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Abstract

Corner reflectors are widely applied to the precise monitoring of crustal deformation. As shown in recently, however, the machining tolerance of rectangle trihedral corner reflectors in the production and deploy process often results in the changes of RCS. The Radar Cross Section (RCS) of rectangle trihedral corner reflectors are calculated based on Physical Optics Method (PO), the objective of this paper is to study the effect of machining tolerance on RCS of rectangle trihedral corner reflectors with respect to angle tolerance, and unevenness tolerance. The result shows that angle tolerance has a little effect on RCS of rectangle trihedral corner reflectors while unevenness tolerance has a major impact on RCS of rectangle trihedral corner reflectors in practical applications.

Keywords: Corner Reflector, Radar Cross Section (RCS), Tolerance

1. Introduction

China is a natural disaster-frequency area due to the complex physical geography conditions, and land subsidence and landslides are the most typical geological disaster. The crustal deformation movement and earthquake has extracted successful by InSAR since 1993[1-6], the InSAR technique is widely used in the fields of crustal deformation worldwide monitoring, such as the ground displacement study was caused by land subsidence, downhill, landslide, earthquake, volcanic activity[7-9], and it has achieved very many results. Although the differential interferometer SAR (D-InSAR) has the advantages of big area, high speed and precision and compensated for the lack of GPS and conventional surveying, its limitations of coherence descent phenomena of homologous points among images caused by decoherence can not be neglected, and this problem recently has also attracted more and more researcher’s attention [10-11]. Synthetic aperture radar (SAR) is a useful tool for ground topography and deformation monitoring. Potentially accurate interferometric results are limited by critical factors, such as temporal and geometric decorrelation [12]. The first of these phenomena is related to the temporal variability of electromagnetic properties, while the second is strictly caused by ambiguous satellite position. Recently, permanent scatterers technique has been proposed to overcome the above difficulties. It is based on the identification of highly reflective pixels, called permanent scatterers (PS), coherent over long time intervals, which must be small enough to have sufficient phase stability. On these pixels, surface deformations can be detected with millimetric accuracy, elsewhere attainable only by optical techniques.

A large number of natural PS exists in regions such as urban and rocky areas, which are then classified as highly coherent. When monitoring poor coherent locations (vegetated areas), artificial PS are needed to solve temporal decorrelation problems [12]. However, there are no useful permanent scatterers in open fields such as sea, desert and grass land area. So the artificial corner reflectors has been proposed and used in SAR interferometer quickly. Artificial corner reflectors are usually employed in actual monitoring. They are metallic structures geometrically designed to reflect most of the incoming energy back in the direction of incidence. Typically, radar cross section (RCS) values lead to the use of large-sized CR for the required SAR application frequency [12], thus these artificial
Corner reflectors are extremely effectively. Their structural configuration, which has an open base facing the satellite radar beam, has a large RCS and strong reflection characteristics.

Corner reflectors have overcome the shortcomings of the traditional D-InSAR technology, and widely used in the calibration of SAR images. Corner reflectors are the strong scattering sources in the side-looking direction, and are dihedral or triangular trihedral structure composed of two or three metal plates. The strong scattering echo appears in a wide range of angles when the metal plates are mutually orthogonal, that is strong RCS. Therefore, the artificial corner reflectors are often made into radar echo enhancement installations of all shapes in the crustal deformation and land subsidence monitoring field [13-14], and forming corner reflector-InSAR (CR-InSAR) technology. The definition of CR-InSAR would be this: the standardized and a number of corner reflectors are set up in region of interest (ROI) in advance. The corner reflectors have strong reflection characteristics for the radar wave, and the positions of the corner reflectors are stable and the deformation is very tiny. The corner reflectors remain a high level of coherence in a few years. CR-InSAR should always pay attention not only to the ground surface settlement in large area, but also to the small deformation in key object region. The corner reflectors have advantages of lower costs in the manufacture and high precision, with wider application prospect [15-17].

Figure 1. Physical map of rectangle trihedral corner reflector

So far the most common type of corner reflectors in study includes dihedral corner, triangular pyramidal trihedral corner and rectangle trihedral corner. After a long term experiment of manufacture and arrangements of corner reflectors in outdoors, the results show that rectangle trihedral corner reflectors has the typical structure of scattering and large RCS under the same conditions[18-19]. As shown in Figure 1, the standard rectangle trihedral corner reflector is made from three mutually perpendicular metal plates. But there are many machining tolerance in the production and deploy process, such as angle tolerance, unevenness tolerance, and so on. These machining tolerances will influence RCS of rectangle trihedral corner reflectors greatly, so it is necessary to study the RCS changes caused by machining tolerances and very important to the manufacture, use and deploy. However, the analysis of the machining tolerance on rectangle trihedral corner reflector is not involved in previous literature. After calculating the RCS of rectangle trihedral corner reflector, this paper analyses the influence of angle tolerance, unevenness tolerance on the RCS. The results of this research have theoretical value in some extent and economic value in practice.

