with spring is 9.1 Kg.

In addition four RTD temperature sensors were mounted to the test stand. The first is attached to the support platform, the second to the stainless steel flange supporting the Vee blocks; the third is mounted to the Aluminum bridge supporting the second Keyence sensor while the fourth measures the ambient air temperature removed from the platform.

The system is controlled by a Windows operated PC running LabView 7.1 programmed for this task. The Keyence output from the LK GD500 readout unit is connected via an RS232 serial interface to the computer while a National Instrument USB chassis with a four channel thermocouple input module and a four channel relay module is used to read the RTD sensors and actuate the solenoid respectively. A loose fitting spring-loaded interface bridges the gap between the actuator plate and the 3.5” moving flange. In the up position the three spheres of the kinematic system are removed from the Vee blocks by about 4 mm. In the down position the spheres make contact with the surfaces of all three Vee blocks. In order to provide rotational freedom about the actuation axis the link between the actuator and the Vee blocks has to be weak.

During the tests the entire setup is enclosed in an insulating box to remove the effects of stray light on the Keyence sensors and to provide a temperature stable environment. The opening angle of the Vee blocks is 90°. We performed tests with stainless steel spheres on unpolished stainless steel Vee blocks with and without lubrication. Similarly we used Tungsten Carbide spheres on polished stainless steel Vee blocks with and without lubrication.

The LabView program is setup to take a reading every 30 seconds while the kinematic mount engages the three Vee blocks.

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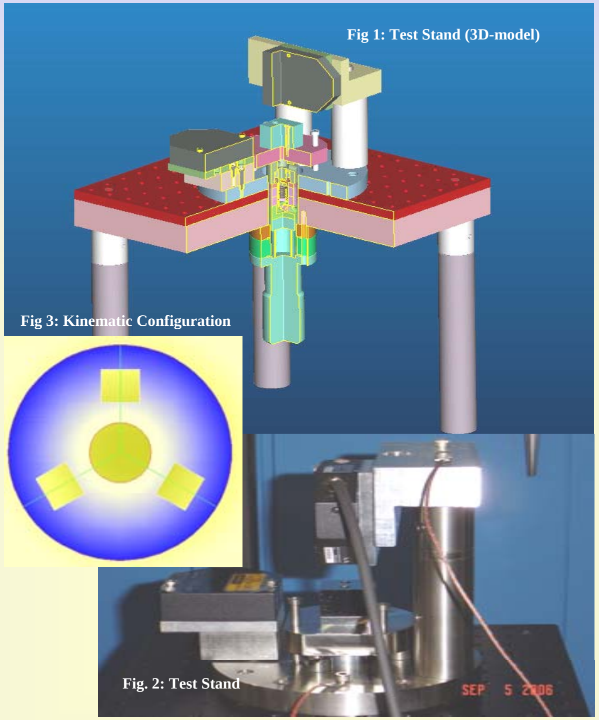


Fig 1: Test Stand (3D-model)

Fig 3: Kinematic Configuration

Fig. 2: Test Stand

2.2 Test Results

Over the course of several weeks we performed many tests with different combinations of materials for the Vee blocks and spheres under spring load and without a spring force and with and without actuation. The following graphs represent a small subset of the measurements. The data shows an unusual event towards the end of the test. It turns out, after about a total of 15000 actuations, the spring providing the additional hold down force of 8 Kg broke.

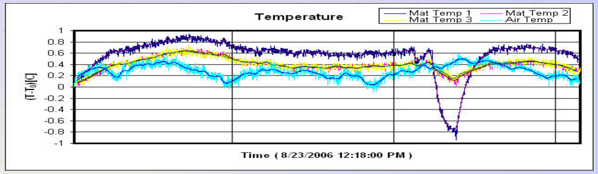
This creates an offset in the readings. However, the repeatability stays the same once the force of the spring is removed. We performed follow-up tests without the additional hold down force of a spring confirming our observation.

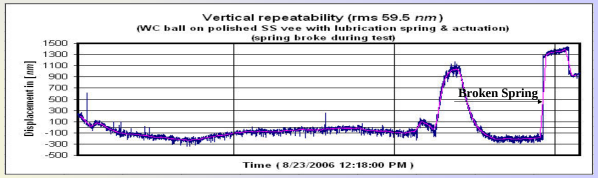
Similarly the introduction of lubricants does not significantly improve the repeatability of the kinematic mounting system. In all the data sets one can see a strong correlation with temperature. After removing the step due to the broken spring we were able to derive a correction value from the large temperature spike seen in the first graph. The red curves in the last two graphs show the average repeatability after removal of the trend due to the temperature effects. The RMS repeatability for the vertical and horizontal direction is in all test cases less than 50nm.

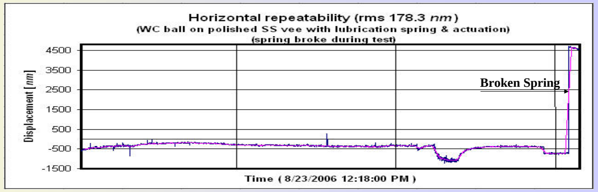
2.3 Conclusion

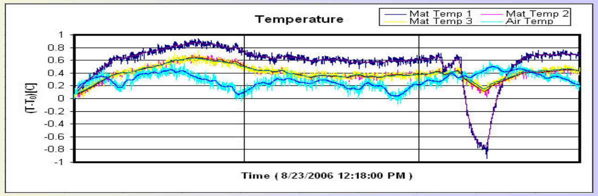
Our initial goal was to achieved a reproducibility on the order of $\pm$ 5 µm. During the tests we discovered that the link between the actuator and the kinematic platform has to be weak as not to over-constrain the system. Once this was accomplished we were able to achieve sub-micron level repeatability with all tested combinations of materials used for the Vee blocks and spheres.

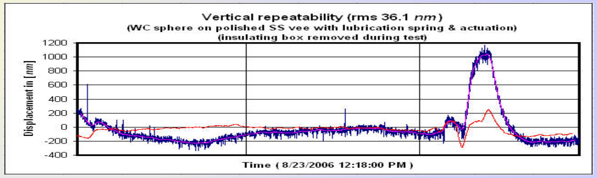
We found a strong correlation between the temperature of the mounting structure and the Keyence sensors that dominates the measurements. As with most electronic instruments stable and repeatable measurements can only be achieved after the sensors and the mounting structure have reached temperature equilibrium. After the removal of the systematic effects due to temperature we obtained a repeatability of the kinematic mounted platform on the order of $\pm$ 50 nm exceeding our initial goal by two orders of magnitude.

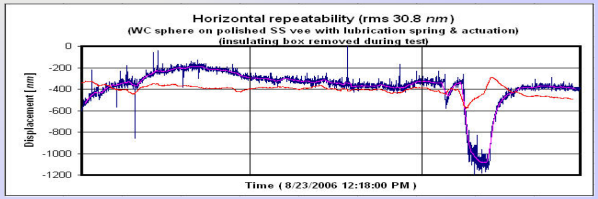












References

[1] Bingxin Yang, Horst Friedsam,”High-resolution accelerator alignment using x-ray optics”. Phys. Rev. ST Accel. Beams 9, 030701 (2006).

[2] Slocum, Precision Engineering **14**, 67 (1992)