

SECTION I:

OPTICAL TELESCOPES, EXISTING AND PLANNED

THE ZELENCHUK 6M TELESCOPE (BTA) OF THE USSR ACADEMY OF SCIENCES

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ABSTRACT: A description is given of the alt-azimuth mounted 6-meter telescope (BTA) installed in the North Caucasus at an altitude of 2070m above sea level and about 40km to the south of Zelenchukskaya village. Some details of the BTA instrumentation and the local astroclimate are also reported.

DEVELOPMENT HISTORY

The preliminary draft project for a 6-meter telescope with an alt-azimuth mounting was approved in November 1960. Seven years later, all the mechanical units of BTA had been constructed. In 1967 the telescope was assembled in the shop of the Leningrad Optical Mechanical Cooperative (LOMO) for testing. The telescope and the 6-meter mirror were brought to the observatory in 1975, installed, and put into test operation. Since January 1976 the telescope has been used for observations at the prime and both secondary (Nasmyth) foci according to the requirements of the scientific programs. Observing time on the telescope is assigned by the Scientific Time Allocating Committee of the 6-meter Telescope.

THE MOUNTING OF THE TELESCOPE

The telescope is constructed with an alt-azimuth mounting. The advantages of this type of mounting compared to an equatorial one are well known and the alt-azimuth system has now become conventional. The 6-year operation of the BTA telescope has left no doubt of these advantages. The main disadvantage of the alt-azimuth design is rotation of the field and this creates some difficulties when measuring light polarization at the Nasmyth focus.

The vertical axis bearing is a portion of a sphere (Figure 1), 6600mm in diameter, which turns on six hydrostatic pads. The surfaces of these were ground until they deviated from the sphere by no more

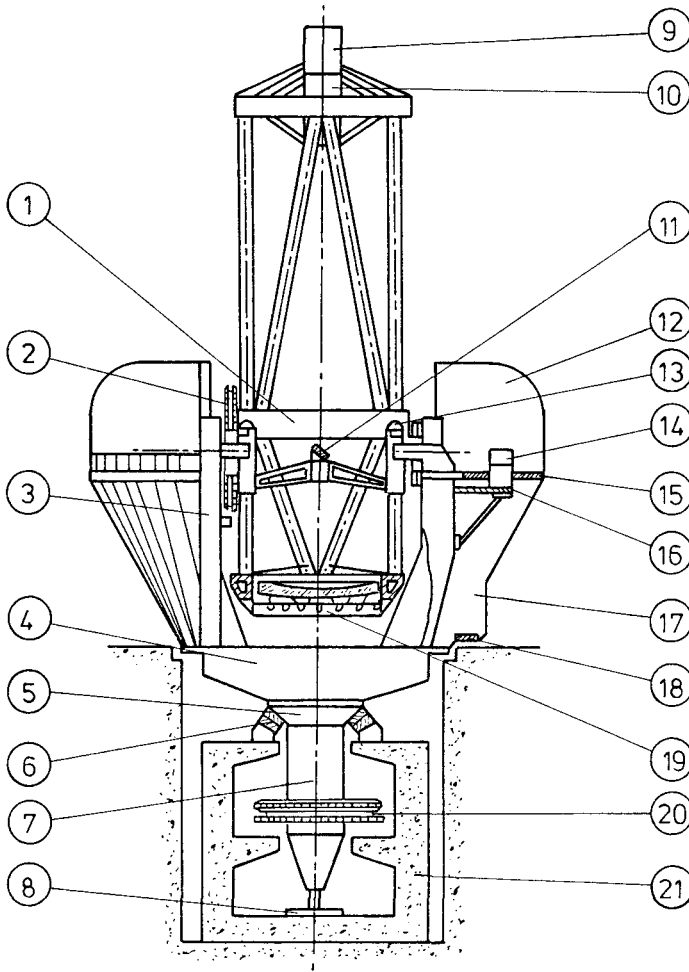


Figure 1. The 6 Meter Telescope (BTA)

1, middle unit; 2, worm gear; 3, elevator; 4, rotation support platform; 5, spherical support of vertical axis; 6, spherical pads; 7, vertical axis; 8, lower bearing; 9, observer's cage; 10, prime focus unit; 11, flat mirror; 12, platform cover; 13, oil pads; 14, main spectrograph; 15, observing platform; 16, support for spectrograph; 17, pier; 18, 2m camera mirror of main spectrograph; 19, primary mirror cell; 20, spur and worm gears; 21, reinforced concrete.

than $\pm 0.02\text{mm}$. The lower bearing of the vertical axis has regulating devices to keep it vertical with an accuracy of 1.5–2 arcsec. The horizontal axis bearings are also spheres that slide on hydrostatic pads. The diameter of each bearing is $2200 \pm 0.05\text{mm}$. The hydrostatic pads are fixed on beams of two piers attached to the rotating support platform. The piers are of welded box construction, each eight meters high. The diameter of the platform is 12m. The mounting construction is very rigid and an imbalance of 3000 kg.m increases the vertical axis rotation error only by one arcsec.

