Contactless method for online control tension of radio-reflective mesh surface of large-sized folding mirror antennas

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Abstract. A new contactless method for online control tension of a radio-reflective mesh surface of a large-sized folding mirror antenna is presented. The method is based on revealing the correlation between Moire patterns and net-shaped curtain uniformity and tension. The advantages of the method are presented. Its main advantage lies in the fact that it is possible to set the net-shaped curtain on the folding skeleton of an antenna reflector in the online mode. The presented method is universal and can be used not only to manufacture antenna reflectors with the working surface in the form of a net-shaped curtain but also in any other structures in which the checked element is a net, regardless of the material of which it is made. A way to apply the method is presented.

1. Introduction

Works aiming to construct a large umbrella reflector antenna with a rigid frame skeleton, which can be opened automatically in orbit, have been performed for half a century in Russia and abroad [1–3]. The diameter of a reflector of such antennas can be over 100 meters and is limited by the size of the payload area under launch vehicle dome where they are placed in a folded state. Thus, the structure of a large-sized mirror antenna should be characterized by a high transformation factor (from 1/10 up to 1/50), and it should be able to open reliably and secure the required rigidity of the frame and tension of a radio-reflecting material after the opening of an antenna reflector. Figure 1 depicts the general view of an umbrella offset antenna reflector with a diameter of 100 m (the transformation factor is \( a/b = k \)). It is one of the first projects for such an antenna type developed in the United States by Langley Research Center (LRC) and Lockheed Missiles and Space Company (LMSC) [1]. In the open state, the antenna reflector represents spacecraft \( I \) with antenna exciters placed in the antenna reflector’s focus \( 3 \) when the frame supports \( 2 \) have been opened (Fig. 1a). After opening the antenna reflector \( 3 \) represents a rigid frame structure consisting of tetrahedral cells \( 4 \) connected by hinges. The tetrahedral cells are made of three diagonal \( 6 \) and six folding \( 7 \) rods connected by central units \( 5 \) (Figs. 1b–1d). Figures 1b–1d depict the tetrahedral cell \( 4 \) in the folded, intermediate, and opened positions. The elastic metallic net-shaped curtain \( 8 \) connected to the folding rods \( 7 \) of tetrahedral cells \( 4 \) from the operating side of the reflector’s frame skeleton is used as radio-reflecting material. All tetrahedral cells \( 4 \) are opened synchronously by the elastic forces of spring mechanisms. When the skeleton has been opened and folding rods \( 7 \) have been fixed, the elastic metallic net-shaped curtain \( 8 \) is tensed with the given force in the rigid frame skeleton of the antenna reflector. The mechanism for opening such
structures (not shown in Fig. 1) can be manufactured on the base of torsion springs placed directly in the hinge joints, on the base of the compression springs placed inside the folding rods, or in umbrella type mechanisms acting on the diagonal rods [1–3].

If it is required to secure a highly rigid structure of the large reflector of mirror antenna, the bicurvature folding frame skeleton consisting of spring-load folding and solid rods connected flexibly is preferable. In this case the frame’s skeletons consisting of tetrahedral cells are characterized by the greatest specific rigidity (Fig. 1) [1]. The working surface of such reflectors is approximated by triangular flat cells (facets) with a net-shaped stockinette material made of metallic mono- and complex fibers stretched over it as they mainly meet the given requirements [4, 5]. We point out that it is very difficult to make a net-shape curtain weight-free under the on-ground processing of an umbrella antenna reflector. That is why in spite of the fact that there is no gravitational force in space conditions, under on-ground processing, the net-shaped curtain should be tensed uniformly to the open reflector’s skeleton with a force excluding its bending caused by its own weight being beyond the permissible values. If the tension of a radio-reflecting net shaped curtain is not sufficient, the contact between gold-plated or nickel-plated metal fibers becomes weaker and the radio-reflecting properties of a net-shaped curtain decrease.

Figure 1.

