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AVERAGED DIGITAL SEXTANT (ADS) FOR FINS INTEGRATION(U)
CELENAY INDUSTRIES INC CHARLESTOWN MA F A LEUCHTER
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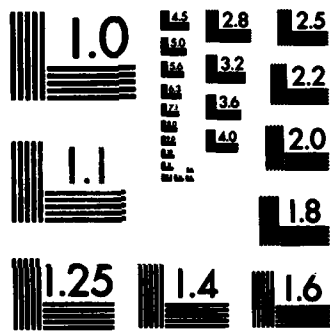
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Procuring Contracting Officer
Office of Naval Research
Dept. of the Navy
800 North Quincy St.
Arlington, VA 22271

Att: David K. Beck

9-30-82

Gentlemen:

As per the requirements of our contract I herewith submit the final report. I must apologize for the late date due to circumstances beyond our control as detailed in the report. Owing to the additional engineering and drafting necessitated by errors in materials and specifications as given, and as delivered by some subcontractors, extra time and effort had to be employed in all phases of engineering, especially mechanical and optical. CeleNav has in fact exceeded the expected expenditure by over twenty thousand dollars.

"The undersigned certifies that the level of effort described herein has been expended in performance of contract #N00014-82-C-0118".


President

I thank you for your time and patience and look forward to the Phase II effort.

Very Truly Yours


Fred A. Leuchter, Jr.
President

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AVERAGED DIGITAL SEXTANT (ADS) FOR FINS INTEGRATION

Fred A. Leuchter, Jr.
Celenav Industries, Inc.
33-25 Rutherford Ave.
Charlestown, MA 02129

20 Sept. 1982

Final Report 1 Jan. 1982 - 20 Sept. 1982

Prepared for

OFFICE OF NAVAL RESEARCH DESAT PROGRAM
Arlington, VA 22217

NAVAL SEA SYSTEMS COMMAND
Washington, DC 20362

NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974



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Figure 6. Report Documentation Page.

SUMMARY

This is the final report on the Averaged Digital Sextant for FINS Integration. The engineering model has not been completed at the time of this report due to mechanical problems with the housing and index arm assembly. However, enough has been accomplished to make a determination that the Sextant and the rotary drum encoder are completely feasible from a production stand point. The materials covered by this report include the housing and mechanical design, the problems with conventional sextant parts, the optics, the electrical design and the fabrication of the instrument and the changes made each step of the way to produce a low cost instrument. The encoder, being the heart of the instrument, is covered in the greatest detail.

Description: This final report covering work performed from 1 January 1982 thru 30 September 1982. Work performed includes:

1. Determination of instrument specifications;
2. Determination of test parameters;
3. Determination of test procedures;
4. Definition of evaluation process;
5. Engineering of model concept;
6. Engineering of model hardware;
7. Design/Drafting preliminary;
8. Final Design;
9. Re-Design of Present Sextant hardware;
10. Design changes for processing electronics;
11. Evaluation of parts;
12. Assembly;
13. Debug;
14. Evaluation of problems;
15. Remedies and recommendations for problems;
16. Final determination.

Design of Sextant Frame and Optics

Although originally proposed to use all of the standard external hardware for the optics from the Mark III Mod 1, except for the horizon mirror, it was found to be impossible because the present instrument contains many design flaws due to the fact that the basic instrument has not been redesigned since it was originally configured in the Eighteenth Century and several hundred years of copying has resulted in a quantitative errors in the angles and mounting of the optics. This necessitated a design and drafting effort beyond the original scope of the proposal to restore the instrument to its basic double reflecting design.

