B. KRASAVCEV. “INSTRUMENTS AND METHODS OF NAUTICAL ASTRONOMY”, 1972

CHAPTER II

NAVIGATIONAL SEXTANT AND OTHER ANGLE MEASUREMENT INSTRUMENTS, CURRENT SITUATION AND PERSPECTIVS OF DEVELOPEMENT

§3. ERORRS AND CORRECTIONS OF NAVIGATIONAL SEXTANTS. SEXTANT SNO-T

Currently marine and commercial fleet is equipped with sextants SNO-M, made in our country, and also with older models SN, SNO, SNO-2M. The industry shifts to production of a new model SNO-T, but the older models will be still in use for a long time.

Let’s take a look at the main sourcies of so called instrumental errors of the sextants with micrometer according to research of Admiral’s S. Makarov Departement of Astronomy.

The errors caused by inaccuracies during manufacturing of the the rack

The main source of the errors of the most part of the sextants (both new instruments and used ones) are caused by systematic inaccuracies during the process of manufacturing of the rack. The only exception is vernier sextants (such models are being made in England) and the sextants with optical reading system (made in East Germany). These sextants have significantly less errors in the scale division engraving.

The rack errors may reach 1,0’ and this error complements other errors, mainly those caused by eccentricity (Fig.4.), as a result the total error of the models made before 1965 may reach 1,5’-2,0’, but the errors of the newer models are 0,5’-0,8’. Experience has showed that the rack engraving errors can change significantly after 5^{o}, therefore the error values are now printed in the sextant certificates with increments of 5^{o}.

The main reason of the errors of the rack — the low quality of manufacturing and imperfect design of the gearing between the rack and worm. These errors are greatly reduced in the design of the sextant SNO-T.

It is worth to mention that foreign sextants also have these errors (sometimes they reach 0,5’), but usually these errors are not reflected in the certificates.

Parallel to systematic errors, the worm/rack gear induces random error, which varies after repeating the measurement of the same angle. This error typically is in range ±0,2’, but old, used up sextants may show even unacceptable ±0,5’ error. This is reason why all the sextants should be tested periodically and rejected, if the errors are out of the limits. For sextant SNO-T this error is typically ±0,1’.

The errors caused by eccentricity of index arm

The eccentricity arrises from the offset between the axis of the index arm and the center of the main arc, from which the readings are taken.

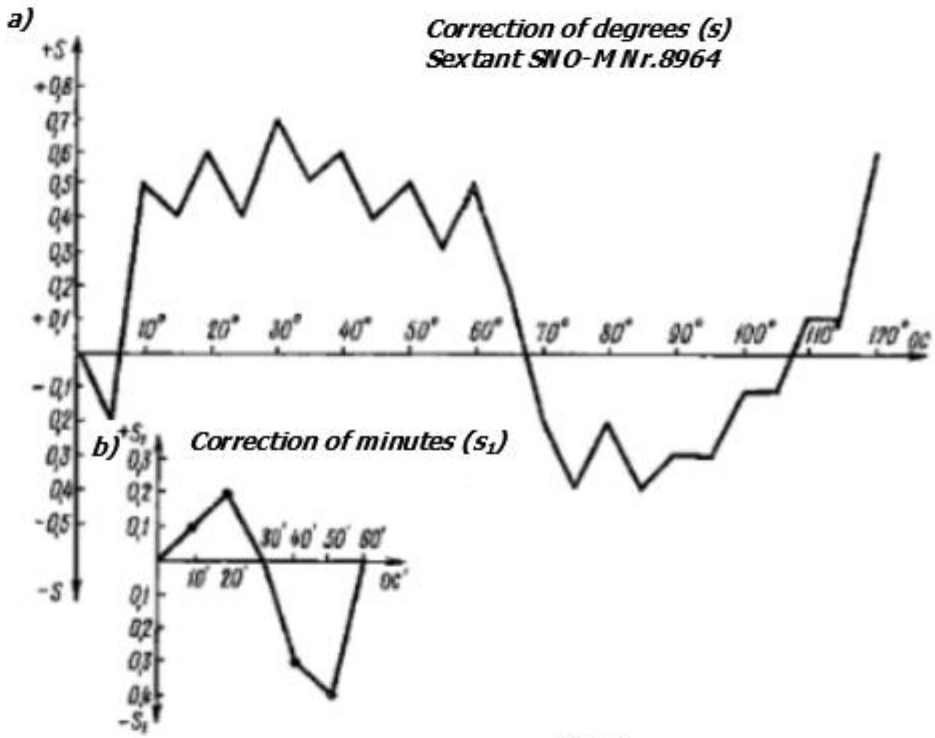


Fig. 4

The eccentricity can be carracterised by direction P and value e_{MM} of the offset. The last mentioned value can be substituted with angular value

$$\varepsilon'' = \frac{e_{MM}}{R \operatorname{arc} 1''},$$

where R — radius of the main arc.