Azimuth gears for telescope rotation about the vertical axis consist of a spur gear and a worm gear. The worm gear is used for accurate telescope tracking and the spur gear protects the worm gear from overload. Another worm gear is mounted at one side of the tube for rotation about the horizontal axis, and a cable reel on the opposite side provides power supplies to the telescope tube and the prime focus unit. Vertical piers carry the two Nasmyth observing platforms of 40 m² each. Arm supports for spectrographs are located under the observing platform floors and are designed for loads up to 1.5 tons.

To create observing conditions similar to those of a coudé focus, there are pavilions made of glass fibre-reinforced plastic on each platform. Each pavilion covers the whole platform, is 2.5m high, and weighs 0.5 tons.

THE TELESCOPE TUBE

The telescope tube is of the usual Serrurier construction with a rectangular middle unit, carrying the bearings of the horizontal axis, and Serrurier trusses made of seamless steel tubing. The telescope is balanced automatically by shifting weights within the tubes. The middle unit also has supports on which a flat diagonal mirror is installed so that the light beam can be directed along the horizontal axis to one of the Nasmyth observing platforms. The mirror can be put into one of two positions by means of an electric drive system and this operation takes about one minute.

The prime focus unit consists of a stationary outer cylinder suspended by four supports to the upper ring of the tube and a movable inner cylinder that can be displaced along the optical axis by $\pm 100\text{mm}$ for focusing. Inside the movable cylinder a hyperbolic mirror and two corrector lenses are attached. They can be moved into the working position through the central control desk in one minute. A rotating table which compensates the field rotation is attached to the upper collar of the movable cylinder. The table is equipped with manual and automatic drives, and allows installation of equipment up to 180 kg. The observer's cage, 1.6m in diameter and 2.26m in height, is positioned above the prime focus unit. The outer diameter of the cage is 1.8m. It has a simply demountable chair which can be moved manually along the cage and inclined by an electric drive.

THE PRIMARY MIRROR AND ITS SUPPORT SYSTEM

The 42 ton primary mirror was made from a solid blank of glass with an expansion coefficient of $3 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$. The external diameter is 6050mm and the thickness is 650mm. The lever type support system is placed in 60 cylindrical blind holes which are 300mm in diameter and 430mm in depth. The levers have hinges in the form of plane elastic steel straps. The radial and bottom supports are combined in one arrangement. The central cylindrical hole, 350mm in diameter, serves to position the main mirror in the centre of the cell. Examination of the mirror support system on the telescope confirmed its high efficiency and reliability. At zenith angles from 0° to 60° the support devices do not degrade the image quality significantly, while at angles not far from horizontal ($>74^\circ$) the image quality expressed in terms of the diameter of the scattering circle is degraded by not more than 0.1 arcsec.

A new 6 meter mirror made of the same glass as the first one but without any defects on the surface was installed on the telescope in 1979. Figure 2 shows results, measured by the Hartmann method, of the image quality of the new primary mirror, expressed as the concentration (%) of energy in the scattering circle plotted against its diameter (arcsec). The dashed curve shows shop measurements, the solid curve represents the measurements made on the telescope. The curves show that 90% of the energy is concentrated in a 0.8 arcsec diameter circle.

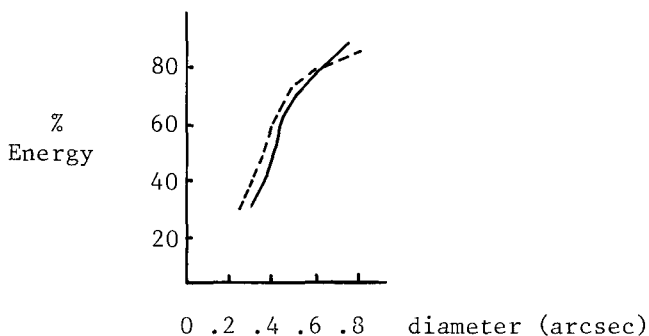


Figure 2. Image quality of the 6m telescope (BTA)

TELESCOPE OPTICS

The telescope has three optical arrangements: the prime focus ($f/4$) and two secondary Nasmyth foci ($f/29$). There is no Cassegrain focus.

The prime focus corrector produces a corrected field of 12 arcmin and consists of a two-lens compensator and a field flattening lens. The compensator is located 2.4m from the focal plane and its diameter

is 700mm. The lower limit of the spectral light transmission of the corrector is 360nm. The prime focus length is increased to 24.7m by using a three lens corrector.

