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MASTER

TITLE ANTARES ALIGNMENT GIMBAL POSITIONER LINEAR BEARING TESTS

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Introduction

Antares is a 24-beam, 40-terawatt carbon dioxide (CO_2) laser fusion system currently under construction at the Los Alamos National Laboratory. For fusion experiments, the 24 laser beams are focused onto a tiny target (typically, 500 μm in diameter) located approximately at the center of a 7.3-m-diam by 7.3-m-long vacuum (10^{-6} torr) chamber. It is desirable to be able to focus each laser independently anywhere within a 1-cm cubic volume surrounding the target center. To accomplish the beam alignment task, we decided to build an instrument that would (1) hold a variety of detectors; (2) point a detector at each laser beam to within ±0.5° of the desired angle; (3) translate the detector ±5 mm from a reference location in the x, y, and z axes; and (4) know the detector position relative to the reference throughout the travel of each motion to within a maximum root sum of squares (RSS) error of 15 μm. To satisfy these requirements, an alignment gimbal positioner (AGP) is being designed. This device basically consists of a gimbal mounted to an x, y, z micropositioner and a set of optics to relay the detector information outside the target chamber. The detector center is precisely located at the intersection of the two gimbal axes. This arrangement allows the detector to be pointed toward any position in space and to be translated to within the limits of the micropositioner. A line drawing of the AGP is shown in Fig. 1.

To achieve the 15-μm maximum RSS error, an error budget was assigned to each of the major mechanical interfaces. The error budget is tabulated in Table I.

Difficulty in reliably positioning a detector with an accuracy of better than 20 μm with the particular linear bearing system used had been encountered earlier. Experience with a previously designed instrument, called a movable Hartmann ball (MHB), revealed that most of the difficulty could be attributed to Abbe offset error. Abbe offset error is associated with the measurement of the position of a point offset from the measurement axis. This is illustrated in Fig. 2. Figure 2 also dramatizes the effect of linear bearing straightness on Abbe offset error. The linear bearings used on the MHB were crossed-roller bearings, lubricated with vacuum-compatible grease, and having an a:b ratio (as shown in Fig. 2) of approximately 6:1. For the AGP, it is desired to reduce the a:b ratio as much as possible and obtain the linear bearing system that will give the best predictability of the detector position.

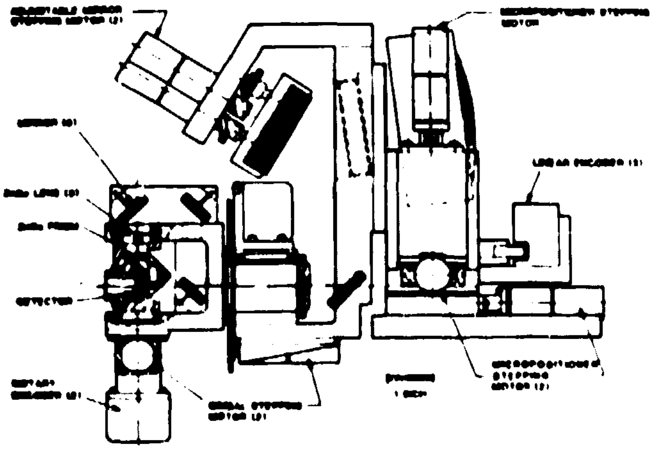

Fig. 1. Schematic of Antares alignment gimbal positioner.

Testing Apparatus

To perform the linear bearing tests, an existing micropositioner whose linear bearing was the same size as that in the MHB was used. (The linear

TABLE I

AGP ERROR BUDGET

1.	Gimbal axes intersections	5.0 μm
2.	Gimbal axes runout	5.0 μm
3.	Detector mislocation	5.0 μm
4.	Detector replacement[a]	3.0 μm
5	x, y, z axes orthogonality	4.0 μm x 3
6.	x, y, z axes Abbe offset error	4.0 μm x 3
7.	Contingency	6.7 μm
	Total RSS Error	15.0 μm

[a]The detector replacement error refers to the positional error introduced when one detector is substituted for another in the gimbal.

