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FLEXURE OF THE BELGRADE LARGE VERTICAL CIRCLE IN THE PERIOD 1976–1980

M. Mijatov and V. Trajkovska

Astronomical Observatory, Volgina 7, 11050 Belgrade, Yugoslavia

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SUMMARY: In the present paper an analysis of the variations in the flexure of the Large Vertical Circle of Belgrade Observatory between 1976 and 1980 is given.

The examinations show a very prominent temperature dependence a significant variation during an observation night, and a dependence on observers and on quality of measurements; no dependence on meteorological parameters such as the pressure and humidity, as well as on weather conditions under which the measurements were made (cloudiness, wind, etc.) was found. Seasonal variations, being most prominent during the autumn season, are found.

The most important systematic influences are collimator displacement and the tube refraction.

The accuracy of the flexure determination is $\epsilon_b = \pm 0''.22$.

1. INTRODUCTION

During the period 1976–1980 together with the compilation of the Absolute Declination Catalogue of 308 Bright Northern Stars (declination zone +65° – +90°) on the Large Vertical Circle (LVC) of Belgrade Astronomical Observatory, the fluxure determination with collimators (d = 80 mm, f = 1000 mm) situated horizontally east and west of the instrument was carried out. The preliminary results of these determinations (including measurements carried out by October 1979) were published by Mijatov and Bozhichkovich (1982).

In the present paper the results of the deterination including the whole period are given and an analysis of the flexure dependence on observers, weather conditions under which the measurements were made, quality of the measurements, variations during an observation night, as well as on seasonal variations,is carried out.

2. OBSERVATIONAL DATA

In the period from March 1976 till the end of 1980 a total of 263 flexure determinations were realised. They were done almost every observation night when observations for the Catalogue were performed, and during a few nights only the flexure was measured. Before the beginning of every determination the internal temperature and the humidity were measured, whereas the pressure was measured at the beginning and the end of the observation night. The atmospheric conditions (clearness, wind etc.) were noted, too.

In Table 1 the number of flexure determinations regarding to observers and the year of determination is given.

In the columns with two observers the first one was setting the collimators and also was setting the telescope to the collimators and the second one was reading the

Table 1

Year	OBSERVERS: MM, DB	DB	MM, BK	MM,MD	MM	DT, BK	BK	Total
1976	–	–	10	9	5	3	2	29
1977	84	–		–	–	–	–	84
1978	25	31		–	–	–	–	56
1979	38	28		–	2	–	–	68
1980	16	10		–	–	–	–	26
1976–1980	163	69	10	9	7	3	2	263

OBSERVERS: MM – M.MIJATOV, DB – DJ. BOŽIČKOVIĆ
BK – B. KUBIČELA, MD – M.DAČIĆ, DT – DJ. TELEKI

circle and the levels. The duration of a series was about 20 minutes when two observers were working and about 30 minutes when there was only one observer.

Unlike the other years in 1976 the flexure was determined by many observers with a small number of determinations. This circumstance, as it was found later on has significantly reduced accuracy.

In Table 2 the number of flexure determinations distributed by the seasons is presented.

The major part of determinations, as seen from Table 2, was performed during springs or summers.

In Fig. 1 the flexure values b_i measured during the observation period are presented.

Table 2

Year	MONTHS				Total
	I–III	IV–VI	VII–IX	X–XII	
1976	–	16	13	–	29
1977	22	34	26	2	84
1978	3	6	36	11	56
1979	13	24	18	13	68
1980	4	7	–	15	26
1976–1980	42	87	93	41	263

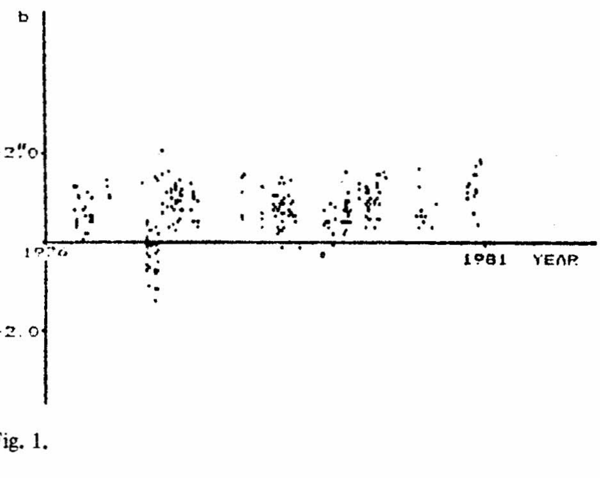

Fig. 1.

