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Dynamic Tracker Test Apparatus

Judson L. Shattuck
Vincent M. Parisi

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

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Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433

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DYNAMIC TRACKER TEST APPARATUS

Static and Dynamic Characterization of a Rotational Table Designed to Evaluate Azimuth Motion

Judson La Moure Shattuck, III^{*a} and Vincent M. Parisi^b

United States Air Force, Air Force Research Laboratory, Human Effectiveness Directorate,
Warfighter Integration Division, Warfighter Visualization Branch (AFRL/HECV),
2255 H. St., Wright-Patterson AFB, OH, USA 45433-7022

ABSTRACT

The Dynamic Tracker Test Apparatus (DTTA) was designed by the Helmet Mounted Sensory Technology (HMST) laboratory to accurately measure azimuth rotation in both static and dynamic conditions. The DTTA was characterized for static position data at various increments through a 360° sweep and for speeds up to 1000°/sec or 17.45 rad/sec. This paper describes the design, construction, capabilities, limitations, characterization and performance of the DTTA.

Keywords: Azimuth Measurement, Head Tracker, Helmet-Mounted Trackers, Dynamic Measurement, Static Measurement

1.0 INTRODUCTION

In military aviation, head tracker technologies have become increasingly important to track the pilot's head position and orientation, allowing the user to quickly manipulate the operational environment. This technology allows the pilot to quickly acquire items of interest and see Fighter Data Link-Type information. Tracker-Assisted Weapons-Slewing to acquire the target on a helmet-mounted display is far more efficient than pointing at it with the nose of the aircraft as previously required for the heads-up display (HUD) type of target acquisition.

The United States Air Force (USAF) has used and evaluated a variety of helmet-mounted trackers for incorporation into their high performance aircraft. The primary head tracker technologies commercially available are magnetic trackers, inertial trackers, and optical trackers. Each type of tracker has its own pros and cons. Hybrid trackers are also available that utilize a combination of technologies, attempting to maximize the pros while minimizing the cons. Kocian and Task¹ made an in-depth study of the hybrid -approach trade-offs, including the increase in cost and complexity.

2.0 BACKGROUND

Each of the aforementioned head trackers have their own method of determining the pilot's head position within the cockpit of the aircraft. Magnetic trackers generally have a small head mounted size and minimal head weight. Since they sense a generated magnetic field, their accuracy can be affected by other magnetic fields or ferrous components within the cockpit. These distortions can usually be accommodated by mapping the area of the cockpit to establish the magnetic field structure, present but any change within the cockpit or on the helmet can potentially invalidate that map and require a new map. Inertial trackers cover the entire head motion box but require constant motion in order to accommodate drifting of the inertial sensors or a secondary system that updates the inertial system, often referred to as a hybrid system. Finally, optical head trackers (OHT) are immune to magnetic fields. Some of their limitations may be daylight/night vision goggle (NVG) compatibility issues and, depending on system configuration, may require numerous emitters and/or receivers to cover a large head motion box and provide a wide field of regard.

^{a*} judson.shattuck@wpafb.af.mil; phone 1 937 255 8742; fax 1 937 255 8366; www.hec.af.mil

^b vincent.parisi@wpafb.af.mil

With the variety of commercialized head trackers available to the USAF, a method to evaluate these various types is necessary. The evaluation method must not interfere with the head trackers normal function. That is, it must not subject the head tracker to excessive ferrous components that would alter magnetic trackers fields for magnetic trackers, create excessive vibration for inertial trackers, or produce excessive light for optical trackers.

Contained in this text is a description of the Dynamic Tracker Test Apparatus (DTTA), which attempts to fulfill this requirement.

3.0 SYSTEM DESCRIPTION

3.1 Component Description

The Dynamic Tracker Test Apparatus (DTTA) is comprised of components as is seen in Figure 1 and Figure 2. It is entirely constructed of non-ferrous components, except for the encoder, thus minimizing magnetic field effects if used for evaluating magnetic trackers. The set screws are standard off-the-shelf nylon except for the 0° set screw, which is nonferrous. All the principle components are custom fabricated from polycarbonate.

