THEORY AND TECHNIQUES
OF TESTOSCOPIC METHOD
OF STEREOROENTGENOGRAMMETRIC SURVEY

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At present the principles of the digital processing of X-ray images, including the photogrammetric methods, begin to be used more and more often for diagnostics of various diseases. However, complexity of the traditional methods of X-ray photogrammetry, caused in the first place by the necessity of strict determination of picture orientation elements, keeps back a wide introduction of the stereoroentgenogrammetric survey in clinic practice. Search of a high-precision X-ray topometric method, which could be accessible for medicine, resulted in a testoscopic method of the stereoroentgenogrammetric survey, worked out at the Moscow Tuberculosis Institute.

The testoscopic method provides determination of three-dimensional coordinates of the object points by means of a constructed object stereomodel using a stereopair of X-ray pictures and intersection of the model target point with a stereoinstrument floating mark relative to the test-object scale images, photographed together with the object of research at the same time /2/.

Fig.1 shows the intersection geometry of the point A of a stereomodel made with the linear marks m and m' .

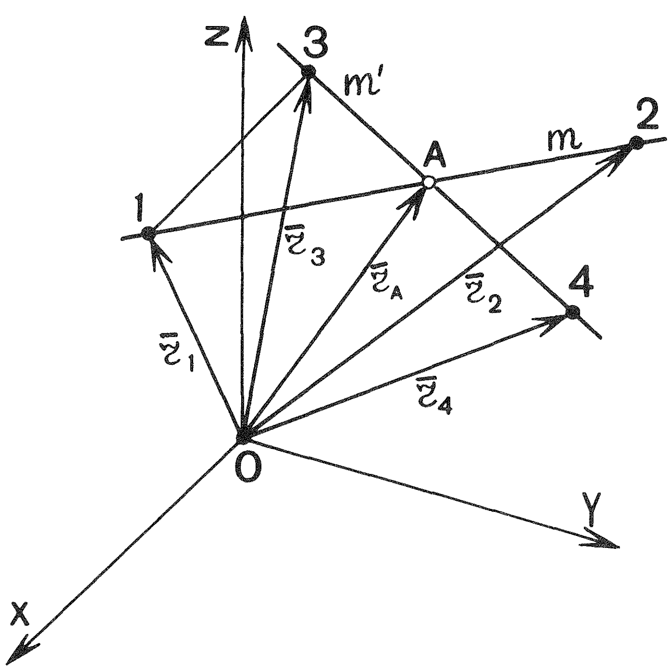


Fig.1

The coordinates of the point A can be determined by solving the following vector equation system:

$$\left.\begin{aligned} \bar{z} &= \bar{z}_1 + (\bar{z}_2 - \bar{z}_1)\,t_1 , \\ \bar{z}' &= \bar{z}_3 + (\bar{z}_4 - \bar{z}_3)\,t_2 , \end{aligned}\right\} \tag{1}$$

where $t_{1(2)}$ - parameter.

The system (1) can be solved provided the straight lines 1-2 and 3-4 lie within the same plane, i.e. the vectors are complanar:

$$(\bar{z}_3 - \bar{z}_1)((\bar{z}_2 - \bar{z}_1)\times(\bar{z}_4 - \bar{z}_3)) = 0 . \tag{2}$$

The straight lines 1-2 and 3-4 can be coordinated by means of the test-object scales, made in the form of side planes of a cube(fig.2).