The values b are within the limits $-1.''3$ and $+2.''1$, but they are mostly positive. The values b corresponding to the first falf of 1977 are mostly negative, thus the flexure in that year was anomalous compared to the other years.

The temperature range was between $-7.8^{\circ}C$ and $+24.5^{\circ}C$.

3. DETERMINATION ACCURACY

The random error of a single flexure determination ϵ_b is obtained from the difference of two successive determinations b_{EW} and b_{WE} during a single series of measurements.

In Table 3 the mean systematic differences $\overline{\Delta b} = \overline{b_{EW} - b_{WE}}$ and ϵ_b are presented. The latter one is calculated according to the relation

$$\epsilon_b = \pm\, 0.625 \frac{\sum_{i=1}^{n} \text{abs}\,(\Delta b'_i)}{n}, \tag{1}$$

where $\Delta b'_i$ – are the values $(b_{EW} - b_{WE})_i$ released from the mean systematic difference $\overline{\Delta b}$ from Table 3 and n – is the number of differences.

Table 3

Year	$\overline{\Delta b}$	ϵ_b	n
1976	$+0.''06 \pm 0.''15$	$\pm 0.''37$	29
1977	$+0.14 \pm 0.06$	± 0.24	84
1978	$+0.09 \pm 0.05$	± 0.20	56
1979	$+0.12 \pm 0.04$	± 0.17	68
1980	$+0.09 \pm 0.06$	± 0.14	26
1976–1980	$+0.11 \pm 0.03$	± 0.22	263

As seen from Table 3 the measurements performed in 1976 are well below the necessary accuracy and this is a consquence, as has been already said, of a large number of observers with a small number of determinations. In the other years the accuracy is at the accuracy level obtained by applying this method on meridian isntruments of similar characteristics. Increasing of the accuracy from year to the year may be attributed to the increasing experience of observers. The accuracy for the whole period is $\epsilon_b = \pm\, 0.''22$ and if the year 1976 is excluded the accuracy is $\epsilon_b = \pm\, 0.''19$. The existence of the systematic difference Δb demonstrates primary that a displacement of the collimators was present (Mijatov, 1971–1972).

4. ANALYSIS OF THE DATA

Soon after the first considerations of the observational material it was clear that a prominent dependence of the flexure on the temperautre exists. This dependence is presented in Fig. 2 and as seen it is approximately linear. After smoothing this fact became more strongly confirmed.

In order to determine this influence we haved used the linear relation

$$b_i = b_o + \alpha(T_i - T_o) \tag{2}$$

where is $T_0 = (\Sigma T_i)/n$. The values of the unknown values b_0 and α are derived by using the least–square method where $T_0 = +12.9^{\circ}C$. From 263 conditional equations of the form (2) we obtain the following values of the unknown quantities: $b_0 = +0.69 \pm 0.03$ and $\alpha = +0.04 \pm 0.01$. The obtained correlation coefficient r = 0.42 indicates that the presentation of the obtained data by a linear relation is quite satisfactory. Such a temperature influence on the fluxure (0.″04/1°C) has been also obtained for other meridian instruments of similar characteristics. This fact is an indication of its reality

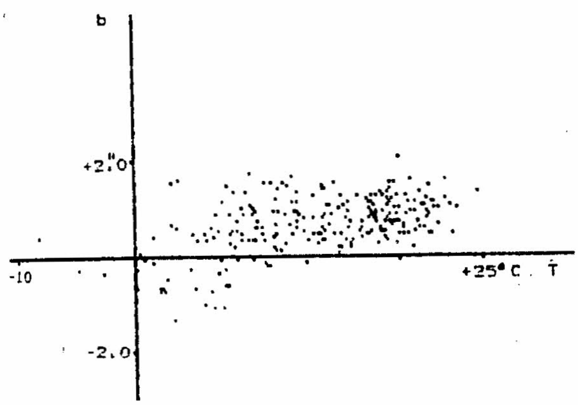

Fig. 2.