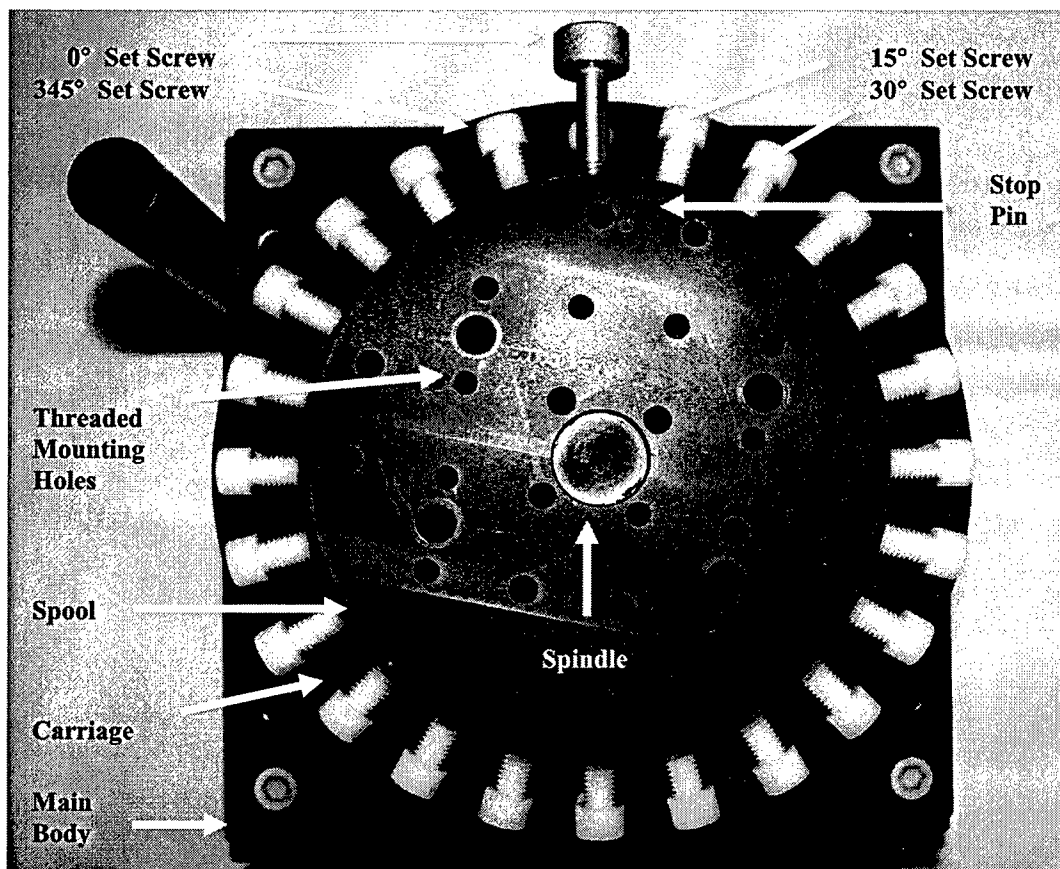


Figure 1. Dynamic Tracker Test Apparatus (Top View)

3.1.1 Spool

The spool is threaded about the outer perimeter, which serves as a guide for the string, which tethers a weight. The spool is mechanically connected to the encoder through the spindle. Both the main body and the carriage are precision bored, acting as guides for the spindle as the spool is rotated. The spool is supported by the carriage through mating shouldered surfaces, and it rotates freely.

The top of the spool is drilled every 1" on center with 1/4"-20 threads, identical to standard optical tables. This allows mounting of standard optical hardware, facilitating custom fixtures. The spool also includes a stop pin that extends into the carriage. The function of the stop pin is described along with the carriage.

3.1.2 Carriage

The carriage serves two primary functions. First, it mechanically supports the spool with a mating shouldered surface and is precision bored to help align the spindle that connects the spool to the encoder. Second, it provides a means to move and stop the spool at any combination of 15° increments about its 360° rotation when the set screws are spun in. Accordingly, the carriage is drilled and threaded about its outer perimeter every 15° to accommodate mating set screws. The set screws are a position aid; they are not intended as an exact reference point.

3.1.3 Encoder

The Encoder is a metrology-grade measurement device specifically designed for rotary tables with a resolution, after 4x quadrature decode and 50x interpolation, of 0.0001° (0.36 arcsec) and an accuracy of ± 1.25 arcsec. The position data output from the encoder is represented by two quadrature pulse streams that can be decoded to 3,600,000 counts per revolution. It also includes an index marker and out-of-tolerance marker. Under dynamic conditions, the encoder can accurately output data at a maximum rate of 1000 rev/min (RPM) or 104.7 rad/sec.

The index marker generates a high output signal at the same physical location with respect to the encoder's internal shaft once every revolution. This index can be used to identify the absolute beginning of a rotation (0 counts) or to determine an offset, by number of counts, from where an absolute beginning is desired. Thus, the exact starting and ending position, within 0.0001° or 1/3,600,000 counts, can be found and repeated. The out-of-tolerance marker generates a low pulse indicating faulty encoder operation.

The encoder is mounted to the main body and connected to the spool through the spindle, as seen in Figure 2. A specialized shaft coupler is used to mount the spindle to the encoder, which protects the encoder if the spindle is moved side-to-side and compensates for any spindle alignment or assembly anomalies.

3.1.4 Data Acquisition

Raw quadrature data are collected from the encoder with a PCI-4E interface card specifically designed for incremental encoders. Encoder data are processed using a 24-bit real time up/down counter with a count range from 0 to 16,777,215 and are stored at approximately 150,000 samples per second to a data array. Each sample consists of four 24-bit encoder position counters and a 33 MHz time stamp. Thus, data can be collected from a static position or dynamically as it rotates. The time stamp allows computing angular velocity and/or angular acceleration.