The angular location of the three optical elements, i. e. the telescope and index mirror and the horizon mirror, has been corrected for previous design errors by redefining the angular relationships as required in the double reflecting principle. This, perhaps, needssome explaining: apparently, since the original design of the double reflecting instrument in the Eighteenth Century when the angular relationships were first defined, subsequent designers and manufacturers simply copied the older designs resulting in 1st, 2nd, 3rd etc. generation instruments and paid no heed to the geometry of the instrument. This results in modern instruments having geometric errors in these angular relationships. Because of our requirement to relocate the index mirror, it was necessary to refigure the angular relationships and we found, on comparison with two Plath instruments, a Navy Mark III Mod 0 and the present drawings for the Mark III Mod 1, that these instruments contained design errors. It is apparently due to the fact that the precision on these instruments is 18 seconds, and never exceeds 10 seconds, that this has never been noticed. Further, it should be noted that Plath has discontinued the use of the conical sextant center bearing in favor of less expensive parallel bearing of inferior quality. We, however, will use the conventional bearing. The external optics, i. e. the telescope, the index mirror and the horizon mirror remain the same except that 1/10th wave front surface mirrors are to be used, as well as, the new centerless horizon mirror for use with a night vision telescope such as the ITT Model F4915 device. The standard mirror/glass should also be an option. As a result of the errors in the present device the engineering and drafting time was increased by over a month.

The Encoder

The encoder design as shown in U.S. Patent No. 4339178 consist of two linear gratings, one fixed and one movable, bent around an armature which is the perimeter of a circle. This approach allows for a dense linear grating, minimizing the diffraction losses of rotary gratings, to configure a low cost, highly accurate optical drum encoder.

The encoder design evolved through several iterations, from the original reflective design to the present one of transmittance.

The original design called for a reflective and a transmissive Ronchi ruling (grating) of a 450 1/mm density to be used with two LEDS, two lenses and two detectors. These gratings were originally fabracated on Corning microsheet glass in a thickness of .004", from holographic masters.

However, cementing problems caused the glass to shatter, either due to thickness of adhesive or due to uneven curing rates of the cement. After a fairly extensive research of adhesives and procedures it was determined that a mylar substrate would be less prone to damage. However, the vacuum deposition of the chrome on the mylar often resulted in damage to the mylar, because of the heat, and another approach had to be found.

It was then determined that Eastman Kodak high resolution film No. SO-343 would be suitable for this application and gratings were prepared at CeleNav of the requisite 450 1/mm density which proved quite satisfactory from a diffraction fringe standpoint.

It appears that this was the first time gratings of this density—or any functional gratings, had ever been produced from this film. The substrate for the film is Estar, a mylar material.

Unfortunately, when fabricating the reflective reference grating the heat from the vacuum deposition was also a problem, but a water jacket cooled the substrate sufficiently to eliminate damage. A large number of tests had to be made before we found the optimal deposition time, however.

The next problem encountered was that the film, due to a green dye in the emulsion, proved to dense for a reflective application and we modified thehousing for a transmissive approach.

Although transmission helped, the green dye was still a problem and it was determined that we should bleach the film to a phase grating. Phase gratings, however, are easier to obtain through other means and it was opted to make a direct holographic phase grating, rather than to bleach the film, which was state of the art a few years ago. As a result, a phase grating of photoresist on mylar was fabricated.

The original design called for a duplex grating to comprize the index (movable) grating, spaced at a $90^\circ \pm 45^\circ$ optical phase to each other, to generate a 90° electrical signal. A phase grating, however, generates a diffraction pattern in the zeroeth order which is at a 90° phase difference to the other orders of diffraction. Thus, if we use the zero and 1st orders of optical diffraction we obtain a 90° signal and no longer need the duplex grating. This also resulted in one holographic master being used instead of two: The reference grating (on the arc) and the index duplex grating (on the arm). It has also been determined through research of the definitive works on diffraction gratings, the references herewith sighted, and through extensive testing, that zero order fringes at grating densities exceeding 1500 l/p/inch are, although present, extremely difficult to see in the zeroeth order of diffraction in a transmissive Ronchi type grating. A test, using the 2 mw laser and projecting the diffracting fringes of the zeroeth order 52 feet beyond the grating surface resulted in a barely discernible fringe pattern to the naked eye.

As a result of this, CeleNav instructed American Holographic, Acton, MA our grating supplier, to fabricate a new master holographic grating of a 450 l/mm density of chrome on a $\frac{1}{4}$ " thick optically polished plate and to replicate this as a 30/30 (comparable to a 1, 0, 0, 1 ruled grating) of photo resist on mylar. After the proper photoresist thickness and exposure/processing time had been determined thru experimentation, the gratings were produced and tested by photometer to result in an equal transmission ratio of 50/50 in the zeroeth and first orders of diffraction. The result was fine gratings of even illumination and contrast for the diffraction fringes in both orders.

