## SPACE SURVEY PHOTOCAMERAS FOR CARTOGRAPHIC PURPOSES.

Viktor N. Lavrov, Dr. Sc., General Director Deputy, SOVINFORMSPUTNIK, Russia.

Commission I, Working Group 3

KEY WORDS: Cartography, Calibration, Resolution, Camera, Accuracy.

**ABSTRACT:**

Despite of the impetuous development of electro-optic survey systems, photo-cameras continue to be broadly in use for space survey. Their use is especially effective in cartography because these cameras provide high resolution and geometrically accurate imagery in large swath as well as allow acquisition of stereoscopic images for relief determination.
The article considers design features and parameters of TK-350 topographic camera and KVR-1000 panoramic camera developed in Russia with the purpose of space survey for cartographic applications.
TK-350 topographic camera has 350 mm focal length and 300x450 mm format. The main advantage of images provided by this camera is high geometric accuracy achieved by calibration of all necessary parameters.
KVR-1000 high resolution panoramic camera has 1000 mm focal length and 18x72 cm image size, it provides 2 m ground resolution at 220 km height of flight and 160 km swath.
Joint use of TK-350 and KVR-1000 cameras integrated with the spacecraft's on-board equipment, measuring external orientation elements of images, allows to obtain information required for photogrammetric processing of the images and production of 1:50 000 scale topographic maps and digital maps. Practically, it is possible to create map of any area of the Earth surface, including the areas where geodetic ground control points are unavailable.

Despite of the impetuous development of opto-electronic survey systems, photo-cameras in Russia continue to be broadly in use for space survey. Its use is especially effective in cartography because these cameras provide high resolution and geometric accuracy in large swath as well as make possible to acquire stereoscopic images for relief determination.

Within the last years photographic images of 10 m and 2 m resolution, made by converted spacecrafts equipped with TK-350 and KVR-1000 cameras, are in use in the interest of Russia and world community. The right of commercial distribution of these images is granted to Association "Sovinformsputnik", which is the first Russian company of such type. The company is aimed to market internationally high resolution satellite imagery and products made therefrom.

Topographic camera TK-350 and panoramic camera KVR-1000 in combination with corresponding detectors for during-the-flight determination of external orientation elements form cartographic system designed for production of topographic and digital maps without any ground control points. TK-350 camera provides high precision images suitable for photogrammetric networks development and relief definition, and KVR-1000 camera is designed for obtaining of high resolution imagery, required for interpretation of ground objects.

### Topographic camera TK-350

As it is known, in stereo photogrammetric processing of the images accuracy of ground point definition significantly depends on the ratio of photo base (B) to shooting height (H). In satellite photography, where it is practically impossible to have H less than 200 km, the only way to increase B/H ratio is to increase frame format. The result was development of Large Format Camera in USA [1] and TK-350 in Russia. Main technical characteristics of TK-350 camera are presented in Table 1 below:

| | |
|---|---|
| • Focal length | 350 mm; |
| • Frame | 300 x 450 mm; |
| • Relative aperture format | 1 : 5.6 |
| • Optical power | 80 lines/mm in center<br>35 lines/mm on the edge |
| • Distortion | 20 mkm - maximum<br>2.5 mkm - RMS of calibration |
| • Light filter | OS-14, orange |
| • Calibration crosses | with 10 mm step |
| • Imagery shift compensation | available |
| • Longitudinal overlap | 60% or 80% |

Table 1. TK-350 camera technical characteristics.

In developing of TK-350 primary attention was paid to increasing of photo base and image accuracy. In this connection rectangular frame format was selected, where long side of image frame coincides with the flight direction. Stereoscopic overlap of 80% allows to have B/H ratio equal to 1.1.

In order to provide flatness of film it is pressed to special flattening glass by means of pressing rollers. In so doing two things are achieved: i) significant pressure in film flattening, and ii) there is no sag of flattening glass at the moment of film exposure when it is held on the glass along the edges by means of vacuum pressing [2]. Since the glass is manufactured so as to meet highest accuracy standards, this method guarantees the value of RMS error induced by film unevenness of 1.5-20 mkm.

Along the whole field of frame calibration and coordinate crosses are plotted with 10 mm step (1305 marks total). Coordinates of these crosses are calibrated with 2.0-2.5 mkm RMS error, which allows to consider film deformation with maximum possible accuracy.

In order to compensate longitudinal shift of the image, flattening glass together with the pressed film moves with certain speed in direction of the spacecraft flight. Range of speed of image shift compensating movement is selected so as to permit prolonged exposure times for low sensitive but high resolution films. Four stationary marks are used to keep external orientation elements constant at any position of flattening glass. These marks are printed onto the film at the moment when shutter is completely opened. Location of stationary marks is shown on Figure 1, and layout of stationary mark and calibration crosses is shown on Figure 2.