Using the PCI-4E driver software, position data are displayed as counts displaced from the index or counts displaced from an arbitrary user established position, which is an offset amount from the index. This arbitrary position is established by the "Re-Set" function. Data can be collected by reading the information from the display or by defining either a sampling rate, specific number of samples, or both.

3.2 System Operation

The DTTA is a mechanical device used to measure rotation about the Z axis or azimuth only. It can rotate in either a clockwise (CW) or counter clockwise (CCW) direction; however, the tethered weight (see Figure 2) only allows assisted motion in the CCW direction. The spool rotates freely in either direction, assuming all set screws are spun-out (see Figure 1). To use the DTTA in the evaluation of a head tracker system, the system's transmitter or receiver is mounted atop the spool as shown in Figure 3. Although head tracker systems usually measure the three axes of azimuth, elevation and roll, the DTTA is only capable of measuring rotation about its vertical (Z) axis as defined in Figure 4. To make measurements in other directions, the item under test must be mounted such that the desired axis of rotation is aligned with the DTTA's Z axis and suitable adjustments to the tracker's complimentary transmitter/receiver/sensor made. For inertial trackers, this will be troublesome because gravity would now be affecting the wrong axis.

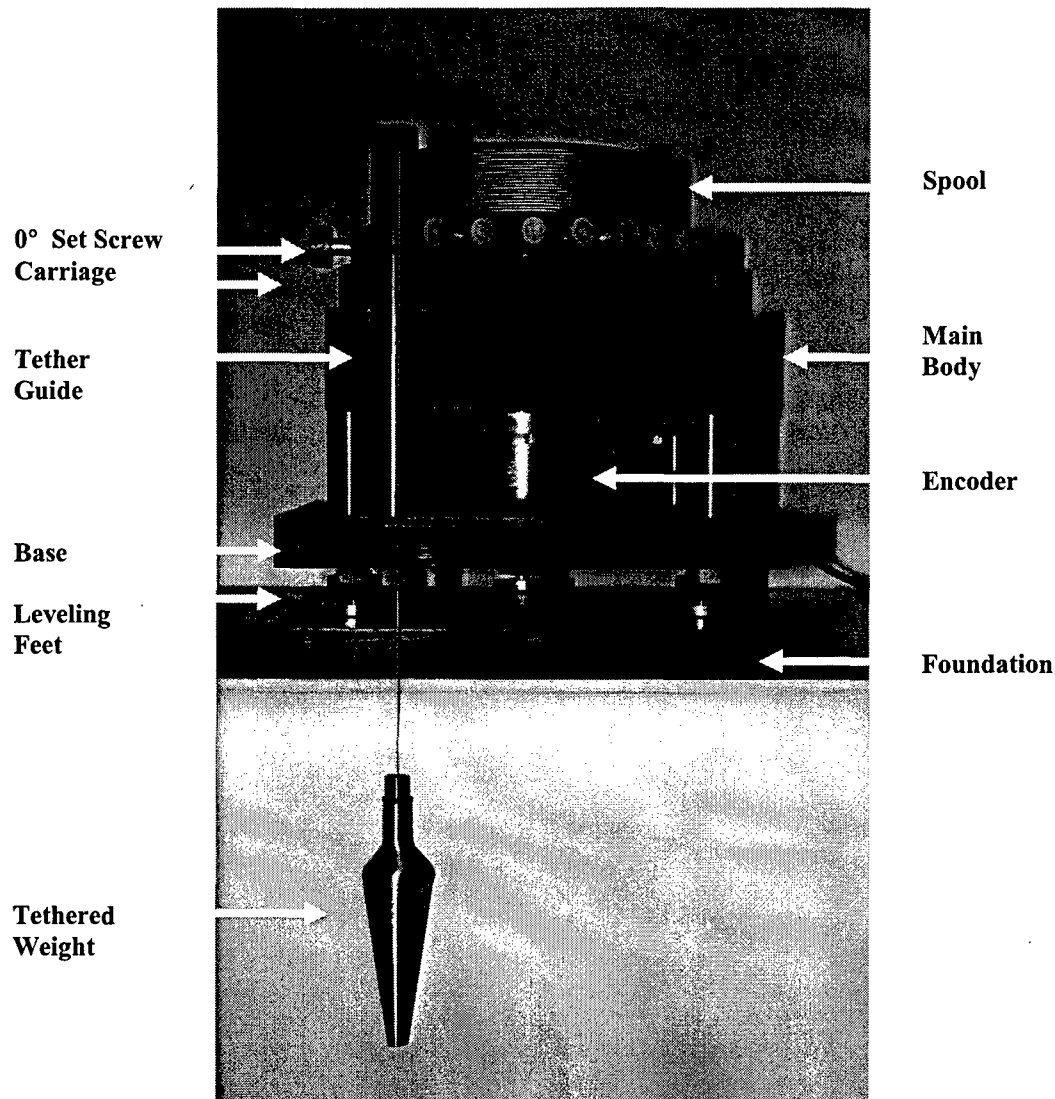


Figure 2. Dynamic Tracker Test Apparatus (Front View)