The goals of this paper is to analysis the machining tolerance of the rectangle trihedral corner reflector in the producing process, the machining tolerance mainly contains angle tolerance and unevenness tolerance. The result shows that angle tolerance has a little effect on RCS of rectangle trihedral corner reflectors and the unevenness tolerance has a major impact on RCS of rectangle
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triangular corner reflectors in practical applications. So we should take more attention to the unevenness tolerance in the production process of the rectangle trihedral corner reflector.

![Figure 2. Schematic of rectangle trihedral corner reflector](image.png)

2. Basic theories

The rectangle trihedral corner reflector is commonly made from metal materials; these possess excellent electroconductivity and permeability, such as aluminum. The geometry structure of rectangle trihedral corner reflector is shown in Figure 2. Due to the regular geometric shapes of the rectangle trihedral corner reflector, a radar beam forms very strong echo signal and RCS after several reflections, and is manifested by a brilliant star patch in SAR image. The rectangle trihedral corner reflector as shown in Figure 1, the bottom surface is 1 m × 1 m, the side surface is 1 m × 1.5 m.

The square root formula of RCS of rectangle trihedral corner reflector based on physical optics method as follows [13, 20]:

\[
\sqrt{\text{RCS}} = -j \frac{k}{\sqrt{\pi}} \int \vec{n} \cdot (\vec{e}_i \times \vec{h}_i) e^{jkr} dS
\]  

Where:
\( k = 2\pi / \lambda \) is freedom space beam formers; \( S_1 \) is the lighting of corner reflector; \( \vec{i} \) is the unit vector of incident wave; \( \vec{s} \) is the unit vector of scattering pattern; \( \vec{h}_i \) is the unit vector of the polarization of incident wave; \( \vec{r}_e \) is the unit vector of far field receiver; \( \vec{n} \) is the normal vector of flat surface of corner reflector; \( \theta_i \) is incident angle; \( \theta \) is angle of emergence.

With regard to arbitrary scatterer, its surface can be simulated by many flat surfaces. For arbitrary polygon surface, the formula (1) can be easily converted to contour integration formula:

\[
\sqrt{\text{RCS}} = -\frac{\vec{n} \cdot (\vec{e}_i \times \vec{h}_i)}{\sqrt{\pi}T} e^{jkr_{\text{RCS}}} \sum_{m=1}^{N} (\vec{P} \cdot \vec{a}_m) e^{jkr} m \cdot \frac{\sin(\frac{1}{2}k\vec{a}_m \cdot \vec{w})}{1/2 k\vec{a}_m \cdot \vec{w}}
\]  

Where: RCSB is the bistatic RCS of Reflection plate; \( \vec{n} \) is the flat normal unit vector; \( \vec{r}_o \) is the position vector nearby source point in flat surface; \( \vec{w} = \vec{i} - \vec{s} \); \( \vec{a}_m \) is the position vector which is used to describe the m-th source point in flat surface; \( T \) is the projective length of \( \vec{w} \) in surface;
\[ \hat{p} = \hat{n} \times \hat{w} / |\hat{n} \times \hat{w}| \text{ is unit vector of } \hat{w} \text{ perpendicular to flat surface; } M \text{ is the number of flat surface brim.} \]

When calculate thin cylinder RCS, \( |w - \hat{i} - \hat{z} - 2i| \), the direction of polarization of reception unit drift to the direction of polarization of incidence wave, \( \hat{z} \times \hat{z}' \) has reached maximum, namely, \( \hat{z} \times \hat{z}' = \hat{z}' \). Then, we got the thin cylinder RCS formula [21]:

\[
\text{RCS} = \frac{\hat{n} \cdot \hat{s}}{2\sqrt{\pi} \cdot \sqrt{1 - (\hat{n} \cdot \hat{s})^2}} \sum_{m=1}^{M} \frac{a_m e^{-j2km}}{|\hat{n} \times \hat{s}|} \cdot \alpha_m e^{-j2km} \sin(-k\alpha_m \cdot \hat{s}) \tag{3}
\]

3. RCS calculation

Figure 2 is the schematic diagram of rectangle trihedral corner reflector. The RCS of corner reflector is controlled by two angles \( \theta \) and \( \varphi \) as well as the edge length \( l \) of the corner reflector aperture. The angle between the radar sight line and the project line of the symmetry axis of the corner reflector on the datum plane is the angle \( \theta \), the angle between the symmetry axis and its project line on the datum plane is the angle \( \varphi \). Along with the direction of the symmetry axis, the RCS of corner reflector changes its value.