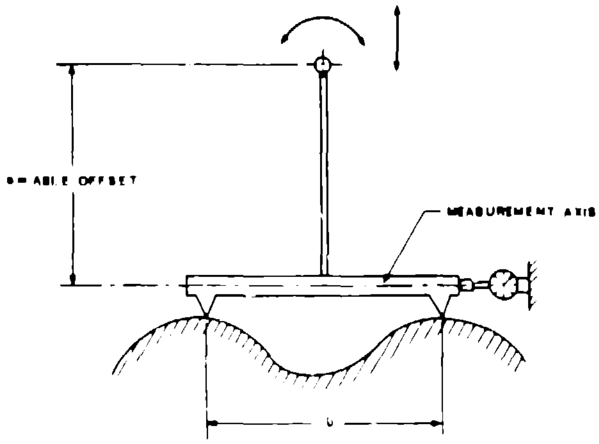

Fig. 2. Illustration of Abbe offset error.

bearing is one size smaller than that being used on the AGP.) A cross section of the micropositioner is shown in Fig. 3.

A Hewlett Packard interferometer was used to measure the repeatability of locating a detector position. The interferometer has a resolution capability of 0.01 μm; however, for this experiment, a resolution of 0.1 μm was sufficient. The testing arrangement is pictured in Fig. 4.

We originally wanted to obtain measurements for the straightness of travel of each bearing configuration. The readily available interferometric hardware to make these measurements had a resolution of only about 2 μm. Measurements were attempted for

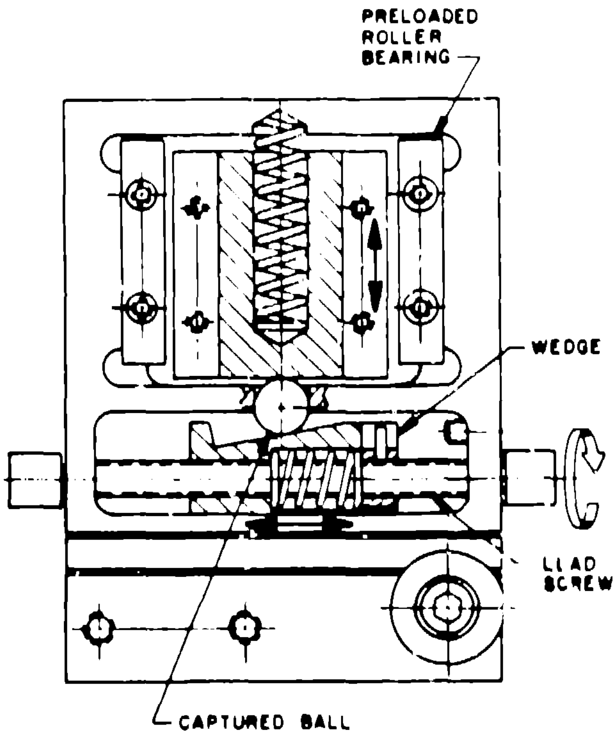

Fig. 3. Cross section of micropositioner.

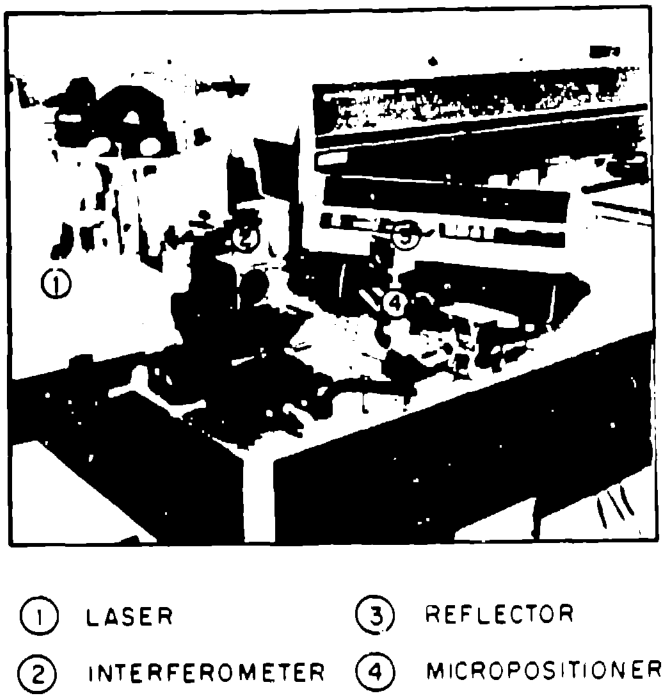

Fig. 4. Linear bearing testing apparatus.