A dependence on other meteorological parameters such as the pressure and the humidity is not noticed.

The residuals $\nu_i = b_i - b_0 - \alpha(T_i - T_0)$, as well as the values $\Delta b_i = (b_{EW} - b_{WE})_i$ and b are subjected to various examinations: the determination of differences among the observers, the determinations of variations due to different atmospheric conditions and different measurement gradings, as well as the determination of variations occuring during an observation night. It is possible to carry out these examinations since we have established that the different systematic differences derived from the existing observational material do not practically affect the determination of other ones.

The difference among the observers is determined only for the observers MM, DB and DB (Table 1), because they performed the major part of the measurements (about 90%). This difference is determined from the measurements performed between 1978 and 1980 only when the two observers were engaged.

Table 4

OBSERVERS	$\bar{\nu}$	$\overline{\Delta b}$	ϵ_b	n
MM, DB	−0.″27 ± 0.″06	+ 0.″08 ± 0.″04	± 0.″18	79
DB	−0.01 ± 0.04	+ 0.14 ± 0.04	± 0.18	69

In Table 4 the values $\bar{\nu}$, $\overline{\Delta b}$, ϵ_b and n for the observers are presented.

The systematic difference between the observers MM, DB and DB of $\Delta = -$ 0.″26 +0.″07 may be considered as a real one because it is obtained within the accuracy limits and also when it is determined for each year separately. The collimator displacement (values Δb) had a larger influence on the flexure determination by the observer DB. This is understandable bearing in mind that the duration of the determination was longer. The determination accuracy b is the same in both cases.

Variations in the flexure can also arise due to the actions of various atmospheric parameters during the measurements. The variations arising in the conditions: clear, partially cloudy, calm and wind are here considered. In Table 5 the values $\bar{\nu}$, $\overline{\Delta b}$, ϵ_b and n corresponding to different combinations of these conditions are presented.

Table 5

CONDITIONS	$\bar{\nu}$	$\overline{\Delta b}$	ϵ_b	n
CLEAR, CALM	+ 0.″02 ± 0.″04	+ 0.″12 ± 0.″04	± 0.″22	135
CLEAR, WIND	+ 0.02 ± 0.07	+ 0.14 ± 0.07	± 0.23	59
PARTIALLY CLOUDY CALM	+ 0.01 ± 0.07	+ 0.05 ± 0.05	± 0.19	54
PARTIALLY CLOUDY WIND	− 0.21 ± 0.18	+ 0.29 ± 0.14	± 0.21	12

As seen from Table 5 a change in ν occurs only when measurements are performed in a partially cloudy and windy weather. This change cannog be considered as quite real, because it is determined from a small number of measurements, though it is in principle possible bearing in mind the influence of the wind on the instrument and collimators which is confirmed by the increased value of Δb. One may claim: since the wind does not cause changes when the weather is clear, nevertheless there are no changes depending on the mentioned atmospheric conditions.

The values of $\bar{\nu}$, $\overline{\Delta b}$, ϵ_b and n as depending on the measurement gradings (bad, satisfactory, good and very good) are given in Table 6 These gradings are derived on the basis of the behaviour of the instrument and collimators in the course of every series.