3.2.1 Static Operation

As shown in Figure 3, an emitter pack from an optical head tracking system is mounted atop the spool in preparation for data collection. After following the head tracker system's alignment procedure, the PCI-4E driver software is initialized. The spool can be rotated to one of the set screws or stopped at any position to make the measurement. If the set screws are used, the weight may be used to apply a constant force against them, allowing for quick placement in approximate positions every 15 degrees apart. In either situation, the encoder and PCI-4E driver software accurately display the actual position.

3.2.2 Dynamic Operation

For dynamic operation, the tethered weight is used to apply a constant force in the CCW direction. With all set screws spun-out, once the weight is released, the spool will accelerate, continuing to rotate until the tethered weight stops traveling and the spool coasts to a stop. The PCI-4E driver software collects position and time stamp data.

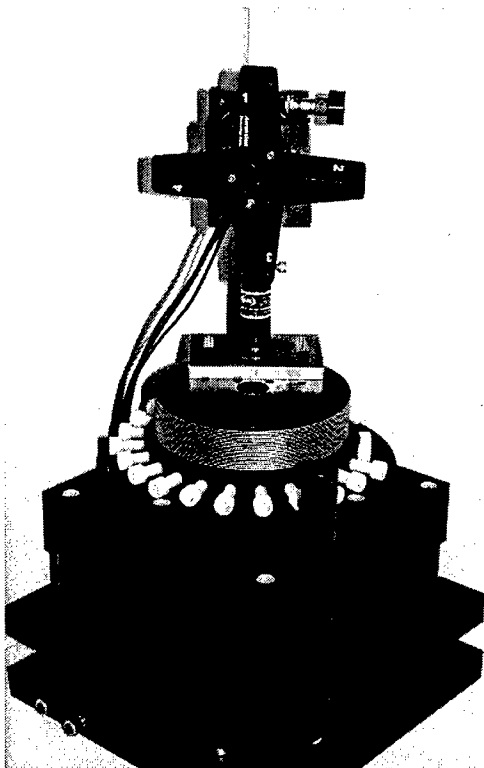


Figure 3. DTTA with Emitter Pack Installed

Figure 5 shows the average of 5 different data collection runs by two individuals. The data shows that, as the spool is rotated from -180° to $+180^\circ$, the elevation varies from approximately $+0.0002''$ to $+0.0026''$, which equates to an angular change of $+0.07$ milli-radian to $+0.904$ milli-radian or ± 0.417 milli-radian from a nominal midpoint position.

An additional set of data was taken to determine the "flatness" of the spool surface because it could affect our measurements. The spool was removed from the spindle and placed on a granite flat surface used for precision measurements. The same dial indicator used in the measurements described above was used for this data. The data were collected in two runs. In the first run, the spool was rotated on the granite surface while the dial indicator remained stationary. In the second data run, the spool remained stationary while the dial indicator was moved around the periphery of the spool. The data were averaged and are shown in Figure 6. The shape of this plot very closely resembles the plots from Figure 5, leading us to believe that the variation in elevation seen in the initial tests were the results of the spool's surface not being completely flat. Subtracting the results of Figure 6 from the results of Figure 5 reveals the changes in elevation due to the spindle being "out of round" or "bent". These results are shown in Figure 7. It can be seen here that the spool rotates essentially flat except for an area around the zero degree point, where the system is affected by an induced

4.0 AXES OF MOTION

The DTTA axes are defined as shown in Figure 4. Rotation about the X axis equates to a change in roll (RL), rotation about the Y axis equates to a change elevation (EL), and rotation about in the Z axis equates to a change in azimuth (AZ).

5.0 STATIC CHARACTERIZATION

Under perfect conditions with a perfect system, the DTTA would rotate only in azimuth (about the Z axis). Because this system is not perfect, we characterized the system to determine cross coupling between the azimuth and the elevation axis.

5.1 Spool Characterization without Head Tracker Equipment Installed

The primary source of additional movement when the spool rotates is elevation. This movement is attributed to two factors. First, the actual flatness of the spool surface and second the straightness of the spindle that rotates the spool. The combination of these factors was measured with a mechanical dial indicator mounted at the top edge of the spool and measurements were taken as the spool was rotated. The results of these measurements are shown in Figure 5.