The secondary focus at one of the Nasmyth observing platforms is obtained using a hyperbolic mirror (760mm in diameter) and a flat diagonal mirror. There is a local viewer on each platform with a 2 arcmin field for searching and setting on a sky object. Behind each viewer, in the light beam direction, there is a flat parallel quartz plate and a photoelectric guide, which is used to keep the image of a star on the entrance slit of a spectrograph. The working field of the photoguide is 20 arcsec.

TELESCOPE GUIDING

Setting and guiding can be done through the central control desk using the guide telescope which is a Ritchey-Chrétien system with a mirror of 70cm diameter (f/17). The guide has three working arrangements:

- 1) Visual (manual) guiding from the observing platform of the Nasmyth focus;
- 2) Photoelectric (automatic) guiding. The control is performed from the central desk. It keeps the star image on the optical axis of the guide with an accuracy of 0.2 times the diameter of the image. The angular field of the photoguide is 70 arcsec;
- 3) Television guiding. The image of a sky area of diameter 37 arcmin is transmitted by a television system to a monitor screen (130mm diameter) on the central desk. After identification, the object is set in the centre of the screen and a new magnification is then selected which provides a field of 12 arcmin on the screen. This magnification allows one to keep the object in the field centre with an accuracy of several arcsec. As in other telescopes, there is a small misalignment between the optical axes of the BTA and the guide which depends upon the zenith angle. The maximum error is 15 arcsec so that this mode is not used when high accuracy setting and tracking of the BTA is required.

TELESCOPE DRIVE AND CONTROL SYSTEM

The central system performs the following procedures:

- a) telescope setting on an object;
- b) tracking of the object;
- c) correction of the position of the visible star image.

These procedures are realized by the combined operation of three systems: a digital computer for automatic control; a compensator for the rotation of the field; photoelectric guiding of an object. The digital computer utilizes information on the angular coordinates of the telescope axes supplied by photoelectric encoder transducers which are mounted on the worm drives of the axes. The accuracy of the angular readout is

0.25 arcsec. Each worm gear is driven with three direct current motors. Setting and tracking motors are combined kinematically through a differential. The third motor provides the photoelectric guiding regime.

Telescope setting is accomplished at three coordinates: azimuth A , zenith angle Z , and position angle P (angle of the field rotation). This regime begins after the object coordinates have been entered into the digital computer and a "start" button on the control desk is activated by the operator. As large telescopes have considerable moments of inertia, the change from setting to tracking is realized gradually using the updated position information. That is, the setting speed begins to decrease more and more as the telescope axis approaches the observing object and at the end of setting the slewing speed becomes zero. At $Z < 20^\circ$ and $\Delta Z < 0$ the setting speed decreases in order to prevent the telescope moving at high speed into the forbidden zone $Z < 5^\circ$. Similar precautions are observed for the zone $Z > 60^\circ$ and $\Delta Z > 0$. When tracking, the telescope is controlled by the computer using position and rate data. In this state the following variants of control system functions can be used:

a) if an image can be seen visually, an observer can correct the image position manually through the computer with the help of control consoles located near the observer at the prime and secondary foci. For this purpose the observer may choose a correction speed out of the following set: 0.2, 0.4, 1, 2, 5 arcsec/sec.

b) if the coordinates of the object to be observed are known, corrections can be applied for the systematic errors caused by elastic deformation of the mounting, tube temperature variations, etc.

c) automatic correction of the telescope position can be made using the photoelectric guide. In this case a reference star can be used for offset guiding. A search for a suitable star is made with the TV monitor on the control desk. The observing star image is put on the spectrograph slit, for example, and the reference star (located using the TV monitor) is set on the optical axis of the guide with the help of the flat parallel plate. At the Nasmyth foci, the photoelectric guiding can also be operated without the digital computer. The guiding is then based on the registration of the star light reflected from the entrance slit of the spectrograph to a photomultiplier. Its signal controls the slope of the parallel plate located in the light beam and keeps the star image in the centre of the slit. The field of this guide is 20 arcsec and the guiding accuracy is 0.2 of the star image diameter.

Experience has shown that the telescope can be aimed automatically to an accuracy of ± 15 arcsec. By digital tracking alone the displacement of a star image in the prime focus eyepiece after 30 minutes working may be 10 arcsec in azimuth and one arcsec in zenith distance.