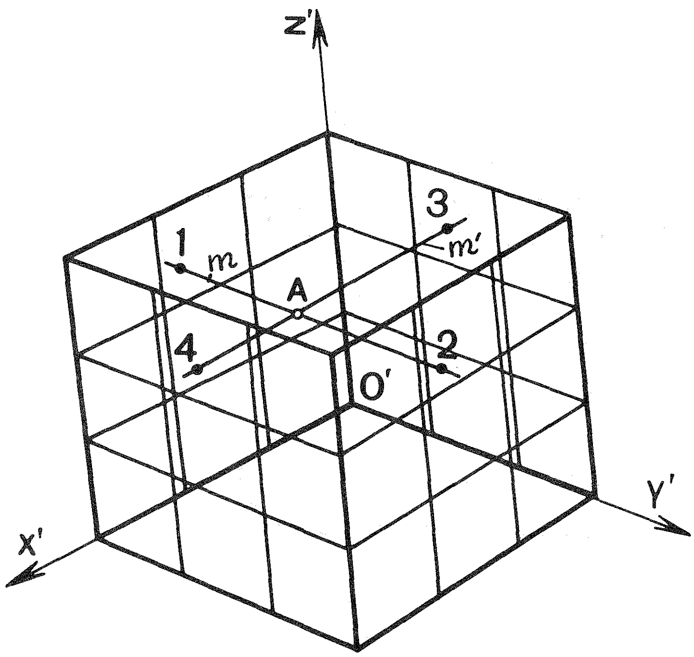


Fig.2

The stereoroentgenography conditions make it possible to position the test-object on the deck of the X-ray holder table so that its axes X and Y were parallel to the corresponding axes of the photogrammetric coordinate system. Then in the conditions of the normal case $X_A = X_1' = X_2'$, $Y_A = Y_3' = Y_4'$, $Z_A = Z_1' = Z_2' = Z_3' = Z_4'$, where X_i', Y_i', Z_i' - coordinates of points 1,2,3,4 of the linear marks m and m' obtained with the test-object scales.

Thus, in order to solve a measurement task with the testoscopic method it is possible to use a test-object with two scales XZ and YZ.

The geometry of a direct-shadow image, received by a dispersing X-ray beam, causes the necessity of using a test-object with inclined scales. The inclination angle can be chosen in the limits of 45°-60°.

The test-object is positioned on the deck of the X-ray table so that its axes X' and Y' were parallel to the longitudinal axis and the lateral axis of the X-ray holder respectively (to the axes X and Y of the photogrammetric coordinate system). The object of research is put on the base of the test-object between the scales $X'Z'$ and $Y'Z'$, as shown in fig.3. Stereoroentgenography is to be performed in the conditions of the normal case.

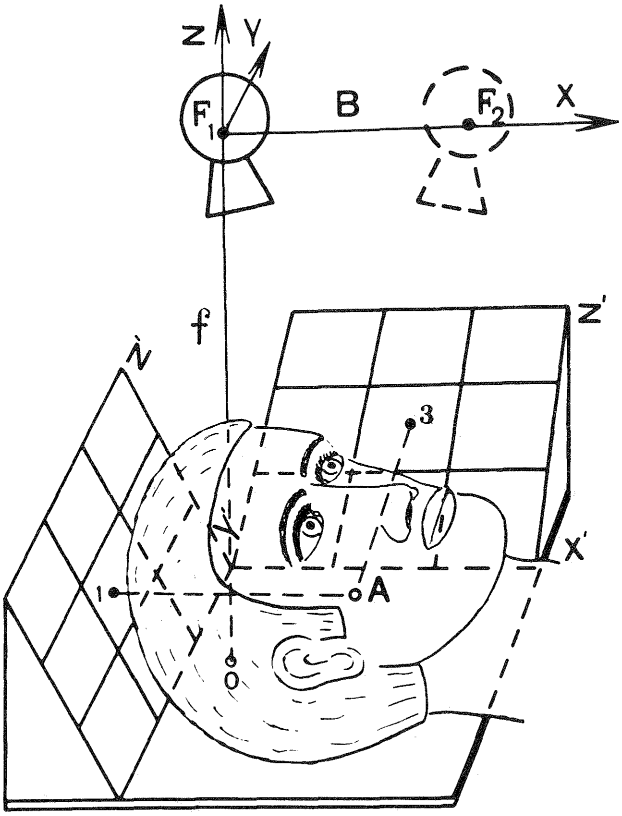


Fig.3

The X-ray pictures are placed on a stereocomparator and oriented so that the images of the axes X' and Y' of the test-object were parallel to the axes x and y of the instrument. The measurement mark of the instrument is to be set to the target point of the stereomodel; after that the mark should be moved in parallels to the axis y of the stereocomparator untill it coincides with the scale $X'Z'$ of the test-object. (The position of the parallaxic screw should not be changed). The scale readings are taken by means of interpolation. In the same way one can determine the coordinate Y of the target point. In this case the mark should be moved in parallels to the axis x of the stereocomparator. The coordinate Z is to be found with the scales $X'Z'$ and $Y'Z'$ simultaneously with the determination of the coordinates X and Y.

The mathematical way to express the stereoscopic intersection is as follows:

$$\left.\begin{aligned} X &= X'_0 + \Delta_X C_X, \\ Y &= Y'_0 + \Delta_Y C_Y, \\ Z &= Z'_0 + \Delta_Z C_Z \sin\gamma, \end{aligned}\right\} \qquad (3)$$

where: X_0', Y_0', Z_0' are coordinates of the reading stroke of the corresponding test-object scales: Δ_X, Δ_Y, Δ_Z are relative scale reading, taken by means of interpolation; C_X, C_Y, C_Z are scale spacings; γ - the inclination angle of the test-object.

