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## Application Strategy Analysis of Hull Deformation Data of Aerospace Survey Ship

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# Application Strategy Analysis of Hull Deformation Data of Aerospace Survey Ship

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**Abstract.** This paper briefly introduces the error source of the measurement data of the deformation equipment. Taking the existing measurement data as an example, the influence of the deformation data on the measurement elements and the orbit determination results of the main measurement equipment is calculated and analyzed. A large amount of data was analyzed to find out the variation law of the deformation data, and the threshold principle of the deformation data was determined.

## 1. Introduction

The measuring equipment of the measuring ship is usually fixed on the hull deck in the longitudinal direction of the stern line. [1-3] The distance between the equipment is more than 10 meters. Since the hull is not a rigid body, it is affected by internal and external forces such as loading, wind, current, tide, etc. Distortion and elastic deformation are generated such that the coordinate system of the measuring device is not parallel to the corresponding axis of the inertial coordinate system, and there is an angular error. [4] This paper introduces the error source of measurement data of deformation equipment, and discusses the influence of deformation constant or actual measurement value and the variation law of deformation data itself.

## 2. The effect of deformation data in two cases

### 2.1. *The influence of deformation data on the elements in two cases*

Using the data of a certain working section A1-A4 of a measurement ship A task (near-field near-circular orbit), the data processing is performed by using the rapid evaluation software, and the simplified correction model is adopted for the radio wave refraction correction. [5-6] The effects of the measured statistical constants and measured data provided by the equipment side on the measured data are analyzed. Table 1 shows the difference in the alignment of the inertial navigation system in both cases.



**Table 1.** Two cases of measurement element comparison error statistics (measured - constant value)

Circle	Device	Ranging R(m)			Elevation angle E (")			Orientation A (")		
		Total error	Mean	Random error	Total error	Mean	Random error	Total error	Mean	Random error
A1	S1	0.001	0.000	0.001	3.6	-1.32	3.36	4.32	2.64	3.42
A2	S1	0.002	-0.001	0.001	5.04	-4.26	2.70	2.10	1.44	1.50
A3	S1	0.006	-0.005	0.001	7.32	-7.14	1.68	1.38	-0.48	1.32
A4	S1	0.004	-0.003	0.002	7.38	-6.78	2.94	2.40	-1.98	1.38

### 2.2. The influence of deformation data on orbit determination in two cases

Table 2 shows the difference in orbit improvement results in both cases. Table 3 shows the difference in the determination results of the single-turn track in both cases.

**Table 2.** A series of tasks external test data test track improvement results (measured - constant value)

Circle	Maximum elevation angle (degrees)	$\Delta a$ (KM)	$\Delta e$	$\Delta i$ (°)	$\Delta \Omega$ (°)	$\Delta \lambda$ (°)
A1	65.8	0.0	0.0	0.00004	0.00005	0.00038
A2	16.6	0.001	0.0	0.00004	0.00005	0.00028
A3	8.1	0.001	0.0	0.00004	0.00005	0.00022
A4	12.2	0.002	0.000002	0.00004	0.00005	0.00013

**Table 3.** A series of tasks external test data test single circle orbit determination results (measured - constant value)

Circle	Maximum elevation angle (degrees)	$\Delta a$ (KM)	$\Delta e$	$\Delta i$ (°)	$\Delta \Omega$ (°)	$\Delta \lambda$ (°)
A1	65.8	0.340	0.000049	-0.00089	-0.00127	0.00661
A2	16.6	-0.058	0.000004	-0.00017	-0.00083	-0.00094
A3	8.1	-0.131	0.000012	0.00015	0.00018	-0.00058
A4	12.2	-0.108	0.000013	0.00008	0.00026	-0.00288

### 2.3. Analysis of deformation data impact in two cases

As can be seen from the above table:

a). The data processing adopts the deformation constant value or the measured value, which has little influence on the value of the ranging, and the magnitude is the meter level. In both cases, the total error of the angular comparison is less than 10 arc seconds.

b). The unicyclic data orbit determination results show that the difference between the two cases is relatively large, and the effect of the semi-major axis is on the order of kilometers (less than 1 km).

c). Track improvement results, the difference between the two cases is small. The semi-major axis varies at the meter level, the amount of change in  $e$  is  $10e-6$ , and the amount of angle varies from  $10e$  to  $5$  degrees.