Throughout this time of grating development, a procedure was determined for grating installation and alignment in the instrument. CeleNav purchased a 2 mw laser, alignment hardware and constructed a specially designed optical bench to align the two gratings. By first aligning the index grating on its bracket by projecting orders of diffraction a distance from the grating onto a plumbed line and second, by adjusting the reference grating to a crossed position with the index grating within the instrument by observing maximum fringe size when the diffraction fringes are projected several feet and at 90° to the optical beam of the laser. All cementing is now done with a cyanoacrylate cement. It has also been determined that this cement dries at a speed, and occupies such little space it is the ideal cement for this purpose. The thickness of the cement being minimal between the mylar and the frame.

Since the gratings are phase gratings, only one illuminator LED and lens are required. The original lenses which were supplied along with the mirrors by Optics Plus, Santa Ana, Calif., were of the incorrect size for the original reflective or transmissive system to image the diffraction pattern for the grating. They are, however, the proper lenses for use in the new illumination and projection systems for fringes.

In the past all fringes were imaged onto detectors by relay and imaging optics placed between the gratings and the detector. A new approach is applied for this purpose. Instead of imaging the diffraction fringes from the grating, a system of projection is employed. Using a .74" focal length lens and a point source LED, a diffraction pattern is generated on the gratings by using the lens first as a collimator for the point source of 670 nm red light and second by adjusting the LED backwards and forwards as a condensing system to project the image of the fringes off the gratings, as one does with an image on film, onto the detector surfaces. This results in a 1mm fringe at 2.5" from the gratings.

Substantive testing has shown that although an optical slit of the fringe width is normally used in front of the detector, it cannot be used in this case due to the rotating diffraction pattern. In general, two gratings being run past each other generate diffraction fringes at right angles to the grating lines. However, since

the gratings are bent around a circular armature, the diffraction fringes start at right angles to the grating lines at the ends of the arc and rotate to a parallel plane at the center. The rate of rotation is directly proportional to the length of the radius.

The electronics package supplied by Control Products, Division of Devar, Inc. of Bridgeport Conn. has been modified for use with one LED and the new projection system but the detector amplifier package in the TC-99 can is physically too large to fit into the instrument at the proper focal distance, due to the 1.5 mm detector size and our 1 mm fringe size. The electronics package is functional, and if held off center in the path of the projected fringe, will count a small amount. The sensitive area of the detector must be small enough to see only one fringe or less, in order to count fringes.

A new electronics package was designed, fabricated and debugged at CeleNav utilizing two photo transistors, an inverter, a comparator and a multivibrator, and a count was established of something less than three degrees. However, mechanical problems with the housing and index arm, having plagued the instrument from the start, are now paramount in the instruments function, all other problems having been solved.

The counter, in degrees, minutes and 1/10 minutes as supplied by C-Tek of Wakefield, MA. and having been returned for redesign four times, is now functional and was used in conjunction with the Devar and CeleNav systems for test.

One final comment on the gratings before addressing the mechanical problems. Since the gratings are now phase gratings, clear, transmissive and sinusoidal in nature, and of 30/30 zero, 1st order design, gratings in quantity will be made by embossing mylar with heat and pressure from a metal plate made by electroplating photo resist on a glass master and dissolving the photoresist. The result is a negative of a sine wave, which is in fact a mirror image plate. This process should reduce the grating cost to several dollars each, making the gratings the densest and most inexpensive now available.

Mechanical Problems

Mechanical problems have been present since the instrument was first assembled. All of these problems consist of a procedural machining errors made when the parts were fabricated. They consist of two areas in which precise instructions were not followed. These problems should not exist and are presently being remedied by Hansco Industries, Inc. of Saugus, MA and its subcontractor. The problems address the spacing, parallelness and concentricity of the main bearing (sextant center), housing, index bracket. The index bracket and grating is never uniformly distant from the main frame arc, and reference grating, resulting in attrition between the grating surfaces (scratching) and wedge angle (pitch) problems. The resultant diffraction fringe pattern is not uniform over the 3" arcuate distance, sometimes not even visible, and the acuity of the fringes is affected. The fringes tend to brake up, disappear and lose contrast as one traverses the arc. Shimming and adjusting only retrieves one lost area at the sacrifice of another. Attrition of the grating surfaces results in loss of contrast, refraction through the scratches and ultimately, useless gratings.