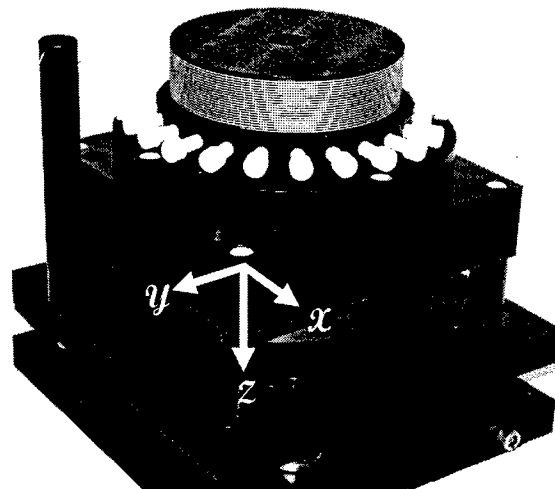


Figure 4. Axis of Motion

elevation change of approximately $-0.0015''$, which equates to -522 milli-radians. The result of this reference frame misalignment from what was thought to be a "perfectly" flat plane that rotates only in azimuth is a reference frame that shows some elevation change. This misalignment results in an "induced" azimuth and elevation measurement error.

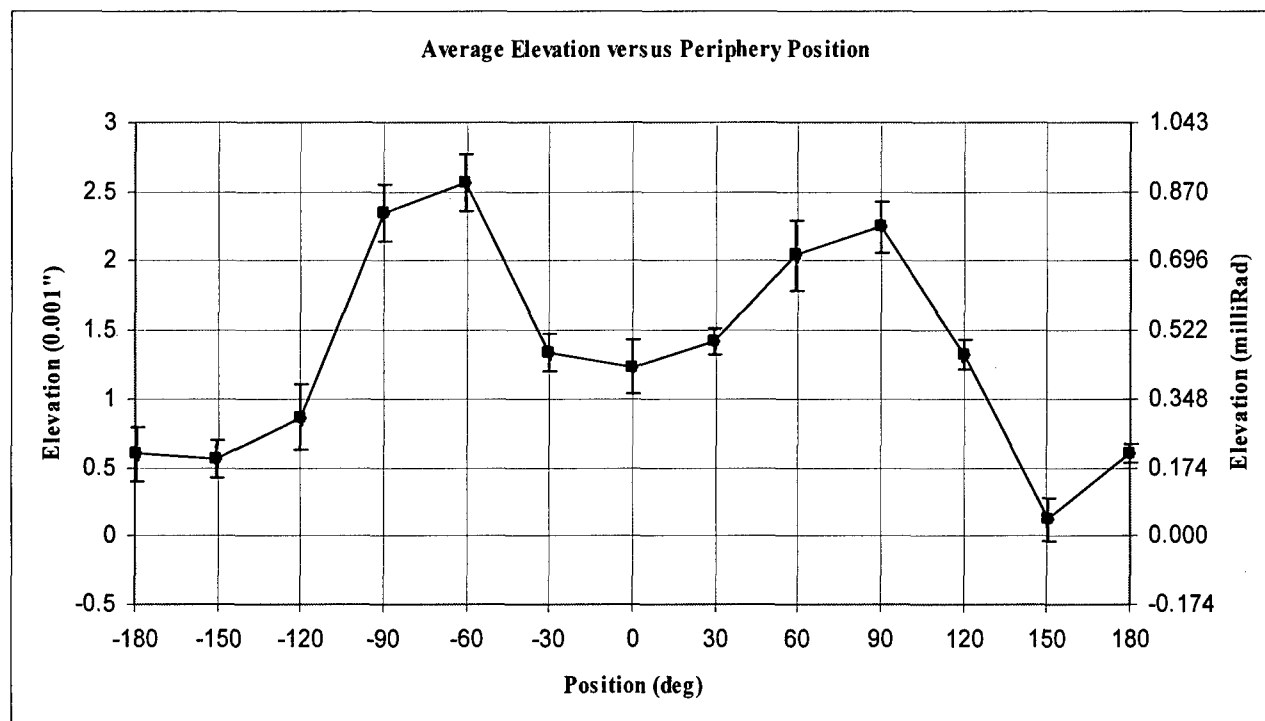


Figure 5 Average Elevation versus Periphery Position -180° to 180°

Figure 8 shows the effect of a reference frame misalignment at the same order of magnitude as seen in our system. Our system exhibited a potential misalignment, as shown in Figure 5, of approximately 1 milli-radian when combined with spool flatness. Figure 8 shows that a 1 milli-radian elevation misalignment will result in an elevation error equivalent to 1 milli-radian. (We thought the spool system rotates "perfectly" flat in azimuth, when in fact it rotates in a plane at a 1 milli-radian angle). Figure 8 also shows that this same misalignment in elevation induces an azimuth error at a maximum of approximately 1.25 micro-radian. For our system we consider this negligible.