In addition, the net-shaped curtain can be heated by the sun during the operation of the antenna and it can weaken a curtain’s tension and as a result the facet’s flatness can be spoiled due to its bulging.
Folds can form on the reflecting surface of an open reflector after its long-term storage. Folds can spoil the geometrical accuracy of the facets’ surface. In contrast, the strong and nonuniform tension of a net-shaped curtain onto the skeleton causes an asymmetric damping impact on the opening reflector’s skeleton, which decreases the opening reliability and also it becomes necessary to increase the springs’ rigidity in the mechanism for opening the rods of a folding frame skeleton or to introduce an additional mechanism for its forced opening [3, 6–9]. The tension forces of metallic stockinette net-shaped curtains on the folding skeletons of modern large space antenna are obtained experimentally. Depending on the type of netshaped curtain, it ranges from 5 to 12 g/cm [4, 7].

Thus, a contradictory problem appears. On one hand, the net-shaped curtain should be tensed with force to secure the required radio-technical performance of the antenna. On the other hand, the netshaped curtain tension should be uniform with the minimal permissible force. To solve this problem, it is necessary to generate efficient methods to check the force and uniformity of the netshaped curtain’s tension in the reflector’s folding skeleton [7].

2. Description of methods of installation of mesh radio-reflection surface on folding structure of large-sized mirror antenna

Currently, there are two main types of large-size folding mirror antennas with a mesh radio-reflective surface. These are folding umbrella-type antennas and folding antennas with truss structure from tetrahedral cells (Fig. 1).

Installation of the mesh radio-reflective surface on a folding framework of the umbrella-type mirror antenna includes the following steps [10, 11].

Step 1. It is manufacturing of a counterpart of the mesh radio-reflecting surface of the folding umbrella-type antenna.

Step 2. Cutting and attaching a mesh radio-reflective surface to the counterpart (Fig. 2, a). At the same time, the tension control of the mesh radio-reflective surface is carried out, for example, by mechanical method by pressing the indenter into the controlled surface with a specified force and measuring the depth of the indentation [12, 13].

Step 3. Transferring the mesh radio-reflective surface to the open folding framework of the umbrella-type mirror antenna by the counterpart and securing it (Fig. 2, b) and deleting the counter pattern.

Installation of the mesh radio-reflective surface on the open truss structure of the folding mirror antenna from the tetrahedral cells is carried out as follows. The initial problem of setting a net-shaped curtain onto the facet of a tetrahedral cell is solved by the transfer method consisting of the following technological operations. The tensed net-shaped curtain 2 is put onto the triangular technological
frame 1 with pins over the perimeter with a force of 5 g/cm along each of the triangle’s meridians (Fig. 3a). Moreover, the sizes of the technological frame’s sides are a few sizes higher than those of the facet’s sides. The distance between pins is 50 mm and the force of the preliminary tension of the net-shaped curtain is 5 g/cm. After that with the help of tensoframes 3, the tension forces of the net-shaped curtain 2 are measured and recorded at the reference points (Fig. 3b). The results are processed, and if the disallowed nonuniformity of the net-shaped curtain’s tension with forces differing from the required ones are revealed, the operator recommends correcting the tension of the net-shaped curtain, which is taken away from the pins in the mentioned places, elastically deformed, and put on again. In this case the correcting displacement of any checked point of the net-shaped curtain initiates the displacement of the neighboring points and as a result the state of the elastic forces obtained previously is violated and the uniformity of the net-shaped curtain’s tension in the examined segment of the surface of the triangular facet is also violated. As a result it is necessary to perform the new iterations during the process to specify the position of the same points. The high number of check points, ranging from several dozen to several hundred for one facet, depending on the facet size, and the need for algorithmic data processing have made it very laborious to check a net-shaped curtain’s tension with the help of tensoframes, especially if the number of facets is high (Fig. 1). When the operation for tensing the net-shaped curtain onto the technological frame is finished, an unstretched tape made of (for example) aramid fibers is sewn over the triangular perimeter of the tensed net according to the real sizes of the side of a specific triangular facet of the skeleton’s tetrahedral cell. The excess of net-shaped curtain is cut off. The obtained triangular segment of radio-the reflecting surface is fixed via the tape to the folding rods 4 from the operating side of the reflector’s skeleton. The folding rods 4 from the operating side and the folding rods 5 from the back side are spring-loaded for opening and hinged by rods 6 similar to the structure presented in Figure 1. The edges of neighboring facets are sewn by metallic fiber. After each opening of an umbrella antenna during its trial, the net-shaped curtain’s tension on the reflector’s skeleton is again selected checked. By considering the fact that the total number of triangular facets made of metallic stockinette fabric of a net-shaped curtain can range from several hundred to several thousand, the process for manufacturing the radio-reflecting surface according to the presented technology is very labor- and time-consuming. In this way, the following complex problem was defined: to develop a method to check online a net-shaped curtain’s tension, which makes it possible to ensure the uniform tension of a net-shaped curtain with the given force and fix it to the folding rods of the working surface of the skeleton’s frame directly on the open reflector’s skeleton [7].