Correction caused by eccentricity can be calculated using following formula:

$$\Delta h''_{э} = 2\varepsilon''\left[\sin\left(\frac{oc}{2} - P\right) + \sin P\right], \qquad (6)$$

It can be seen from this that the correction value increases with the angle.

The investigation of the sextants reveals that new SNO-M sextants has small errors from eccentricity, but older models has significant errors. These errors of eccentricity are acting together with errors of the rack (Fig.4,a). About 30% of sextants does not have considerable error of eccentricity. Still some instruments show such an error over time as a result of impacts or damage of index arm axis. Instruments of such kind should not be used. The sextant SNO-T does not have considerable error of eccentricity.

Errors from prismaticity of index mirror

A prismaticity (or wedge-shaped form) is unparallelity of the front and back surface of the index mirror; an angle between these two surfaces is called the angle of wedge. As reflecting surface of the mirror is the backside, the prismaticity causes an additional error which becames larger by increasing the angle. The prismaticity induces doubling the reflecting image when the measured angle is large. Instruments of such kind should not be used. The mirrors of the sextant SNO-T are with front reflecting surface, therefore these instruments does not have this sort of error.

Instrumental correction s

Errors of rack, eccentricity and prismaticity acts together and therefore they are evaluated together as total correction *s* —instumental correction of the main arc; it is printed in certificate for the angles after each 5^o.

Errors caused by inaccuracies of engraving and position of tangent screw

The tangent mechanism has worm gear which makes it possible to read fractions of degree of measured angles—minutes and fractions of minutes. These values are proportional to the turning angle of the worm.

If there is so called “cyclical error” in the worm gear the angle of the drum turning wont’t be proportional to the movement of the index arm and as a result there will be an additional error in minutes reading.

The research on this has showed that this error is typical for sextants SN and other older models (the error value can reach 1,0’). For sextants made after 1965 this error is not more than 0,5’ (Fig.4,b). The error of this kind is typical also for the most part of the foreign sextants like “Plath”, etc. This error is not common for the instruments made in Eastern Germany and also for the sextant SNO-T.

To get exact values of these errors the sextant should be tested on special verification device. The correction values s_1 can be measured with angle increments of 10’. This value s_1 must be added to the correction of the main arc *s*.

This error is the reason why the index correction obtained from the Sun (i_{SUN}) differs from the correction value obtained by observing a star (i_{STAR}). Indeed $i_{STAR}=360^o-oi_{STAR}$, where oi_{STAR} contains only the correction of the main arc at 0^o. But observations for index correction by the Sun contains readings around 30’, therefore micrometer error s_1 around 30’ should be applied. Only then $i_{SUN}=i_{STAR}$:

$i_{SUN}=360^o - ((oi_1+s_1)+(oi_2+s_1))/2=360_o - oi'_{av} - s_1$ (7)

or

$i_{SUN}= i'_{SUN} - s_1=i_{STAR}$ (8)

where

oi'_{av} — average reading without corrections;

i'_{SUN} — index correction obtained from the observations of the Sun by common methods;

s_1 — corrections taken from the certificate at 30'.

As it can be seen the correction i_{SUN} should be corrected according to angles close to $0^o30'$ (or $359^o30'$), not for 0^o; but i_{STAR} is referable to correction value at 0^o. If the correction value of micrometer error is not known and it is impossible to apply it according to formula (7), it can be used such a strategy:

-index correction by star is used when the measured angle is close to full degrees, for example oc=$28^o7,4'$ etc.;

-index correction by the Sun is used when the measured angle's minutes are close to 30', for example oc=$28^o37,4'$.

An approximate value of the correction s_1 at 30' can be calculated using formula (8).

Wedge shaped form of shades

It happens when the surfaces of the shade glass are not parallel thus causing additional error in readings. According to technical rules non-parallelism should not exceed 10", then final error in the readings won't be larger than 0,1'. The results of research reveals that most of the shades does not have noticable error. Only 1/3 of shades causes errors in range 0,2'-0,3'; only in some extreme cases this error may reach 0,6'. Such shades should be replaced after testing on special device.

It should be noted that the colours of the shads (blue, red) are bad choise because sometimes makes observations difficult. There are no shades that improves contrast of the horizon (for example, orange colour). The same disadvantages can be refered to the new sextant model SNO-T. The wedge shaped form of the shades, skewness and sometimes covered surfaces with dirt causes so called "fake Sun" effect, and this makes observations more difficult. In such a situation one should clean shades and look for skewness. If the "fake Sun" does not disappear, it means that one (or multiple) shades are wedge shaped and they should be replaced.