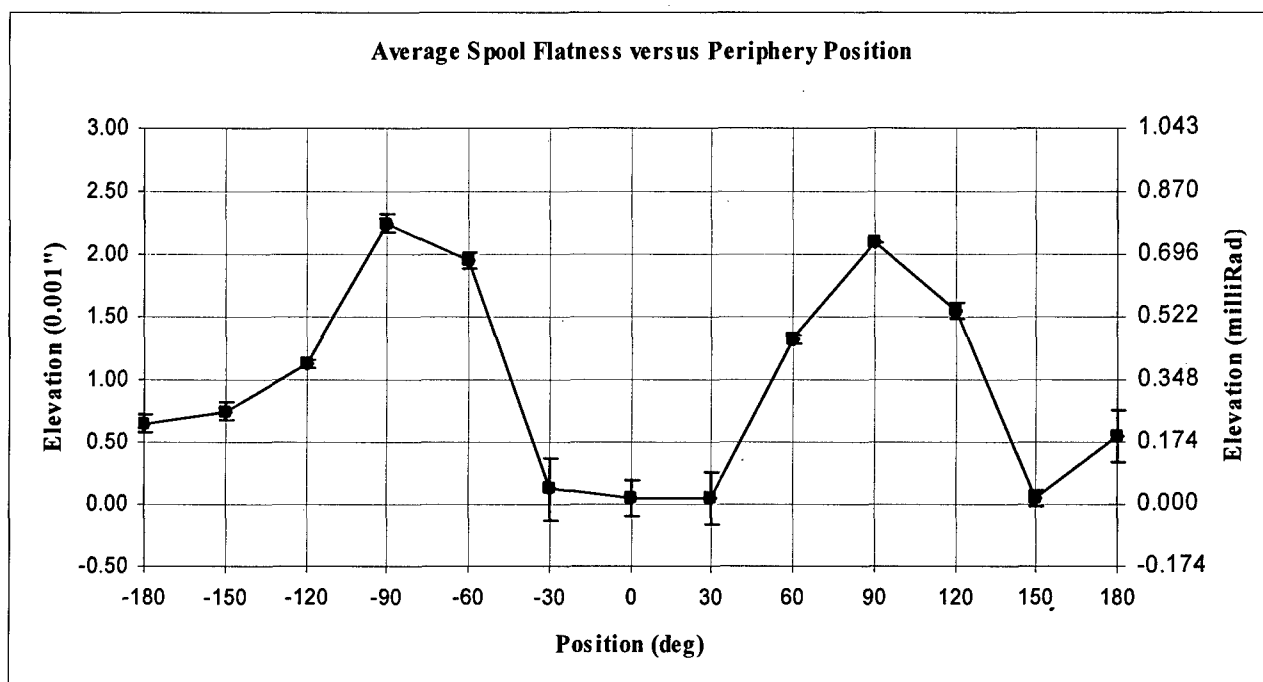


Figure 6 Average Spool Flatness versus Periphery Position

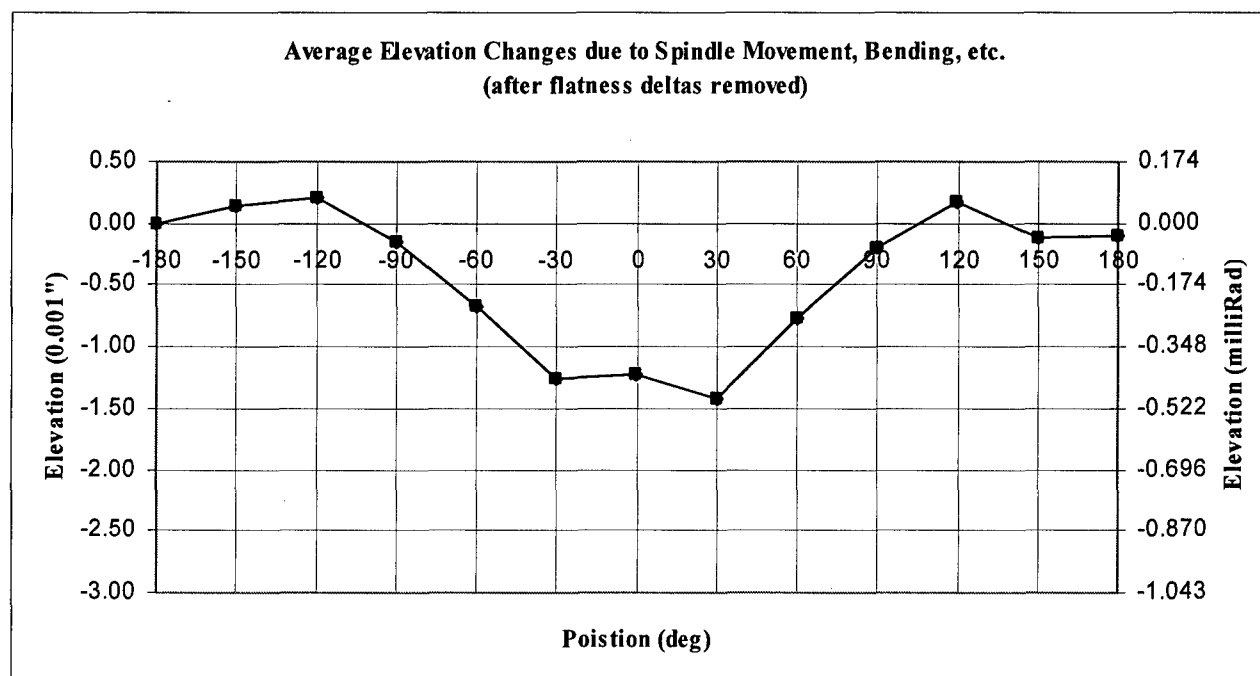


Figure 7 Average Elevation Changes due to Spindle Movement, Bending, etc. (after flatness removed)

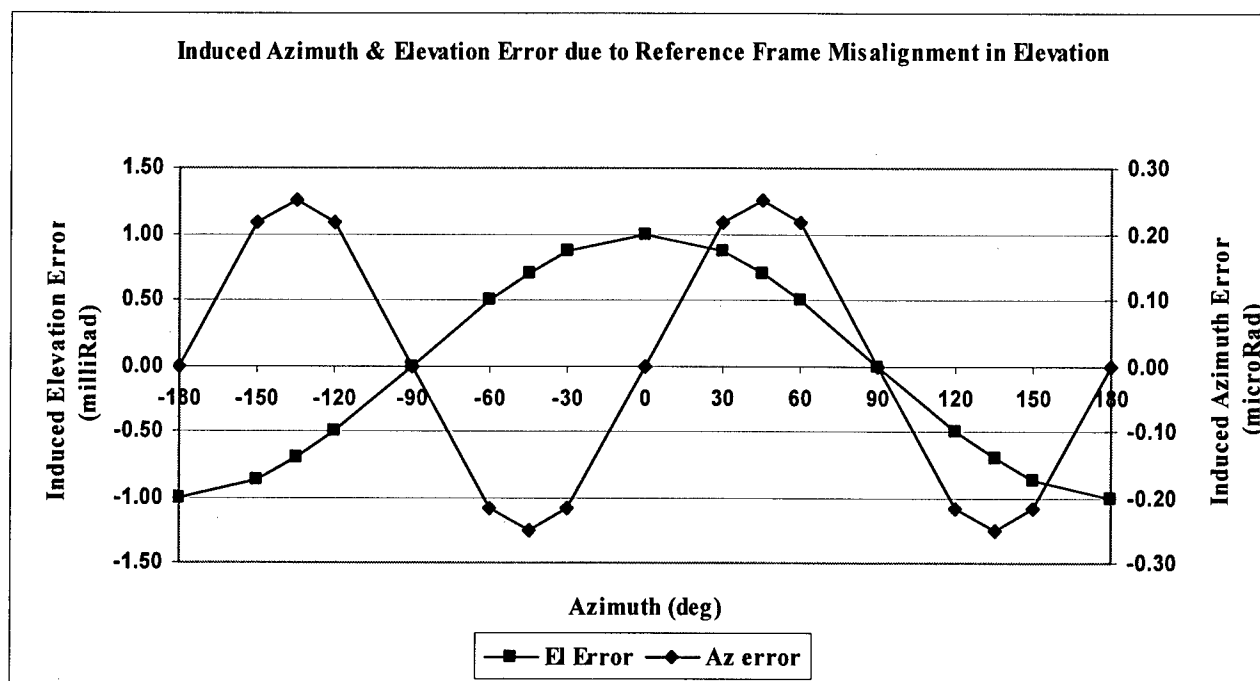


Figure 8 Induced Azimuth & Elevation Error due to Reference Frame Misalignment in Elevation

6.0 DYNAMIC CHARACTERIZATION

6.1 Determination of Head Rotation Rates

To evaluate head tracker systems under dynamic conditions, the DTTA required characterization while the spool was freely rotating. Figure 2 shows the DTTA and the tethered weight, an 8 oz brass plum bob, which provides the spool's rotational acceleration.

Before beginning the characterization of the DTTA under dynamic conditions, a maximum target rotational speed is required. In association with the Personal Protection Branch of the Human Effectiveness Directorate at the Air Force Research Laboratory, a series of experiments were conducted to determine approximately how quickly a person could rotate their head in the Z or azimuth axis.

For each experiment, the subjects wore a pilot's helmet with a 2 pound weight mounted near the visor to simulate the weight of an NVG and head tracker. Accelerometers were positioned about the helmet to collect data in the X, Y, and Z axis direction. Each subject then rotated their head several times in quick single bursts in a continual or back and forth fashion. The objective was to mimic head rotations a pilot might do while looking around inside the cockpit. A quick single burst would simulate a quick look over their shoulder or looking back and forth under surveillance conditions. The results of the experiment are shown in Table 1 below.