When it is required to determine only bedding depth of a pathological formation or any foreign body, it is sufficient to use a measurement test-object which contains only the Z'-axes scale.

The testoscopic method requires neither determination of orientation elements of pictures or using of mathematical formulas, because transformation of a stereoscopic model into a geometrical one is performed directly on a stereocomparator by comparing the required values with the standard ones.

At the Moscow Tuberculosis Institute a large family of measuring test-objects with flat, spheric, imaginary scales of a stiff type has been worked out, supplied with a self-alignment mechanism /2/, /4/, /3/, /5/. As the base of the test-object scales a rigid X-ray transparent material (plexiglas, getinax) is used, and the strokes are made of a material with a high atomic number (copper, lead).

The orthogonal coordinates of the target points, obtained with the scales of the test-object, include errors caused by errors of the stereoroentgenogrammetric process, i.e.:
1) errors of X-ray image formation;
2) alignment errors of the X-ray camera;
3) orientation errors of the test-object;
4) errors of orientation of pictures on the stereocomparator;
5) measurement errors of the stereomodel.

Errors of the inner orientation of pictures as well as of the stereoroentgenography basis are not dangerous for the testoscopic method of the stereoroentgenogrammetric survey.

A clinical X-ray picture is obtained by registration of the X-rays, which have passed through the patient, on a two-side film, placed in the cassette between the intensifying screens. Application of the intensifying screens caused by the necessity of reducing the radiation load on the patient, makes the resolution of the X-ray picture considerably worse. The resolution of the system "an X-ray film + intensifying screens" doesn't exceed, as a rule, 5 lin/mm/6/.

A two-side X-ray film is subject to systematic regular deformation (0,24 mm per 100 mm filmlength) which results in reduction of the picture scale /6/. Such a deformation is not dangerous for the testoscopic method, as it has a regular influence upon the images of the object of research and the test-object. The random component of the deformation doesn't exceed 7 mkm, which is almost two orders less than the measurement accuracy of the X-ray picture /6/.

A special construction of the X-ray cassette provides for a proper quality of flattening of the film.

Table 1 shows tolerances for deviation of mutual orientation elements ($\Delta\alpha$, $\Delta\omega$, $\Delta\varkappa$, γ, τ) and maximum permissible values of the test-object orientation elements (α', ω', $\varkappa'$). The table shows also a real precision for securing of these tolerances.

Table 1

Errors	Maximum permissible value	Real value
$\Delta\alpha$	1'	0-30"
$\Delta\omega$	1'	0-30"
$\Delta\varkappa$	4'	0'
ν	42'	1' - 3'
τ	13'	5'
α'	7'	30"
ω'	7'	30"
$\varkappa'$	7'	1' - 3'

The mean-square measurement error of the stereomodel by the testoscopic method is characterized by the next relation:

$$m = \sqrt{m_1^2 + m_2^2 + m_3^2} \quad , \tag{4}$$

where: m_1 - error of mark guidence on the stereomodel point; m_2 - error of reading on the test-object scales; m_3 - instrumental errors.

The instrumental errors of the photogrammetric instrument and the test-object are at the minimum one order less than the real precision of measurement of X-ray pictures. Therefore, they will not have any noticable influence upon the cumulative error. Hence we can write down:

$$m = \sqrt{m_1^2 + m_2^2} \quad . \tag{5}$$

The guidance precision of the mark on the stereomodel depends mainly on the contrast and the geometric blur of the image. In the course of the experiments it was ascertained that for the objects of high contrast $m_1 = 0{,}07$ mm, and for the objects of mean contrast $m_1 = 0{,}1$ mm.

The reading error on the test-object scale is determined mainly by interpolation precision. On the grounds of (3) we shall obtain

$$m_2 = C\, m'_\Delta \ , \tag{6}$$

where m'_Δ - mean-square interpolation error on the corresponding scale of the test-object.

The experimental investigations showed that when using a test-object with flat scales, positioned at the angle of 45° towards the instrument base plane, $m'_{\Delta X} = m'_{\Delta Y} = 0{,}05$ and $m'_{\Delta Z} = 0{,}09$.