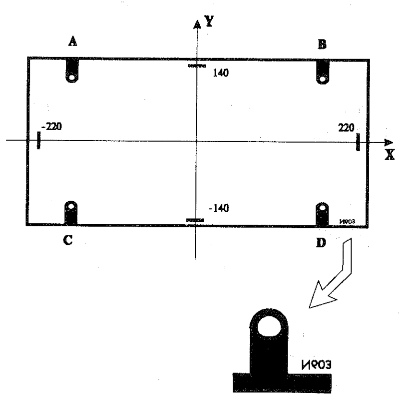
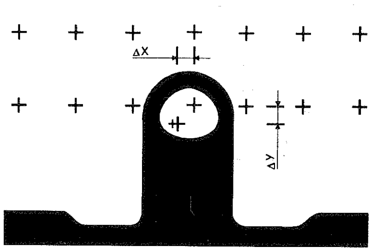



Figure 1. Location of stationary marks.




+ control crosses

-|- - stationary mark.

Figure 2. Layout of stationary mark and calibration crosses

Calibration of TK-350 camera, i.e. determination of its internal orientation parameters and distortion, is made using high precision spatial comparator with automatic electro-optical sighting. This comparator allows to measure in outer bunch of projecting beams spatial angles $\varphi_x$ and $\varphi_y$ for each cross placed on flattening glass of camera, as it is shown on Figure 3.

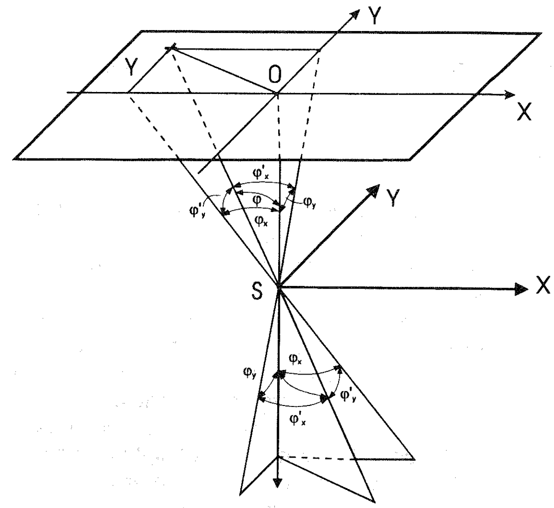



Figure 3. Measuring of spatial angles $\varphi_x$ and $\varphi_y$

Angles $\varphi_x$ and $\varphi_y$ must have one and the same zero point corresponding to direction to the central cross of photo camera, and the edges of these dihedral angles must be mutually normal, which fact provides rectangular coordinate system. Principal scheme of comparator is shown on Figure 4.

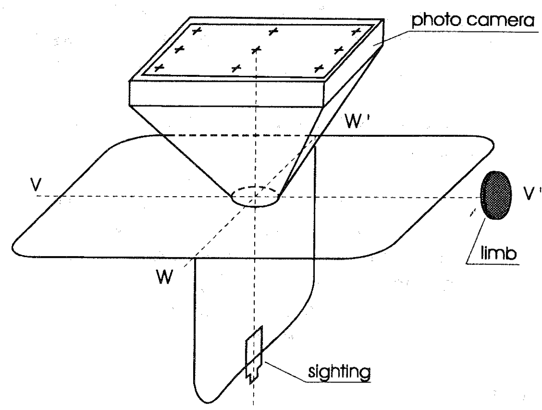



Figure 4. Principal scheme of comparator

Sighting is assembled in special mount which allows it to spin around two mutually normal axes. Sighting axis passes trough the crossing point of rotational axis. V-V' axis is primary, it means that sighting rotation around this axis causes change of spatial position of secondary axis W-W'. Since, depending on observation perspective, crosses in comparator are transformed, the only rotation to be measured is the rotation around V-V' axis. At the same time one group of angles is measured, for example $\varphi_x$, and for measuring of another group of angles $\varphi_y$ precision rotation of camera by $90^0$ angle is made.

Sighting module of comparator has visual and photo-electronic circuits. Photo-electric device provides automatic observation of crosses in dynamic mode, which fact provides high accuracy and productivity of measurements. Spectral sensitivity of photo-electronic circuit corresponds to spectral sensitivity of

isopancromatic film with OS-14 light filter, which excludes influence of chromatic distortion.
Resulting from the measurements on comparator photogrammetric distortion is calculated as:

$$\delta_x = x_k - f\,tg\varphi_x + x_0\,tg^2\varphi_x \qquad (1)$$
$$\delta_y = y_k - f\,tg\varphi_y + y_0\,tg^2\varphi_y \qquad (2)$$

where:
$\delta_x, \delta_y$ - meanings of distortion;
$x_k$, $y_k$ - coordinates of crosses;
$\varphi_x, \varphi_y$ - angles measured using spatial comparator;
f - photogrammetric focal length;
$x_0$, $y_0$ - coordinates of man point.