BTA INSTRUMENTATION

Five spectrographs have been constructed for spectral observations:

a) A main stellar spectrograph (OZSP). The spectrograph is installed inside one of the vertical piers of the BTA. The slit part of the OZSP is located on the observing platform. The spectrograph has three optical cameras with focal lengths 3013mm (f/11.6), 604mm (f/2.3) and 300mm (f/1.15) and 5 gratings 600g/mm blazed for the first, second, and third orders. The collimator is a spherical mirror ϕ 300mm (f/26). Reciprocal linear dispersions of the OZSP are 1.5, 5, 9, 14, 28, 56 A/mm in the range 300-1100nm; spectra are registered on photographic plates.

b) A fast spectrograph with an image tube at the prime focus has four optical cameras f/1 and f/2 with an outer focus for adjusting to different image tubes, and 3 gratings 200, 300, and 600g/mm. The focal length of the mirror collimator is 400mm. Reciprocal linear dispersions are 60, 127, 360 A/mm in the range 300-800nm;

c) An echelle spectrograph at the secondary focus has a Bowen type camera with a focal length of 182mm (f/1.4). The focal length of the mirror collimator is 3640mm. In the range 330-660nm the spectrograph records 11 spectral regions in orders 10-20 with a dispersion from 24 to 48 A/mm; in the range 650-1080nm the spectrograph produces 10 spectral regions in orders 16-25 with a dispersion from 44 to 69 A/mm.

d) A planetary spectrograph at the secondary focus has an off axis mirror camera (f = 647mm) with an outer focus. The focal length of the mirror collimator is 2400mm. Three gratings on a rotating turret give dispersions 4, 7, 12, 52 A/mm.

e) A spectrograph for the prime focus with television registration of the spectrum in the photon counting mode. It consists of a camera with an outer focus 150mm (f/2) and 3 gratings which give dispersions 50, 100, 200 A/mm. The scanner has 2 lines with 500 channels each and a 33 μ m resolution element (Somova et al., these Proceedings).

Other instrumentation options are:

f) Direct photography at the prime focus (the corrector field is 12 arcmin). A plate holder is positioned on the rotating table. There is a set of light filters and 12 interchangeable plate holders.

g) A slitless spectrograph with a transparent prism grating (grism) having 100g/mm for use at the prime focus and giving spectra with a dispersion from 1300 to 400 A/mm in the range 360-800nm.

h) A photometric system for the search of optical variability on time scales from 3×10^{-7} to 300s (Beskin et al., these Proceedings).

i) A magnetometer (both photographic and photoelectric) which uses the main stellar spectrograph. The photoelectric part operates in the photon counting mode and a Fabry-Perot etalon with stepped scanning is used to increase spectral resolution. The sensitivity of the device is 5G.

j) An electrophotometer (one channel) is used in the photon counting mode with filters of the U,B,V,R system. The recording system of the photometer provides the following options: standard photometry; short period light curve registration; recording of the time intervals between photons; high speed photometry with exposures from 0.001 to 10s.

BUILDING AND DOME

The building is a steel pillar construction covered outside with large plates consisting of two aluminium sheets with foam materials 10cm thick between them. Double walls for the dome were constructed exactly as for the walls of the building. Between the walls there is an air ventilating space, 2m wide. The diameter of the dome is 45m. The slit width of the dome is 11m. To take equipment to the telescope, a 2 ton travelling crane is used. When setting and tracking, the dome slit follows the telescope tube synchronously. The slit can be reduced by a blind from below and by a shutter from above to the aperture which is sufficient for the light beam.

There are three floors in the building with 2 passenger lifts and 1 freight lift. The ground floor contains a room for film demonstration, an entrance hall, a mechanical shop for repairs, and rooms containing power and time equipment. Photolabs, digital computers, electronic equipment for observations, and observing staff accommodation facilities are situated on the first floor. The second floor includes a visitors' gallery and an aluminizing chamber. Location of the vacuum chamber at the level of the turning support platform of the BTA simplified the aluminizing of the 6 meter mirror and also other small mirrors of the telescope.

ASTROCLIMATE

The number of clear nights or night hours and the image quality (seeing) are determined routinely during observations with the BTA. Seeing is assessed visually by comparison with the width of an entrance slit. The number of clear night hours has shown considerable yearly variations, from 1200 to 1800 hours per year. The maximum probability for clear nights occurs during August, September and October, and the minimum occurrence of clear nights is from April to June. The image quality encountered most often is 2-3 arcsec. The observing time with good transparency, a clear night sky and seeing not more than 3 arcsec is approximately 400 hours per year.

CONCLUSION

Successful operation of the 6 meter telescope over a period of 6 years provides some evidence for the correctness of the principal engineering solutions chosen for this unique construction. Preparations are now under way for the manufacture of a new 6m mirror of Sitall (similar to Cer-vit) which will increase efficiency of the telescope. The digital control computer will be replaced by a new one which will allow an increase in reliability of the control system and reduce setting and guiding errors.