Table 6

MEASURING GRADING	$\bar{\nu}$	$\overline{\Delta b}$	ϵ_b	n
BAD	+ 0.″14 ± 0.″06	+ 0.″32 ± 0.″09	± 0.″36	66
SATISFACTORY	+ 0.05 ± 0.05	+ 0.09 ± 0.04	± 0.19	97
GOOD	− 0.12 ± 0.06	− 0.02 ± 0.04	± 0.15	62
VERY GOOD	−0.18 ± 0.08	+ 0.04 ± 0.03	± 0.10	38

The flexure variation for different gradings from bad to very good ones has a continuous trend of decreasing the values $\bar{\nu}$ and the total variation is greater than 0."3. On the reality of the obtained systematic differences one can, at present, say nothing reliable. A final statement will be possible only after their application to stellar observational data. However, one should here specially-emphasize that if these systematic differences are real and the observational data are corrected by their application for one or a group of gradings, one will be able to answer the question of what kind of selection should be applied to the flexure values in the future. If the determinations are bad, the values $\overline{\Delta b}$ and ϵ_b are significant, whereas in the case of the other gradings these values are smaller than the corresponding values for the whole period.

In their preliminary results Mijatov and Bozhichkovich (1982) found a significant change in the flexure during an observation night which can attain even 0.4. In order to examine this effect more thoroughly we order the values ν_i also according to the time interval t_m between the end of the twilight (moment of the sunset plus 0.5 hours) and the moment of determination of the flexure. The end of the twilight is assumed as the beginning of the time calculation t because this is the moment when the stabilization of the ambient conditions begins after the end of the insolation period and in the further course of a night the stability of the ambient conditions is growing. The observational material makes possible to follow the flexure change during a night within time intervals longer than seven hours. In Fig. 3 the dependence ν_i from t_m is presented.

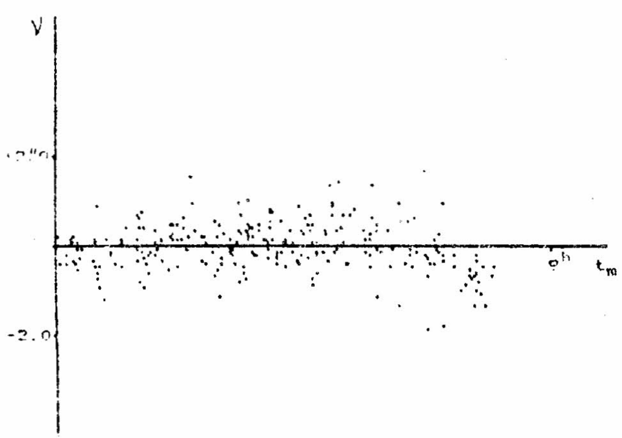

Fig. 3.

As seen this dependence has approximately a parabolic character being more confirmed by smoothing and thus we decide to determine the change of ν_i from t_m from a quadratic equation

$$\nu_i = a_o + a_1 \, t_m + a_2 \, t_m^2 \, . \qquad (3)$$

By applying the least–square method one obtains the values of the unknown coefficients from 263 conditional equations: $a_o = -0.26 \pm 0.09$, $a_1 = +0.22 \pm 0.05$ and $a_2 = -0.03 \pm 0.01$. On the basis of the value of the correlation coefficient $r = 0.33$ one can say that the presentation of the dependency by a quadratic relation is quite satisfactory.

The curve representing the variation of ν_i from t_m is presented in Fig. 4.

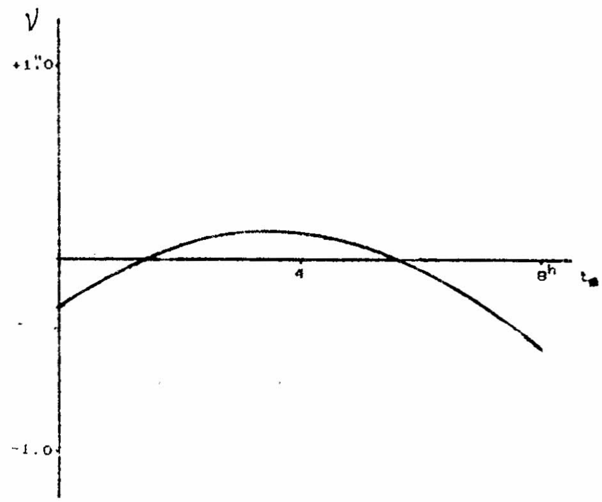

Fig. 4.