three configurations, but were halted because the lack of straightness of the bearings was smaller than the instrument resolution. A straightness of better than 2 μm is acceptable, so it was decided to make the comparisons based upon repeatability data.

Testing Method

The six configurations tested are described pictorially in Figs. 5 through 7. Data on each system are shown in Table II.

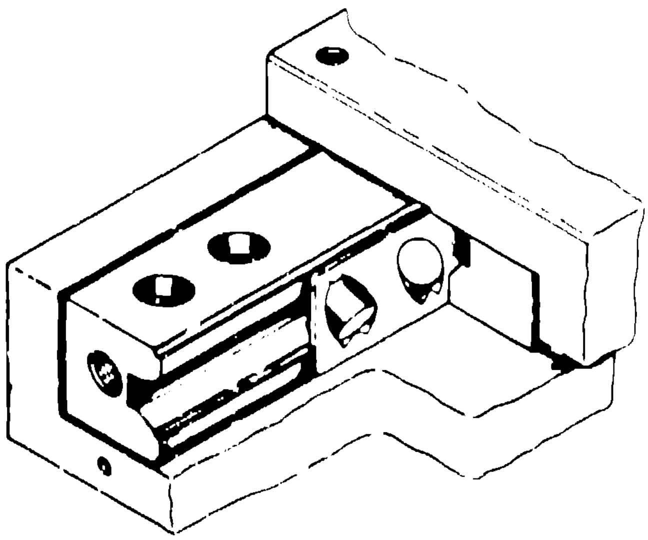

Fig. 5. Linear bearing mechanical arrangement for configurations 1 and 6.

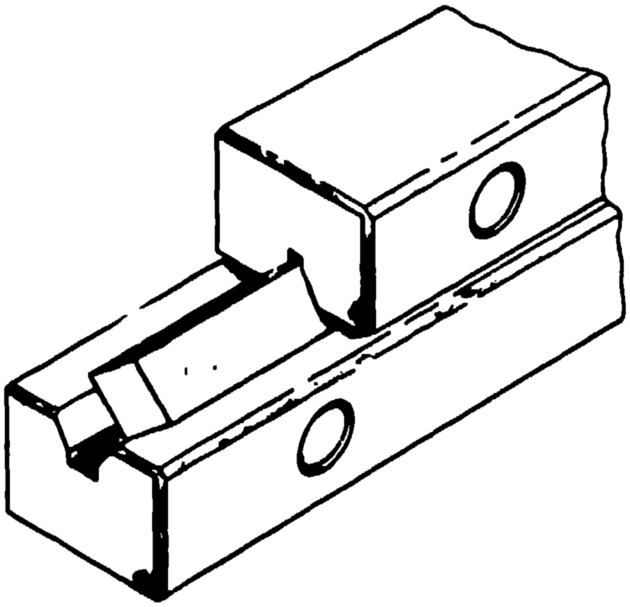

Fig. 6. Linear bearing mechanical arrangement for Configurations 2 and 3.

Each configuration was cleaned so that no loose particles could be observed on the bearing surfaces at 50X magnification. All micropositioner assembly was performed on a laminar flow bench to minimize the likelihood of particles migrating onto the linear bearings. When the assembly was completed, the micropositioner was placed in the interferometer setup located in a temperature-controlled room and allowed to thermally stablize for at least two hours.