Note: The above conclusion is a discussion of the type of near-earth near-circular orbit of the new ship A series. The constant value of deformation is the statistical constant value provided before the equipment end task.

### 3. Deformation angle error source

There is hull deformation between the measuring devices, so that the corresponding axes of the measuring coordinate systems of each device are not parallel, and deformation correction must be performed to eliminate the systematic error caused by the deformation. Deformation measurement data is usually measured in three angular quantities: stem  $K$ , vertical, and  $\Theta$ . The angular error is mainly composed of the following error sources:

(a). Quantization error

For self-aligned measuring tubes, the quantization error is CCD pixel width / 2 times focal length. Align the straight measuring tube, the quantization error is the pixel size / focal length.

(b). Temperature drift error

After the measuring light tube is energized, the CCD driving and amplifying circuit and the bromine tungsten lamp generate a certain amount of heat, and the heat will cause the measured value to drift.

(c). Installation error

Due to the error in assembly, the slits in the measuring light pipe are not perpendicular to the respective measuring directions. Since the deformation is a spatial effect, the CCD also has a displacement relative to the center of the slit, which causes a coupling error of the measurement. Assuming that the slope of the slit is  $\beta$  and the measured angle of view is  $\pm\omega$ , the maximum coupling error is  $\delta_{\max} = \pm\omega \times \tan \beta$ .  $\beta$  is caused by the adjustment error of the slit in the light pipe and the mounting error of the light pipe on the ship.

(d). Calibration error

(e). Lamp replacement error

The service life of bromo-tungsten lamps is limited and needs to be replaced in long-term use. Despite the consistency measures, the test proved that changing the bulb still caused the measurement to be non-repetitive.

(f). Ghost error

Due to the presence of planar optical components in the measuring tube, internal reflections, ie ghosts, are caused during the transmission of light. At a specific location, the ghost image is superimposed on the photoelectric signal, causing measurement errors.

(g). Dynamic error

The ship swing is basically sinusoidal, and the deformation is also sinusoidal. Therefore, there is a relative motion between the slit image falling on the CCD and the CCD device, and the CCD device pixel data needs to have an integration time, thus generating Dynamic error.

Among the above seven errors, the first term is an equal probability distribution; the second and fifth terms are Gaussian distribution; the third and fourth terms are Gaussian distribution and inverse sinusoidal distribution; and the sixth and seventh terms are inverse sinusoidal distribution.

### 4. Change law of deformation data

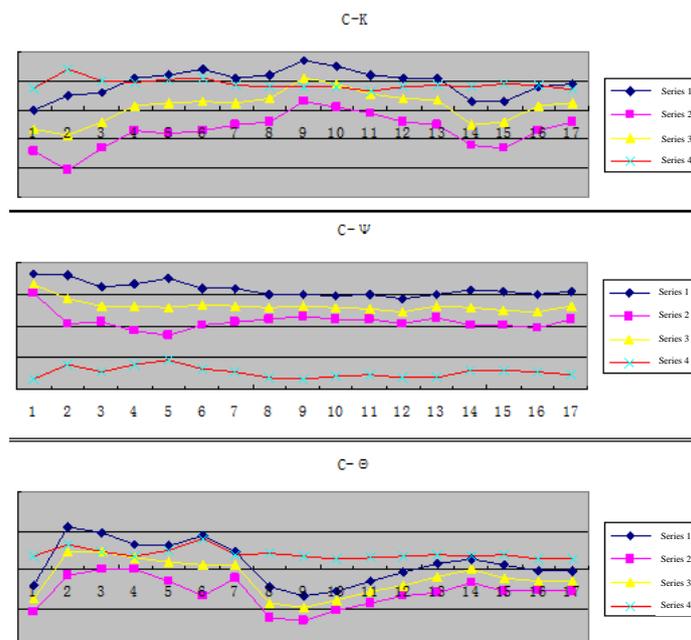
#### 4.1. . Change in deformation data

The maximum and minimum values of the measured data of the A series and the B task are counted, and CK, C- $\Psi$ , and C- $\Theta$  respectively represent the bending, longitudinal and transverse twisting of the deformation C, DK, D- $\Psi$  D- $\Theta$  indicates the deflection, longitudinal deflection, and transverse twist of the deformation D, respectively. Combined with content 3 and actual combat experience, the deformation measurement data is affected by factors such as temperature, swell, and ballast distribution. Due to environmental constraints, Table 4 only describes the measurement point location, swell height, and statistical data points for the task arc.