The maximal flexure change during a night according to Fig. 4. at the intervals t_m at which the measurements were performed is equal to about 0.5.

The values $\overline{\Delta b}$, ϵ_b and n corresponding to different time intervals t are given in Table 7.

Table 7

t_m	$\overline{\Delta b}$	ϵ_b	n
0–1	+ 0."33 ± 0."11	± 0."32	26
1–2	+ 0.15 ± 0.10	± 0.22	35
2–3	+ 0.16 ± 0.08	± 0.24	32
3–4	+ 0.02 ± 0.07	± 0.22	48
4–5	+ 0.01 ± 0.08	± 0.22	43
5–6	+ 0.06 ± 0.07	± 0.19	31
6–7	+ 0.17 ± 0.10	± 0.27	23
7–8	+ 0.11 ± 0.06	± 0.17	25

The maximal values of b correspond to the first hour of determinations and the minimal ones correspond to the interval $3^h - 6^h$. One should point out that after 6^h the values of $\overline{\Delta b}$ are enlarged, i.e. the action of the factors strengthening the instability of the collimators begins. The values of b are also maximal within the first hour of determinations and within other intervals they are at the accuracy level for the whole period. Since there is a significant systematic influence of the collimator displacement on the flexure determination during the first hour as well as a small accuracy, one should avoid measuring at the beginning of an evening.

Since determinations evaluated with had gradings possess significant deviations from the mean value for the whole system ($\bar{\nu} = 0$) and the measurements were performed with a low accuracy and with a significant systematic difference Δb, a question of to what degree their elimination from the whole observational material contributes to their improvement arises.

The temeprature effect derived from 197 conditional equations of form (2) after exclusion of measurements with bad gradings for $T = 13.3°C$ yields the following values of the unknown quantities: $b_o = +0.75 \pm 0.04$ and $\alpha = +0.03 \pm 0.01$. As seen the sample without bad determinations has a temperature influence smaller by about 25%.

Bearing this in mind we decided to carry out all the examinations done with the residue also with a sample without bad measurements. The results obtained for the change of the flexure on the basis of the whole observational material are also confiremed on this sample. Only the values of Δb and ϵ_b, as could be expected, are somewhat smaller for the sample than in the case of the whole observational material.

We suppose that the obtained systematic differences between the two groups of observers as well as, those arising from the determination gradings, are consequences of the systematic measuring errors in the following way: in the first case above all because of the difficulties in mutual setting of the collimators; in the second one because of different actioons of – above all – the collimator shifting and instrumental errors. The variations during a night, as will be seen, may be to some degree attributed to the tube refraction action.

In their paper Høg and Miller (1986) demonstrated that the flexure determinations for the 6–inch meridian circle of the U.S. Naval Observatory were not free from a systematic influence due to the tube refraction. This influence can be according to them represented by the following expression.

$$b_i = c_o + c_1 \text{ abs}(\dot{T}_i), \qquad (4)$$

where c_o is the mechanical flexure, $c_1 \text{ abs}(\dot{T}_i)$ is the influence looked for and $\dot{T}_i$ is the change of the temperature with time for a certain value of b_i. Instead of b_i we use in (4) the values of ν_i obtained earlier, but in that case for the mechanical flexure one obtains a value less by the amount of the mean flexure b_o from (2).

The values of $\dot{T}$ are determined from the temperature change in the course of time at different values of t_m. In order to obtain the values of $\dot{T}$ we use the temperatures measured during observation nights when the flexure was determined. The dependence of $\dot{T}$ on t_m is presented in Fig. 5. The values of $\dot{T}$ are very prominent for the first three hours of t_m to become only slightly changed afterwards.