Experiment	Rotation Direction	R _Z (rad/sec)	R _Y (rad/sec)	R _X (rad/sec)
1	Positive	11.64	5.52	1.91
1	Negative	10.66	4.11	2.13
2	Positive	9.49	3.82	3.00
2	Negative	9.52	1.86	1.99

Table 1. Rates and head rotations when the head with helmet and 2 pound NVG ballast is rotated about the Z axis.

From Table 1, it is seen that the DTTA should rotate at 11.64 rad/sec or greater. Another conclusion drawn from Table 1 is that, although pure rotation about the Z axis was desired, there were rotations about the X and Y axis in all experimental runs.

6.2 Dynamic Characterization of the DTTA

The dynamic characterization began by elevating the DTTA to a height sufficient to allow the spool to spin 3 to 4 full rotations. These rotations allowed the tethered weight to overcome the frictional forces of the DTTA and approach a steady state velocity. Referring to Figure 9 it can be seen that there are four acceleration curves, each one increasing as read from left to right: 4.659 rad/sec, 12.843 rad/sec, 15.932 rad/sec, and 18.026 rad/sec, respectively. The accelerations are increasing as frictional forces are overcome. Several runs were made in this test and the results compared favorably.

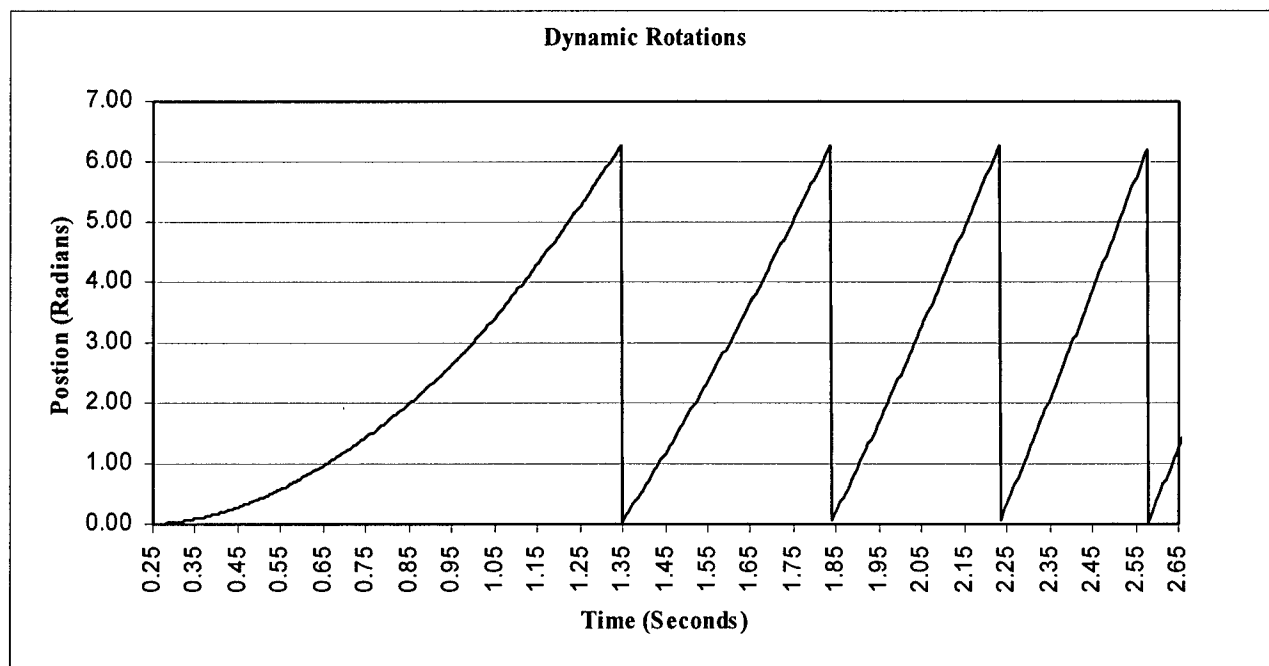


Figure 9. Dynamic Rotation of DTTF

7.0 CONCLUSION

This paper describes the construction, and characterization of a Dynamic Tracker Test Fixture for use in evaluating helmet-mounted trackers about the azimuth axis in a laboratory environment. The system can be used for very accurate static or dynamic measurements about this single axis. Depending on the tracker technology being evaluated, it may be possible to evaluate a tracker's other axes (elevation and/or rotation) by rotating the tracker element on the fixture such that, as the fixture rotates in azimuth, the tracker rotates about one of these other axis. It is further noted that, even though the dynamic forcing function is not accurately controlled, the measurements taken during the dynamic process are very accurate. Thus, comparisons can be made from measurement run to run by matching up velocities and/or accelerations. Several runs may be necessary to completely evaluate a tracker system in its entire operational envelope.

It is felt that this system offers an effective and accurate method to evaluate helmet-mounted tracker systems in both the static and dynamic environments.

8.0 REFERENCE

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