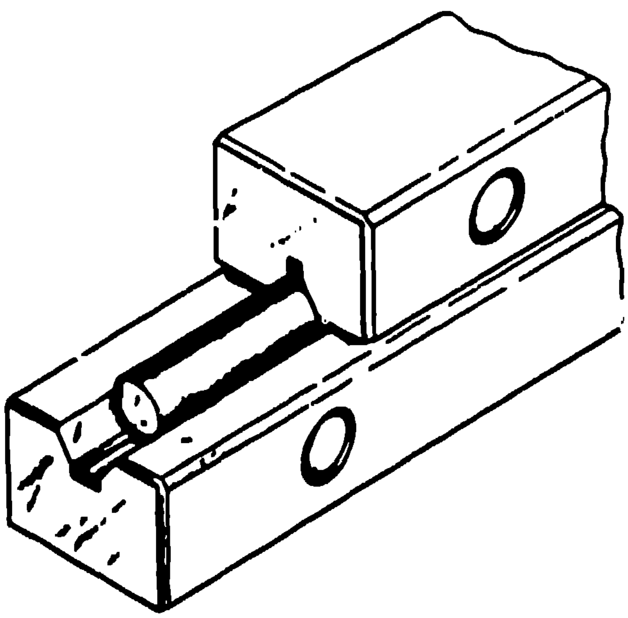

Fig. 7. Linear bearing mechanical arrangement for Configurations 4 and 5.

TABLE II

LINEAR BEARING CONFIGURATION DATA

Configuration Number	Configuration Description	Roundness or Parallelism of Rail or Roller, μm	Surface Finish μm RSS
1	Dry, crossed-roller bearings	1.25	<0.2
2	Fomblin[a]-lubricated bearing ways and square cross-section rails	1.0	0.05
3	Nedox[b]-coated bearing ways and square cross-section rails	1.0	0.05
4	Nedox[b]-coated bearing ways and circular cross-section rails	1.25	<0.2
5	Fomblin[a]-lubricated bearing ways and circular cross-section rails	1.25	<0.2
6	Fomblin[a]-lubricated rollers	1.25	<0.2

[a]Trade name of a liquid vacuum lubricant from Montedison USA, 114 Avenue of the Americas, New York, NY 10013.

[b]Trade name of lubricating coating from General Magnaplate Corporation that basically consists of a hard plating with a controlled infusion of Teflon. General Magnaplate Corporation is located at 1331 US Route No. 1, Linden, NJ 07036.

A dial was attached to the lead screw and was read with the aid of a pointer. The reading resolution was estimated to be about 0.1 μm. Data on micropositioner travel (approximately 1.2 mm) and dial settings were obtained in the following manner. The dial was divided into 10 settings, numbered 0 through 9. For each setting, the dial was moved to position 0, back to the setting, to position 1, back, and so on to position 9 and back to the original setting. This was done sequentially for settings 0 through 9. A displacement reading was made at the end of each movement. This procedure resulted in 19 data points consisting of dial settings and displacement readings for all possible single movements between any 2 of the 10 dial settings. After the test on a configuration was completed, the linear bearings were examined under a microscope to determine if any particles had migrated into the bearings. For one set of data for Configuration 6, some small aluminum chips (that probably were generated from a misaligned spring rubbing on the aluminum housing) were discovered in the linear bearings. This set of data was discarded.

Testing Results

The standard deviation of position as a function of dial setting for each configuration is plotted in Fig. 8. These results indicate that the solid rails in each of their configurations (Configurations 2-5) are superior to the rollers (Configurations 1 and 6). The solid circular rails in the Fomblin lubricant (Configuration 5) was the best. A formal analysis of the data from each of the configurations was performed as an aid in screening out those that were unacceptable.

The standard deviation plots in Fig. 8 indicate the variability of true position associated with each dial position. The question of interest is how accurately can the position of target be determined from the dial setting. It was observed that some of the variability at a specific dial setting could be attributed to the distance traveled from the previous dial setting. That is, true position after the dial is moved to a particular setting depends on where the dial was moved from. The term "approach" is used to mean the signed difference between a dial setting and the previous dial setting.