Thus, when the scale spacing of the test-object is 10 mm, $m_{2X} = m_{2Y} = 0{,}5$ mm and $m_{2Z} = 0{,}9$ mm.
From the formula (5) we shall have $m_X = m_Y \approx 0{,}5$ mm and $m_Z \approx 0{,}9$ mm.

As an example we shall cite an experimental estimation of the precision of the testoscopic method, using a test-object with flat inclined scales with the scale spacing of 5 mm. The investigation was made with the help of a standard with 16 control balls (steel balls of 1 mm diameter) fixed at the butt-ends of the posts of different height, made of plexiglas. The posts were fixed on a flat-and-parallel base of a square form, made of plexiglas. The coordinates of the control points were determined in the rectangular coordinate system of the standard $\overline{OXYZ}$ relative to the point No.15 by direct optical-and-mechanical measurements with accuracy of 0,05 mm.

The standard 1 was placed between the scales of the measurement test-object 2 and then oriented so that its axes $\bar{X}$ and $\bar{Y}$ were parallel to the corresponding axes of the test-object (fig.4). Stereoroentgenography was carried out in the conditions of the normal case. The approximate parameters of the survey are: f = 1000 mm (principal distance), B = 200 mm (base).

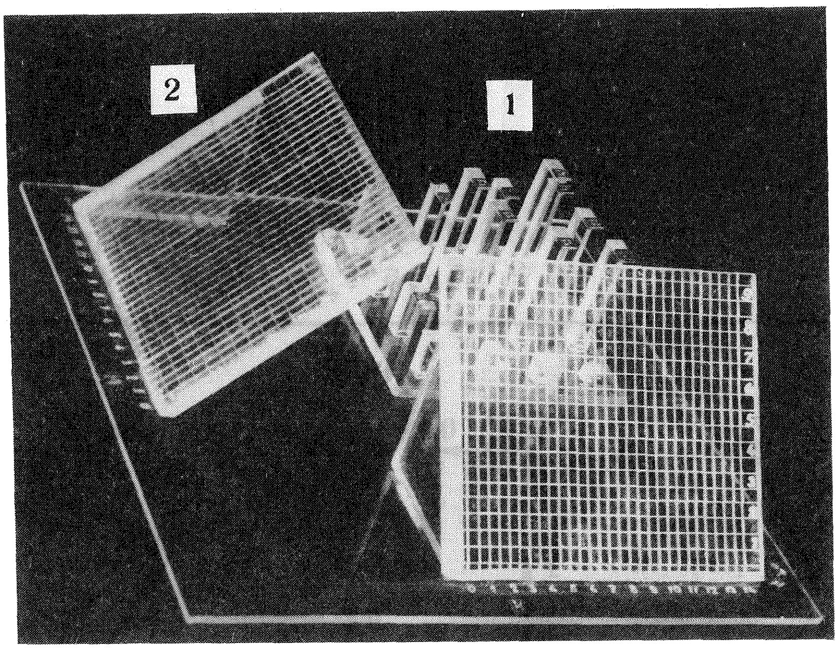


Fig.4

Fig.5 shows the right picture of the X-ray stereopair of the standard, where with figures 1, 2, 3 the images of the standard, the test-object and the coordinate marks are designated relatively.

The photogrammetric processing of the X-ray pictures was carried out on a stereocomparator.

In accordance with the results of the stereoroentgenogrammetric and optical-and-mechanical measurements a graph of errors of the coordinates of the standard control points was made (fig.6), where for each point the radius-vector showed the value and the direction of the resulting error along the axes $\bar{X}$ and $\bar{Y}$ of the standard, and the figures (mm) designated the errors along the axis $\bar{Z}$.