After a long test in field about the distribution of corner reflectors, the RCS have reached a maximum value when the bottom plates are \( 1 \times 1 \) m, lateral plates are \( 1 \times 1.5 \) m and \( \theta = 45^\circ \text{ or } 90^\circ \). This paper, the commonest \( \theta = 45^\circ \text{ or } 90^\circ \) is taken as an example, while \( \varphi \in (0^\circ - 90^\circ) \) and the incident frequency is 10 GHz, the results as shown in Figure. 3. The peak values of RCS curve are essentially coincident with each other when \( \theta = 45^\circ \text{ or } 90^\circ \), and the maximum values have reached 14 dB. According to the maximum value formula of RCS: \( \text{RCS}_{\text{max}} = 12 \pi a^4 / \lambda^2 \), this calculation’s result basically coincides with the measurement’s results of rectangle trihedral corner reflector.

Through the analysis of the RCS curve of rectangle trihedral corner reflector and the maximum, the results show as follows: the calculation method of RCS which is based on physical optics method has smaller computation error and higher accuracy; when the angle among the neighboring plates of rectangle corner reflector is \( 90^\circ \), the maximal value of RCS is achieved, and the RCS curve will have a wide scattering peak value, the corner reflector is the easiest to identify in SAR image. At the same time, the more deviated the angle is from \( 90^\circ \), the more obvious the decrease of the peak value and beam width.

![Figure 3. The RCS curve of rectangle trihedral corner reflector](image-url)
4. Effects Analysis of Machining Tolerance on RCS

The machining tolerance on RCS of rectangle trihedral corner reflectors in the production, use and deploy mainly come from angle tolerance, unevenness tolerance.

4.1. Angle tolerance on RCS

From Figure 4, supposed that the incident frequency is 10 GHz and OA = OB = 1 m is remain unchanged, the point A, B deviate 2° along the X, Y axis, all points in the rectangle trihedral corner reflector will be deviate n°/2, where n = 0, 1, 2, 3, 4, 5, 6, etc. At that moment, points A and B are in the XOY plane. The RCS was calculated both in $\theta = 45^\circ$ and $\varphi \in (0^\circ-90^\circ)$. The RCS reduction curve of rectangle trihedral corner reflector was gotten; the RCS reduction curve is shown in the Figure 4.

![Figure 4. The relationship between angle tolerance and RCS](image)

4.2. Unevenness tolerance on RCS

In this study, we focus on the effectiveness analysis of unevenness tolerance on RCS of the rectangle trihedral corner reflector. We supposed that all three plates are backle outward, the biggest backle outward height lies in the middle of length orientation of plate surface, the shift extent of backle outward from perimeter to center will be slow down. The unevenness tolerance index h is defined as ration of the maximum backlit outward height and the side length of plate. The height h is bigger, the more the extent to backlit outward height.

When incident frequency is 10 GHz, azimuth angle $\varphi = 45^\circ$, elevation angle $\varphi \in (0^\circ-90^\circ)$, the relationship between h and RCS with h = 1%, 2%, 3%, 4%, 5% and 6% is calculated, respectively. The relationship curve gained unevenness tolerance index h with RCS as Figure 5 shows.

![Figure 5. The relationship between the h and RCS](image)
5. Conclusions

There are many natural PS exists in regions such as urban and rural area. But there are few in the open area such as desert and grasslands. The artificial corner reflectors are proposed in this condition. The artificial corner reflectors have the important role in earthquake crustal deformation, land subsidence and landslides monitoring. Their structural configuration, which has an open base facing the satellite radar beam, has a large RCS and strong reflection characteristics. They are metallic structures geometrically designed to reflect most of the incoming energy back in the direction of incidence. Typically, radar cross section (RCS) values lead to the use of large-sized CR for the required SAR application frequency. This paper took the rectangle trihedral corner reflector as an example, firstly, the RCS of rectangle trihedral corner reflector was calculated based on the physical optics method; secondly, the machining tolerance of rectangle trihedral corner reflector in manufacturing process was introduced and analysis including angle tolerance and unevenness tolerance; finally, we discussed the analysis of machining tolerance.

This paper proposes a new method of corner reflectors using angle tolerance, unevenness tolerance based on image processing information. On the base of the RCS calculation of rectangle trihedral corner reflector, the influence of machining tolerance on RCS in production and deploy process was discussed. For angle tolerance and unevenness tolerance, the relationship between the different types of machining tolerance and RCS under given incident frequency conditions was obtained. The results show that the angle tolerance has little effect on RCS and could control angle tolerance in a proper range: unevenness tolerance have a major impact on RCS, with the large of unevenness tolerance, the loss of RCS increased gradually, and it is difficult to control unevenness tolerance and slotting tolerance in actual operation.

6. Acknowledgements

This work was supported by the Key Project of Shanghai Leading Academic Disciplines of China (No.J50103), and partially by the Key Project of National Technology Support Program of China (No.2008BAC35B04).

7. References

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International Journal of Digital Content Technology and its Applications, Volume 5, Number 7, July 2011