The machining failed to follow two basic and critical instructions.

1. The index bracket must be turned as a 6" circle and then cut into the proper sized segments for bracket fabrication, the fabricator failed to do this on two attempts at the index bracket.
2. The main housing arc area must be cut after the frame is finished and the conical bearing installed, utilizing the bearing as the turning center. In the event this is done, as on conventional sextant rack-gear hobbing, a bearing which is not mounted exactly at 90 to the frame center does not cause a problem since the arc is cut concentric to the center bearing and any error in bearing mounting is compensated for by the arcuate cut being fully concentric to the bearing axis. This was not done, although requested, and suspected at the time, was not determined until the fringes were observed. If these two criteria are met when the housing and index brackets are fabricated, there will be no encoder mechanical problems.

Because we are not able to correct these problems by adjusting and shimming,

the fabricator has been requested to refabricate or repair the unusable housing and bracket, or replace the defective parts.

The refabrication of the mechanical components and reassembly of the instrument will result in working device.

Conclusion

As a result of the forgoing development, CeleNav has determined that a viable instrument can be fabricated at reasonably low cost comparable to the Mark III Mod 1 which will meet the following specifications:

Instrument Specifications for the CeleNav ADS

- A. Gearless.
- B. Digital Readout.
- C. Computer Compatible.
- D. One Second Crystal-Controlled Chronometer/Stopwatch.
- E. Observer Error Averaging.
- F. Instrument Error Averaging.
- G. Totally Self Contained Design.
- H. Ambidextrous Operation.
- I. Optical Design for 24 Hour Operation (Night Vision Compatible).
- J. Optical Design Compatible with Bubble Horizon.
- K. Weight, with Telescope 3 lbs. 8 oz.
- L. System Resolution within 6 Arc Seconds.
- M. Accuracy of Instrument and Observer Error-Averaging Circuitry is 3 Arc Seconds with a Sample Rate of 0.5 Seconds.
- N. Encoder Precision $\pm$ 3 Arc Seconds.
- O. Sight Reducing and Position Reading.

The optical drum encoder will consist of two 450 1/mm 30/30 phase gratings of inexpensive mylar bent around two circumferences of almost identical radii, a single LED and lens combined collimating, condensing and projection system and two photo detectors looking at zeroth and first orders of diffraction. The electrical information generated by the two detectors will be processed into a

and direction level signal to be counted in an up/down counter.

ure and Standards

turntable-collimator system shall be used to determine sextant
The turntable shall be calibrated with standards traceable to the
reau of Standards and indicate an accuracy of 3 seconds or less.
xtant mirrors are adjusted, the angular precision of the sextant
etermined at 15° increments from -5° to +95° and at 1° increments from
further that the angular precision be determined at 10 minute
etween 45° and 46° and at 6 second (0.1 min.) intervals between 45°
45° 40 minutes. At least three sets of inclination and three sets of
readings shall be run for each position tested. The average difference
ination and declination runs shall be calculated.

otics shall remain the same as on the Mark III Mod1 except as noted:
ors shall be first surface aluminized with a quartz overcoat on a
of fused quartz and increased in thickness by 1.9 mm. The change
al and increased thickness is to guarantee the dimensional stability
h wave capability.

ion mirror shall be of centerless design to optimize use with night
struments.

or mounts were redesigned to accomodate the increased thickness
ew location of the index mirror which had to be moved relative to
nt center because of the first surface design.

period of endeavor extensive meetings were held with Naval
t the Washington Navy Yard, Standard Laboratory, CeleNav Industries,
, MA; meetings were also held between CeleNav and its sub-
at CeleNav's offices and at the subcontractors, Control Products,
Devar, Bridgeport, Conn. , Hansco Industries, Saugus, MA, American
, Acton, MA, and Optics Plus, Santa Ana, Calif. A joint research
Digital Sextant was given by P. Kenneth Seidelman, Director of the
ice U. S. N. O. , Mr. Sidney Feldman, Physicist Naval Surface

Weapons Center, White Oak, MD, and Fred A. Leuchter, CeleNav Industries, at the Institute of Navigation 30th Annual Meeting, Airforce Academy, Col. Springs, Col.

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