In order to minimize the value of distortion photogrammetric focal length and main point coordinates are calculated under condition $[\delta_x] + [\delta_y] = \min$.

When camera is placed into the spacecraft, illuminator glass is also calibrated. In addition to that gas environment inside of the spacecraft is measured, and during the flight actual value of temperature and pressure are controlled. This allows to consider influence of illuminator and inner refraction and to make necessary corrections in camera's focal length determination. As a result of all on-ground calibrations and in-flight measurements summarized RMS of TK-350 images is 5 mkm.

**Panoramic camera KVR-1000.**

Providing high accuracy of stereoscopic images, which is necessary to define location of ground points in height and in plane, topographic camera TK-350 let one to have 10 m ground resolution. For the purpose of mapping it is also important to know the details of topographic map. Completeness of the map content depends mainly on ground resolution, which has to be near 2 m, i.e. much higher than TK-350 allows to have.

To provide this high resolution on condition of large swath, KVR-1000 camera was developed in order to obtain required high ground resolution. In developing of KVR-1000 camera panoramic photographic solution was chosen, where high resolution in central part of lens system viewing field is kept along the whole frame, and it is possible to obtain significant swath. Main technical characteristics of this camera are listed below in table 2.

| | |
|---|---|
| • Focal length | 1000 mm; |
| • Frame | 180 x 720 mm; |
| • Viewing angle | $11^0$ 40' |
| • Relative aperture format | 1 : 5 |
| • Optical power | 60 lines/mm |
| • Distortion | 16 mkm - maximum |
| • Coordinate marks | at the angles $0^0$, $10^0$, $-10^0$ |
| • Time marks | with 128 Hz frequency |
| • Type of panoraming | by moving mirrors |
| • Panoraming angle | +/- $20^0$ 40' |
| • Compensation of the image shift | by decentralized mirror rotation |
| • Compensation shift error | less than 1% |
| • Light filter | OS-14, orange |
| • Imagery shift compensation | available |
| • Slit width | 0.3-15 mm |
| • Longitudinal overlap | 6% - 12% |

Table 2. Technical characteristics of KVR-1000 camera.

Panoramic camera KVR-1000 provides 2 m ground resolution from 220 km height and 160 km swath. Thus, the area covered by one TK-350 image is also covered by 7 KVR-1000 images, when two cameras operate together as a companion system. Mutual layout of TK-350 and KVR-1000 images is shown on Figure 5.

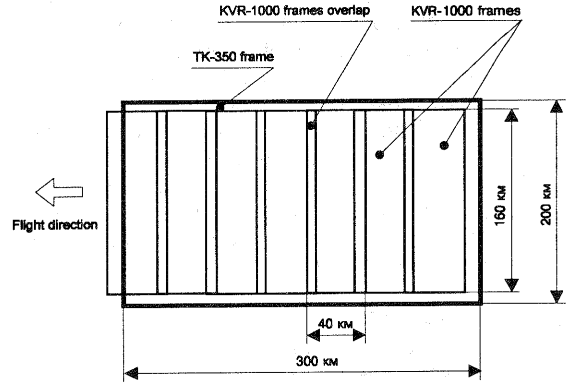



Figure 5. TK-350 and KVR-1000 image layout.

Panoraming is made by means of rotation of two mirrors projecting the imagery onto stable slit. In the process of taking picture film is moving with preliminary assigned speed, and the exposure is regulated by the slit width. There are two protecting glasses in a set of equipment. First one, placed in front of the lens, provides its protection from external heat flow, and second one placed beside the lens provides hermetization of spacecraft descending module. In front of the slit light filter is mounted. This filter is made from OS-14 glass, and to control optimal position of imagery plane seven control filters OS-14 can be applied. These filters provide +/- 0.3 mm defocusing with 0.1 mm step. This measure allows to select optimal positioning of imagery plane. Scheme of KVR-1000 camera is shown on Figure 6.

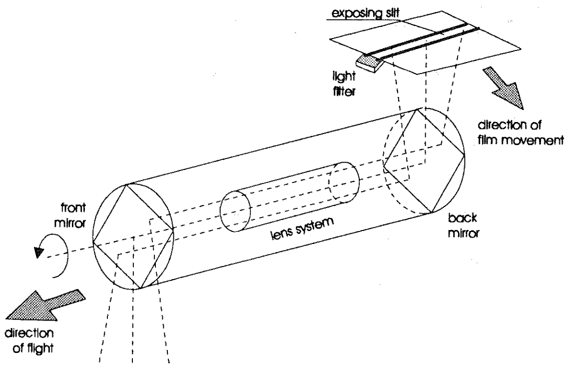



Figure 6. Scheme of KVR-1000 camera.