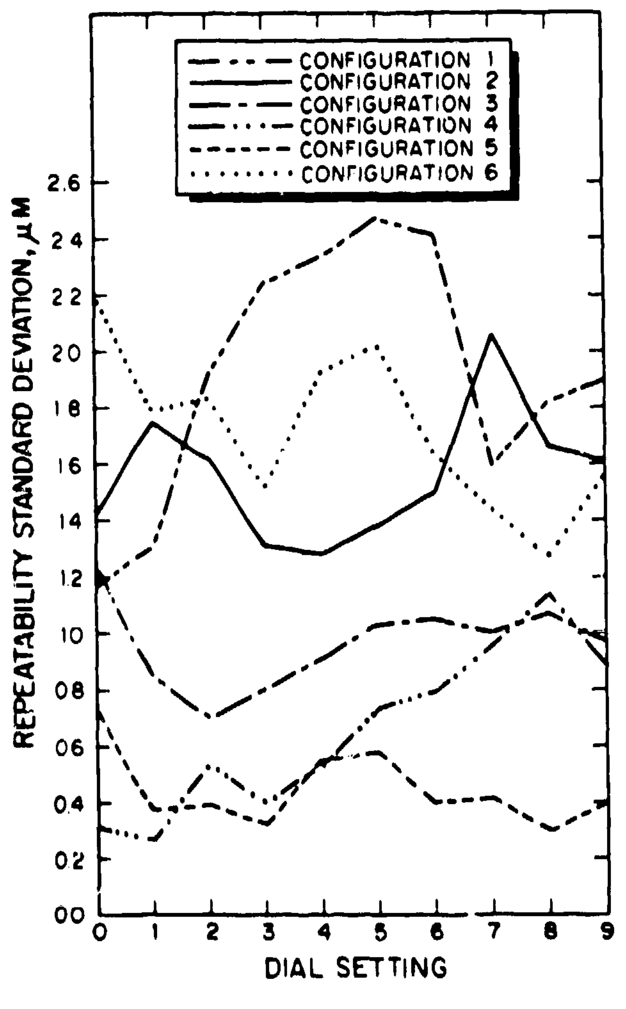

Fig. 8. Plot of positional standard deviation vs dial setting for all configurations.

The relationship between position and a polynomial function of dial setting (up to third degree) and approach (linear) was studied, using regression analysis. The form of the polynomial function was determined separately for each configuration, using a best subsets regression algorithm. The polynomial approximation seemed adequate for screening purposes.

Table III shows estimates of intrinsic variability for the six configurations. Column 2 is the RSS average of the standard deviations in Fig. 8. These averages only approximately summarize the curves in Fig. 8. Column 3 contains estimates of the variability of the "best" polynomial fit. Column 4 contains estimates of the limit in precision attainable through a fitted function (curve). All of the entries in the table have errors associated with estimation. Hence, the estimated limit of precision for Configuration 1 is larger than the estimated precision for the fitted function. Nevertheless, the numbers can be used to compare configurations and fits.

The final fits for each configuration indicated how well true positions could be estimated for each of the six configurations. Again, Configuration 5 was judged the best.

The next stage of testing will involve determining better functions (calibration functions) to approximate the relationship between position and dial setting, taking approach into account. A modification of the procedure used to obtain micropositioner data will allow better estimation of the limits of precision that can be obtained with calibration functions.

Conclusions

The data indicate that of the six configurations tested, the solid circular rails with either the wet or dry lubricant are superior to the other configurations. Therefore, these two will undergo additional tests. These tests will consist of (1) modifying the testing procedure to obtain a better estimation of the limits of precision, and (2) subjecting the bearings to moments more closely approximating the actual conditions they will undergo on the AGP.

The results have been quite encouraging. The prediction error of the polynomial fit for Configuration 5 is less than 1.5 μm (at 99 per cent confidence) for all dial settings. This is significantly smaller than the 4.0 μm budget error.

TABLE III

STANDARD DEVIATIONS IN μm

Configuration	Average Over Dial Settings	Polynomial Fit	Limit of Precision
1	1.97	1.36	1.62
2	1.57	1.71	1.62
3	0.97	0.85	1.08
4	0.71	0.65	0.68
5	0.47	0.46	0.48
6	1.74	1.97	1.79

Although more severe tests to be performed in the future are likely to result in poorer fits to the data, the precision obtained thus far has provided confidence that the allotted error budget can be met.

Acknowledgments

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