The experimental methods for investigating tensions and deformations are well known and some of the main ones are given below: tensometry, polarization-optical method, brittle coating method, analogy method, and separating nets method [7, 14]. However, they are not able to solve the defined problem. This is due to the fact that the contact methods directly affect the main parameters of a net-shaped curtain’s tension and they are very labor-consuming to implement for bicurvature surfaces of large (with a diameter of at least 30 meters) folding structures. Therefore, the contactless methods are of interest. A method for determining a net-shaped curtain’s tension is presented in [15], based on methods for processing, analyzing, and neurally classifying the textural photographic images of a net-shaped curtain. The procedure for determining a net-shaped curtain’s tension consists of three stages: to calibrate the classifiers for the given type of net-shaped curtain; to take photographs of the net-shaped curtain; and to calculate the tension forces and generate tension topograms according to the photographs with the help of the developed software. In contrast to measurements with the help of tensoframes (Fig. 3), this method is contactless and makes it possible to increase the measurement accuracy. However, just as the other methods, it is a discrete method, which does not allow us to implement online a net-shaped curtain with uniform tension with the given stretching forces directly onto the skeleton of an antenna reflector. Checking the uniformity of a net-shaped curtain’s tension with the given forces online during its installation onto the skeleton of an umbrella antenna reflector makes it possible to significantly decrease the labor-intensiveness of the technological process and increase the automation level. In this way, the contactless online methods for checking the tension of a
net-shaped curtain’s radio-reflecting surface of large umbrella antenna reflectors are promising and topical. Let us examine the online method based on the Moire phenomenon [7].

![Figure 3. Net-shaped curtain placed on folding skeleton of antenna reflector with triangular facets by transfer method.](image)

It is known that if at least two nets consisting of lines, points, or other geometrical elements are overlaid, the Moire pictures consisting of alternating dark and light strips appear [14, 16]. It is reasonable to use the Moire phenomenon due to the following effects [7]: it is not necessary to place any nets on the measured object since it is a net itself; the Moire phenomenon visualizes deformations over the entire examined surface; therefore, the epictures, appearing when the reference net is placed on the measured object, give a complete picture of the uniformity of the tension in a net-shaped curtain and the tension forces; the physical properties of the net’s material does not influence the measurement result, since the Moire phenomenon has a geometrical character; the reference net can be virtual.

Let us describe and give an example of a practical application of a contactless online method by using the Moire phenomenon for checking online a net-shaped curtain’s tension during its assembly on the folding skeleton of an antenna reflector [7].

Preliminarily we need to generate virtual images of the reference net of a specific type and the reference Moire pictures obtained when the deformed net is placed on the reference one. The size and view of Moire pictures depend on the orientation angle of the second reference net and the degree and direction of the deformation with respect to the first (basic) one.

For this purpose the real net-shaped curtain is stretched uniformly on any technological skeleton with less than the required force, which is determined by one of the described methods and the obtained image is fixed with the help of a graphical software, for example, Windows 7 Paint, or a later version. The same net is placed in the transparent mode on the image of the obtained basic reference net. After this the second net is rotated and deformed with respect to the first one. As a result the set of graphical samples of reference Moire pictures are obtained for different angles of rotation (Fig. 4: 15° (a), 30° (b), 45° (c), 60° (d), 75° (e), 90° (f)) and degree of deformation (Fig. 5). From Figure 4 it is seen that the sizes of Moire pictures become maximal under an angle of rotation of 90° and angles up
to ±15°. These positions can be accepted as the initial ones. Also, it is possible to accept the angle of rotation of 0° as the initial one, when the Moire pictures are absent.