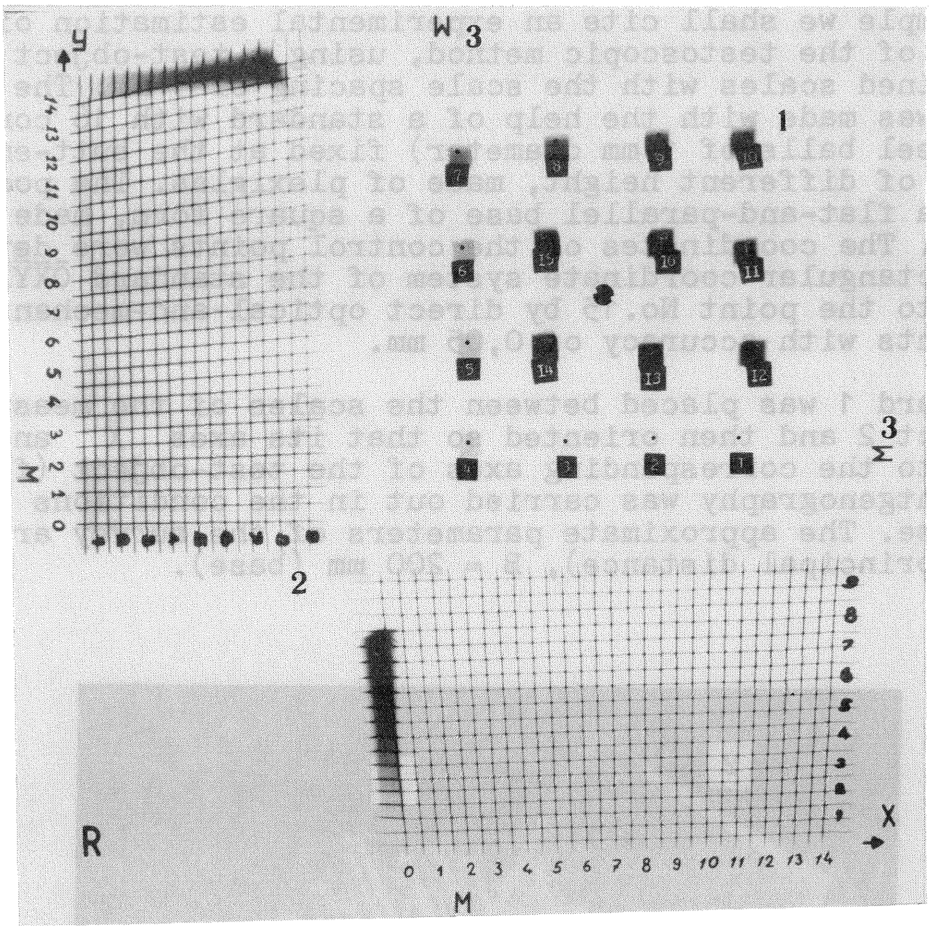
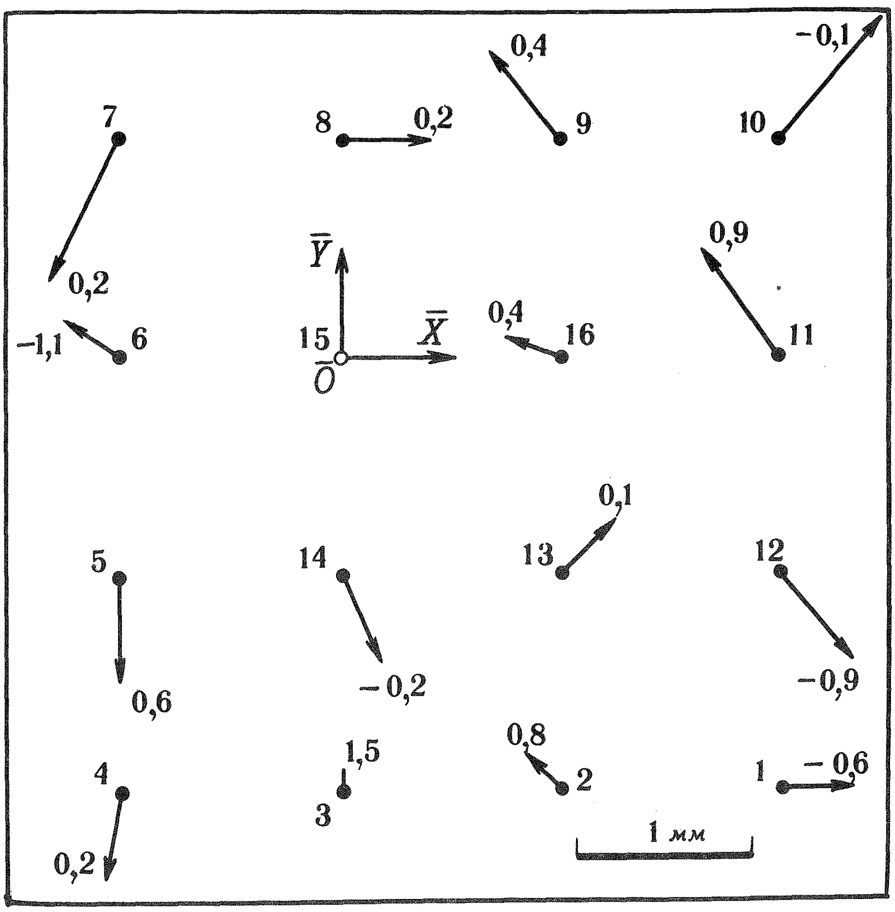