Backlash

It is a difference in readings when measuring a constant angle initially turning micrometer drum in one direction an then in other. Besides typically there is no noticable free movement.

According to the results of the research the following typical distribution of the backlash error has been found:

Backlash value	0-0,1'	0,2'-0,5'	0,6'-1'	1,1'-1,7'
% of sextants	18	64	14	4

Usually used sextants have large backlash errors, therefore during observations it is recomended to do following steps. Experience have showed that backlash is constat for all angles, therefore the user should always turn micrometer drum in one direction – in direction of increasing angle; this should be done during the observations and as well during index correction check. The same method is used on the test devise to get value *s*.

Measuring instrumental corrections on the verification device

Some foreign firms, VEB (East German) and Plath (West German), are producing verification devices, which are almost identical, differencies may be found only in details. The best one is the device from VEB (Fig.5). The device consists of following parts: reference circle with accurate divisions 5, reading device 1, platform and console 3 for fastening the sextant which is to be calibrated, colimator 4 in which image of a distant object can be seen, telescope 2, and lighting system 6.

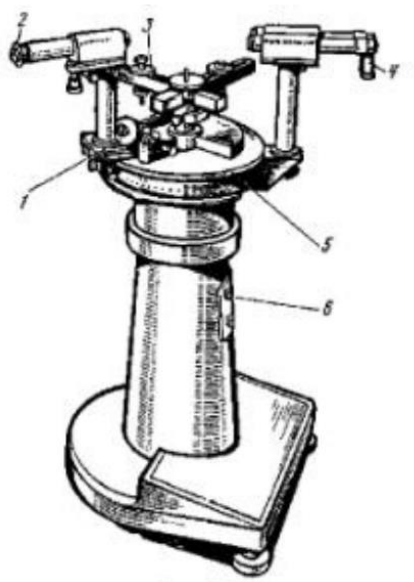


Fig. 5

Adjusted and oiled sextant is mounted in the center of the device. By turning the micrometer drum in one direction sextant is positioned on angle values 0^o, 5^o, 10^o, 15^o etc. These angles are compared with accurate angle values from verification device. As a result it is possible to get *s* values with according signs. Each angle must be measured several times and then the average value is obtained.

The correction of the micrometer is obtained in the same way. The backlash is checked on this device as well.

Devices like above mentioned should be availabe at every shipping company, but at present time they are available only in some specialised departaments and also in foreign harbors.

The sextants should be tested periodically in laboratory because the corrections *s* cant't be obtained on board of the ship (method of Star distances is not wildly used by navigators).

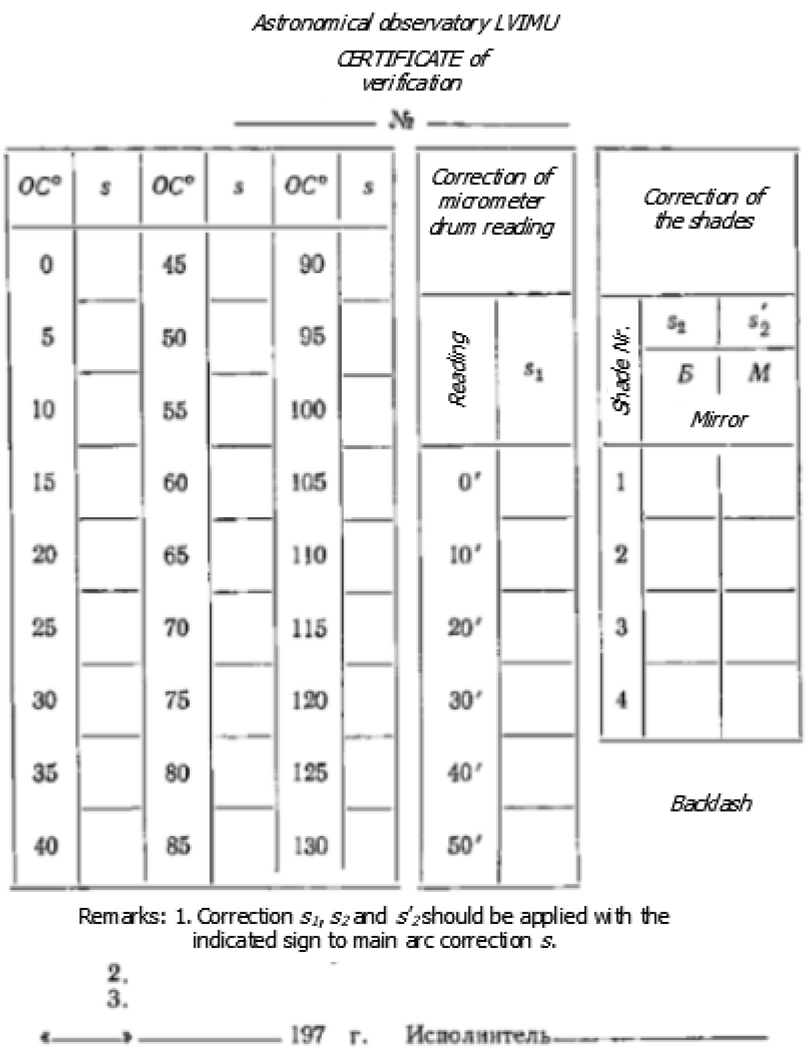
The corrections *s* and s_1 are recorded in certificate book of the sextant or in special form offered by the verification departament (example can be seen in Fig.6). The total correction for the given angle s_o can be derived by combining two components — one for degrees, other for minutes of degree:

$s_o = s + s_1$

This value is used to correct the observed angle *oc*.

The change of corrections during time

Repeated investigation of the sextants during time period from 1 to 3 years reveals that change of the correction *s* is smaller than 0,3'; and never exceeds 0,5'. The correction s_1 typicaly does not change more than 0,1'-0,2'. There are some individual cases when the rack is damaged and as a result the correction's *s* value has changed up to 1' in some intervals of the main arc. After 5 years of use large changes in correction values becomes more frequent. This is reason why it is recomended to repeat the tests after every 3 years; the tests should be performed also in cases when sextant is damaged.



Astronomical observatory LVIMU

CERTIFICATE of verification

______ № ______

OC°	s	OC°	s	OC°	s
0		45		90	
5		50		95	
10		55		100	
15		60		105	
20		65		110	
25		70		115	
30		75		120	
35		80		125	
40		85		130	

Correction of micrometer drum reading

Reading	s_1
0'	
10'	
20'	
30'	
40'	
50'	

Correction of the shades

Shade Nr.	s_2	s'_2
	Б	M
	Mirror	
1		
2		
3		
4		

Backlash

Remarks: 1. Correction s_1, s_2 and s'_2 should be applied with the indicated sign to main arc correction *s*.

2.

3.

«___» ________ 197 г. Исполнитель ________

Fig.6

Short conclusions and recomendations

1. The sextants SNO-M should be tested every 3 years and also after damages. It is recomended to organise testing departaments under the management of shipping companies.

2. The rack of the sextant should be cleaned with stiff brush periodically and then oiled, after these operations the micrometer drum should be turned continously covering all the range of the angles from 0^o to 120^o. The rack should be protected from impacts, dust, ice etc.
3. It is necessary to know that micrometer may have systematic error and this must be taken into account as a correction which is to be applied to measured angle *oc*.
4. When index correction is derived from the Sun, correction of the micrometer should be applied to each reading. To avoid appling additional correction, index correction should be derived from observations of the Star.
5. The angle measurements should always be measured by turning micrometer drum in the direction of increasing angle. The same rule must be considered when the index correction is measured. In this case the effect of the backlash will be minimal.

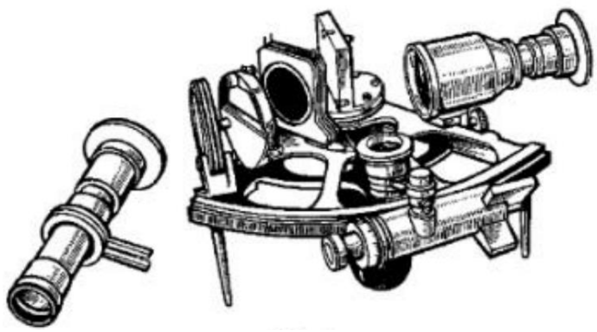


Fig.7

Sextant SNO-T

Starting with 1972 our contry's industry will produce a new model of sextant SNO-T (navigational sextant with illuminator, tropycal). The first prototypes (Fig. 7) were tested in 1970 and the results approved the high quality of these instruments. The main features of the new model: improved quality of the metal for manufacuring the frame and the details, altered the shape of the frame and the axis of the index arm (index arm is moving inside the frame), mirrors are with frontside silvering, shads have been changed, attached two telescopes of new design. The wight of the sextant is 1,3kg, the range of angle measurement 120^o, instrumental correction less than 0,3'-0,4', accuracy of readings 0,1', backlash 0,1'-0,3'. The error in measured altitude of the Sun ε_{oc}= ±0,3'-0,4'; the error in measured atlitude of the Stars: ±0.5'.