Figure 4.
Figure 5. Moire pictures formed by placing two identical reference nets on one another with one of them being horizontally stretched with respect to another one by 10% (а), 20% (b), 30% (c); same under vertical stretching by 10% (d), 20% (e), 30% (f); same under horizontal stretching by 10% (g), 20% (h), 30% (i).

Figure 5 depicts the Moire pictures formed if we place two identical reference nets on each other with one of them stretched horizontally (а–c), vertically (d–f), and horizontally-vertically (g–h) by 10, 20, and 30%, respectively, with respect to another one. From Figure 5 it is seen that the sizes of Moire pictures decrease if the deformation of the stretching curtain is increased. In this way, the tension force of a net-shaped curtain is related to the geometrical sizes of Moire pictures and it can be determined by measuring its linear sizes. The relationship between the tension force and degree of deformation is determined experimentally for the chosen type of net-shaped curtain. As a result a virtual set of graphical samples of reference Moire pictures is obtained and it can be used for different purposes.

Figure 6 depicts the general view of a device for implementing the contactless online method for checking the tension of the net-shaped curtain 1 on the folding skeleton of an antenna reflector generated by using the Moire phenomenon.

The folding skeleton is similar to the structures presented in Figs. 1 and 3 and consists of the breaking rods 2 (spring-loaded for opening) of the working surface and of the breaking rods 3 of the back surface hinged to each other by the diagonal rods 4. The video-camera 5 is placed (the support arm is not shown) when installing the net-shaped curtain 1 in the bottom part of the skeleton. It is connected by a cable or by a radio-line with recording units. Monitor 6 with the reference Moire picture corresponding to the required tension uniformity of a specific type of net-shaped curtain and to the force, and monitor 7 with the current online video-image of net 1 on the skeleton, are placed near the operators. Monitors 6 and 7 are also connected by a cable or a radio-line with the recording unit. On the working surface of each of the breaking rods 2, the support arms 8 with deflected “ears” 9 are set to fix a net-shaped curtain 1 to the skeleton. The net-shaped curtain is stretched taut and fixed to the skeleton as follows. The operators stretch a segment of a net-shaped curtain and place it on ears 9.
Moreover, the respective Moire picture appears on monitor 7. After this by replacing the net-shaped curtain on ears 9, we try to obtain in monitor 7 a Moire picture that is similar to the Moire picture in monitor 6, with an acceptable level of uniformity and forces of tension of the net-shaped curtain 1 on the skeleton. The geometrical sizes of the obtained Moire pictures are measured directly on the screen of monitor 7. Therefore, the measurement accuracy can be increased by a fragmentary increase of the examined part of the images on the monitors. The operation is then repeated for the neighboring segments (facets) and the installed segments of the net-shaped curtain are finally fixed to the support arms 8 by bending ears 9 and by pressing them in to the respective hollows in the support arm 8. The excess of the net-shaped curtain is cut or tightened. The segments of the net-shaped curtain on the support arms are placed with overlapping, and as a result, a reliable electric contact between them is achieved.

Figure 7 depicts the fragment of the folding skeleton of an antenna reflector, on which the presented procedure is used for placing a uniformly tensed net-shaped curtain with the given force.

![Figure 7. Fragment of folding skeleton of antenna reflector with net-shaped curtain placed by using developed contactless method based on Moiré phenomenon.](image)

### 3. Conclusion

We have presented the method makes it possible to minimize costs and check online a net-shaped curtain’s tension over the cell surface during its installation on the folding skeleton of an antenna reflector, increase the measurement accuracy since the Moire strips increase the images and displacements [7, 16], exclude the metrological processing of the results of the technical measurements, reduce the errors of a device [17, 18], and simplify the measurement system (with respect to the known methods), since it is not necessary to place any nets or devices directly on the object, and which is characterized by a low degree of sensitivity to temperature oscillations and environmental dust.

The developed method also makes it possible to increase the degree of automation of the tension process of a net-shaped curtain on large folding skeletons of antenna reflectors and allows the
technical staff to check this technological operation online simultaneously on several distant units with the help of a telebridge.

The developed method is universal and can be used not only to manufacture antenna reflectors with the working surface in the form of a net-shaped curtain but also in any other structures in which the checked element is a net, regardless of the material of which it is made.

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