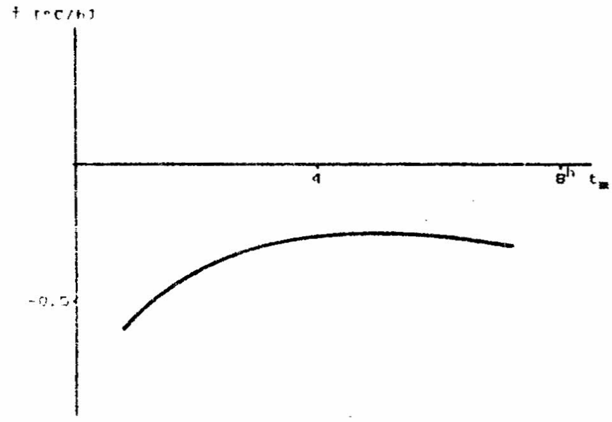

Fig. 5.

By applying the least–square method we obtain the values of the unknown quantities from 263 conditional equations of the form (4): $c_o = +0.17 \pm 0.11$ and $c_1 = -0.48 \pm 0.29$; this means that the mechanical flexure $b = 0.86 \pm 0.11$ and the refraction influence is equal to $-0.48 \text{ abs}(\dot{T})$. Since $\dot{T}$ is varied within the limits -0.60 °C/h and -0.25°C/h, the maximum refraction infulence can attain about 0.″3 and its variation about 0.″2.

The flexure variations during an observation nihgt in the course of first five hours of t_m (Fig. 3) agree sufficiently well with the flexure variations due to the tube refraction and therefore the may be, to a somewhat degree, explained by existence of this influence. However, the promient variation appearing afterwards, especially after six hours of t, cannot be explained by this influence only, since there are probably additional significant systematic influences in this part of the observation nihgt – first of all – the collimator shifting having been already established by an enlarged value of b.

The annual seasonal variations derived from the whole period (Fig. 6) are determined from the values of ν corrected for the difference between the two observer teams, systematic differences due to the determination gradings and to the variations during the observation night.

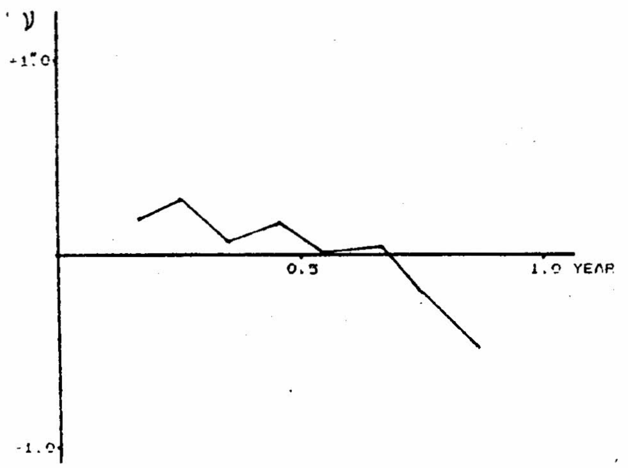

Fig. 6.

As seen, the seasonal variations in the first half of a year except January, when there were no measurements, are about +0."2 with slight fluctuations; from July to the middle of September there are almost no fluctuations, and than beginning with the midseptember a singnificant variation appears attaining −0."5. Therefore, the most significant variations occur during the autumn season and the largest variations at a season change are those occuring between autumn and winter.

5. CONCLUSION

The examinations of the LVC flexure show that determinations of this quantity realised with collimators situated horizontally are not free from random and systematic errors being especially prominent in measurements performed in the beginning of an evening. The influences due to the collimator shifting and tube refraction are specially expressed. Therefore, in future flexure determinations one should avoid measuring in first evening hours when the temperature field is still unstable and subject to rapid variations. Among significant systematic errors of determination is also the difference between the observer teams. In order to remove this influence it is necessary to carry out observations with a reversing prism in the future. In the present measurements it was not the case. The dependence of the flexure on the determination grading requires, as has been already said, additional examinations. The flexure variations during a night found here are explained, to a larger degree, by tube refraction action, but to give a complete explanation of this important phenomenon it is necessary to continue the examinations in this direction.

We hope that the application of the obrained systematic differences will improve the system of measured flexure values and in this way achieve a better accuracy of determinations of absolute declinations of celestial bodies with this instrument.

ACKNOWLEDGEMENT

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