Fig.5



7
0,2
8
0,2
0,4
9
10
−0,1
$\overline{Y}$
$\overline{X}$
15
$\overline{O}$
0,9
0,2
−1,1
6
0,4
16
11
0,1
5
14
13
12
0,6
−0,2
−0,9
4
0,2
1,5
3
0,8
2
1
−0,6
1 мм

Fig.6

By Gauss' formula the mean-square errors of determination of the difference of three-dimensional coordinates were calculated. As a result we have obtained: $m_{\Delta X} = 0,3$ mm, $m_{\Delta Y} = 0,4$ mm and $m_{\Delta Z} = 0,7$ mm.

Table 2 shows the data, which characterize accuracy of the testoscopic method, obtained in the experimental way using test-objects of different constructions.

Table 2

Characteristics of the test-object	Mean-square errors		
	$m_{\Delta X}$(mm)	$m_{\Delta Y}$(mm)	$m_{\Delta Z}$(mm)
Inclined linear with 2 mm reading space (C)			0,5
Three coordinate test-object with flat scales (C = 5 mm)	0,3	0,4	0,7
Three coordinate test-object with flat scales (C = 5 mm). Measurements were carried out on Steko 1818 (Carl Zeiss, Jena) with reduced pictures	0,4	0,4	0,7
Three coordinate test-object with spheric scales (C = 10 mm)	0,8	0,8	1,3
Three coordinate test-object with imaginary scales (C = 10 mm)	0,4	0,4	0,9

The data given in Table 2 prove conclusively that the accuracy of the testoscopic method is one order higher than that of the traditional methods in X-ray topometry (using coordinate scales, correction factor, etc).

The testoscopic method has found practical application in diagnostics of foreign bodies /1/, in study of the vibrational disease /7/, when treating for varicose veins /8/. In the latter case application of the testoscopic method has made it possible for a doctor to plan surgical treatment exactly and strictly, which allowes to shorten the time of the operation and to reduce traumatical heaviness and painfulness. Thanks to the above the number of after-operation complications and stay-time of the patient in clinics are considerably reduced. The surgical treatment for varicose disease of lower extremities gives an economic effect of average 250 rubles per one patient (doctor Prokopyev S.P. at the Scientific Methodical and Medical Centre of vascular surgery, Penza, USSR). By the new method over 5000 patients have been already cured.

The theoretical and experimental investigations described above as well as the experience of the practical work show that the testoscopic method combines high accuracy with simplicity of solving the measurement task, because coordinates of target points are determined directly on a stereocomparator without formulas of photogrammetric transformation. It is a serious precondition for a wide application of the stereoroentgenogrammetric method for X-ray diagnostics.

REFERENCES:

I. Демин В.А., Черний А.Н., Пузин С.Н. Клинико-рентгенологическое исследование при экспертизе трудоспособности лиц, получивших ранения конечностей на фронтах Великой Отечественной войны. - Клиническая медицина, I985, № I0, с.58-62.

2. Черний А.Н. Тест-объект. - А.с. № 644463 /СССР/. Заявл.3I.05.76 /2367687/. Опубл. в Б.И. I979, № 4.

3. Черний А.Н. Мира для стереорентгенографии. - А.с. № I045093 /СССР/. Заявл. 28.06.82 /346I258/. Опубл. в Б.И. I983, № 36.

4. Черний А.Н. Тест-объект для рентгенотопометрии черепа. А.с. № I026773 /СССР/. Заявл. I8.02.82 /3398743/. Опубл. в Б.И. I983, № 25.

5. Черний А.Н. Тест-объект. - А.с. № I0570I4 /СССР/. Заявл.26.08.82 /3487788/. Опубл. в Б.И. I983, № 44.

6. Черний А.Н. Рентгенотопография. - М.: Недра, I98I.

7. Черний А.Н., Дружинин В.Н. Методические аспекты применения стереорентгенограмметрии при изучении воздействия вибрации. - Гигиена и санитария, I986, № 5, с. 3I-34.

8. Черний А.Н. - Стереорентгенограмметрия в диагностике и хирургическом лечении варикозной болезни. - Геодезия и картография, I987, № 5. с.54-58.