In order to compensate imagery shift caused by spacecraft's movement, the axis of mirror rotation is displaced with respect to the lens system by 26.07 mm.

To set into compliance rotation of scanning mirrors and film movement high precision system of synchronously-tracking drives is used. Scanning drive provides imagery evolution with preliminary established angle velocity. Drive of pulling roller gives the film movement with the speed equal to the speed of imagery movement in the range 925.8 - 1805 mm/sec with error not more than 1%. Additional drive provides tension of the film in order to flatten it in focal drum in front of the slit.

Slit shutter mounted on the shell of focal drum (together with light filter) provides required exposure times by means of changing of the slit width in 0.3-15 mkm range. Special block combined with the slit shutter provides printing of coordinate and time marks on the frame edges. Coordinate marks are the strokes. Beginnings of these strokes correspond to panoramic angles $-10^0$, $0^0$ and $10^0$, exact values of these angles are calibrated for each camera system. These marks tentatively divide the whole frame of 720 mm length by four parts, which is necessary in imagery processing. Time marks having 128 Hz frequency are made to provide even pulling of film.

Cassette of KVR-1000 camera is designed to hold and keep the film. Six film rolls are used in the system, combined with special roll changer. Film pulling mechanism includes also carriage/frame accumulator, which is required to expose single frame with high speed. There is also special module mounted on the roll. This module prints auxiliary information into the inter-frame space of film. This information includes film number, frame number and W/H code marks.

It was considered earlier that it is difficult to use panoramic photo cameras for cartographic applications because of the difficulties in determination of their internal orientation elements and low geometric accuracy of imagery caused by mechanical movements of camera's components in exposing the film.
Having high precision design and calibration of all relevant parameters (lens system distortion, de-centering of mirror rotation, coordinate and time marks, code marks W/H), panoramic camera KVR-1000 provides highly accurate panoramic images suitable for production of large scale photoplans and orthophotoplans. It is also necessary to use geometric model of panoramic image which takes into consideration above mentioned calibration parameters.

**Satellite cartographic system capabilities.**

Satellite cartographic system combined from topographic camera TK-350 and high resolution camera KVR-1000 integrated with on-board equipment for external orientation elements determination is designed to provide large scale topographic and digital maps. On-board equipment includes two star cameras, laser altimeter, navigation sensors and synchronizing devices. In order to obtain joint operation and to provide required accuracy all the hardware is integrated into the common system based on constructional, accuracy and timing parameters. Cartographic capabilities of the system are presented in Table 3 below.

| Camera type | TK-350 | KVR-1000 |
|---|---|---|
| Average shooting height | 220 km | 220 km |
| Scale | 1:630 000 | 1:220 000 |
| Covered area | 284x189 km | 158x40 |
| *Mapping accuracy using no ground control* | | |
| scale of maps | 1:50 000 | - |
| accuracy of planimetric location | 20-25 m | |
| accuracy of height definition | 10 m | - |
| Horizontal section | 20 m | - |
| *Mapping accuracy using ground control* | | |
| scale of maps | 1:50 000 | 1:10 000 |
| accuracy of planimetric location | 15-20 m | 7-10 m |
| accuracy of height definition | 5-7 m | - |

As one can see, the use of TK-350 and KVR-1000 images allows to produce topographic maps of 1:50 000 scale, as well as digital and thematic maps of any region without ground control information. Images made by KVR-1000 camera allow to produce photoplans and orthophotoplans of 1:10 000 scale. It is also possible to increase the accuracy using ground control points, for example GPS. Corresponding method is described in paper [3] presented on the congress.

As a result of conversion both archive and newly acquired TK-350 and KVR-1000 images are available for foreign customers. Since modern technologies are digitally oriented, TK-350 and KVR-1000 images can be digitized with required pixel size and used for further digital processing.

## Conclusion.

Russian high resolution satellite images are suitable for a wide range of different mapping applications. Satellite mapping system allows to produce topographic, digital or thematic maps of any area, from specific scenes to the whole regions or countries.


## References from Journals.

1. Frederick J. Doyle, A Large Format Camera for Shuttle. Photogrammetric Engineering and Remote Sensing, Vol. 45, No.1, 1979.
2. В. Н. Лавров, Определение прогиба выравнивающего стекла аэрофотоаппарата. Геодезия и Картография, No. 11, 1984.

## References from Other Literature.

3. Mikhail M. Fomtchenko, Vladimir F. Chekalin, The Use of Russian TK-350 Images and GPS points In Generation of DEM. Paper presented at XVIII ISPRS Congress.