**Table 4.** Mission brief

Number	Number of data points	Surge	Data measurement date
1	7200	1.0~1.5 m	X1
2	18000	1.5~2.0 m	X2
3	17660		
4	7300		
5	17480		
6	9520		
7	7820	1.0~2.0 m	X3
8	8600		
9	8920		
10	7640		
11	7520		
12	9420	1.0~2.0 m	X4
13	9620		
14	10220		
15	9620		
16	7360		
17	9340		

The data statistics of the deformation C and deformation D of the above 17 task arcs are respectively plotted. In Fig. 1 and Fig. 2, curve 1 indicates the maximum value of the data, curve 2 indicates the minimum value of the data, curve 3 indicates the mean value of the data, and curve 4 indicates the mean value of the data. The maximum amplitude of the data relative to the mean change.



**Figure 1.** Numerical statistical trend graph of deformation C (C-K, C-Ψ, C-Θ) of a survey vessel

#### 4.2. Analysis of the variation law of deformation data

As can be seen from the above figure:

a). The variation laws of the maximum, minimum and mean values of the deformation data are basically the same. The data changes in Figures C-K and C-Ψ are relatively stable. The data changes in the C-Θ, D-K, D-Ψ, and D-Θ segments (2 to 7 points, 8 to 13 points, and 14 to 17 points) are relatively stable, and the segments belong to the same day.

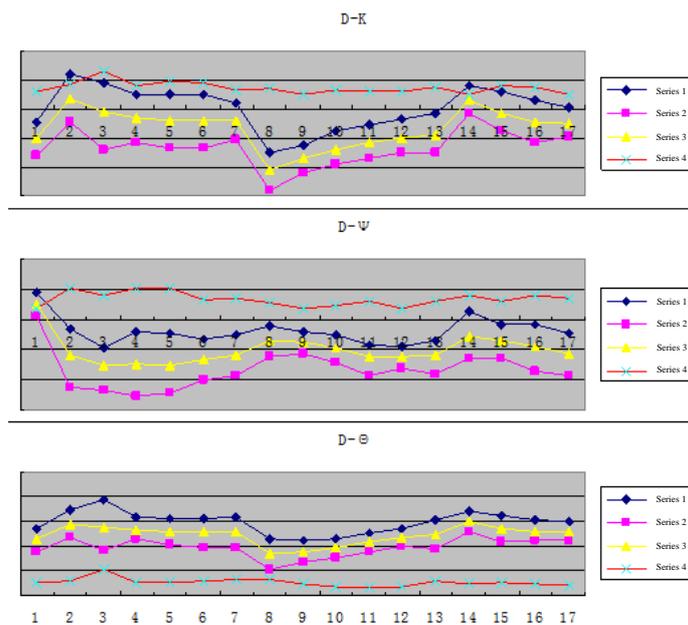
b). The maximum, minimum, and mean values of the deformation data are all varied. The observation data of the same deformation has different maximum amplitudes of relative mean values in different task arcs.

#### 4.3. The phenomenon that affects the use of deformation data

The following situations usually affect the use of deformation measurement data:

- The deformation data time code is not continuous;
- The deformation data status code is not normal;
- The deformation time code is continuous, the status code is normal, and the measurement data has a large number of jumps.

At the same time, affected by the stability law of the deformation equipment itself, long-time start-up, ship maneuvering, slamming and so on will affect the stability of the equipment.



**Figure 2.** Numerical statistical trend graph of deformation D (D-K, D-Ψ, D-Θ) of a survey ship

#### 4.4. in conclusion

In view of the above reasons, it is recommended that the new generation of measurement vessels determine whether to use the measured data according to the working state of the equipment according to the type of measurement and control tasks performed. If the measured value of the deformation is used, firstly, the maximum variation amplitude of the deformation constant value and the relative average value is respectively calculated in the task sea area, and then the threshold replacement value is determined. It is recommended that the threshold substitution value be taken as  $\text{Average} \pm K \cdot \text{Max} |\Delta X|$ .

## 5. Conclusion

It can be seen from the above research results whether the influence of the measured values on the angle measurement data of the equipment is relatively large. Since the statistical mean value of the deformation data is constantly changing, but the amplitude change of the relative mean is relatively stable, the deformation threshold can be effectively determined as the precision threshold value to prevent the catastrophic consequences caused by the large number of measured data jumps, such as an antenna. Flying cars, etc.

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