Sains Malaysiana 44(12)(2015): 1701–1706

Radar Return Reduction for Wind Turbines using Bump Structures

(Pengurangan Radar Pantulan Gelombang untuk Kincir Angin Menggunakan Struktur Bonggol)

SHYH-KUANG UENG* & YAO-HONG CHAN WEI-HSIEN LU & HENG-WEN CHANG

ABSTRACT

Wind turbines are massive electrical structures. They produce large returns when illuminated by radar waves. These scatterings have a great impact on the operation of surveillance, air traffic control and weather radars. This paper presents two geometric modelling methods for reshaping wind turbine towers so that the Radar Cross Section (RCS) of wind turbines is reduced. In the proposed reshaping methods, bump structures are created on the surface of the conventional cylinder wind turbine tower. When a reshaped tower is illuminated by radar waves, the bump structures scatter incident radar waves into insignificant directions so that the strength of back-scattering is declined and the RCS of the wind turbine is decreased. The test results confirmed that the proposed methods significantly reduce bi-static RCS values of wind turbines. The proposed reshaping methods are practical, flexible and effective in alleviating the scatterings of wind turbines.

Keywords: Radar cross section; reshaping method; stealthy technology; wind turbine

ABSTRAK

Kincir angin merupakan struktur elektrik yang besar. Ia menghasilkan pantulan gelombang radar yang besar apabila dipancarkan. Taburan ini memberi kesan yang besar terhadap operasi pengawasan, kawalan trafik udara dan radar udara. Kajian ini menjelaskan dua kaedah pemodelan geometri untuk rekaan semula bentuk menara kincir angin supaya Keratan Rentas Radar (RCS) angin dikurangkan. Dalam kaedah yang dicadangkan, struktur bonggol diletakkan di atas permukaan silinder menara kincir angin biasa. Apabila menara kincir angin dipancarkan dengan gelombang radar, bonggol menyelerakkan gelombang tersebut ke pelbagai arah. Jadi kekuatan serakan balik berkurang dan keratan rentas radar kincir angin turut berkurang. Hasil ujian menunjukkan, keratan rentas radar dwi-statik kincir angin telah dikurangkan dengan banyak. Kaedah ini adalah praktikal, fleksibel dan efektif bagi mengurangkan serakan balik kincir angin.

Kata kunci: Kaedah pembentukan semula; keratan rentas radar; kincir angin; teknologi stealthy

INTRODUCTION

Wind-turbines are large electrical structures. They generate significant radiations when illuminated by radar waves. The scatterings from wind-turbines have a great impact on the operation of surveillance, air traffic control and weather radars (Matthews et al. 2007). Researchers had proposed stealthy technologies to reduce the radar returns of wind-turbines (Matthews et al. 2008). One well-known method is to coat the wind-turbine surfaces with Radar Absorption Materials (RAM) so that portions of the radar wave energy are absorbed and the scattering is decreased (Mathews et al. 2006; Pinto et al. 2009). However, RAM is expensive and not endurable under severe weather conditions. Its weight also increases the load of the wind turbine tower. An alternative strategy is to reshape the wind-turbine tower to reflect the incoming radar waves toward insignificant directions so that the scatterings in the designated directions are declined (Mathews et al. 2006; Pinto et al. 2009). Reshaping methods are usually more effective, endurable and less expensive than the coating method (Pinto et al. 2009).

In the work of Ueng & Chan (2015), they proposed two systematic reshaping methods for reducing the RCS of wind turbines. In their methods, convex structures were added on the surface of a conventional cylinder wind turbine tower. These convex structures disturb incident radar waves and thus the radar returns in designated directions were declined. The test results verified that their methods were effective and practical. However, the effectiveness of their methods was decided by the height and number of the convex structures. The limitation of their methods and optimal designs of wind turbine towers were not studied and reported in their work either. In this article, we revised their approaches and proposed innovative reshaping methods to reduce the RCS of wind turbines. The limitation and characteristics of the proposed reshaping methods are also studied and formulated in this paper. Optimal design strategies are searched and discussed so that engineers can rely on the data to design wind turbine towers according to their needs.

MATERIALS AND METHODS

The study in Pinto et al. (2009) surveyed the scattering capabilities of individual components of a wind-turbine and concluded that 75% of the radar returns were produced by the tower. Furthermore the tower is a stationary component. It does not rotate as the blades do. If the radiation from the tower is decreased, the entire scattering of the wind-turbine is constantly reduced. Thus, reducing the radar returns of the tower is the top priority in the reduction of the RCS of the wind turbine. We will focus on the reduction of RCS for the wind turbine tower in this work.

In the work of Baldauf et al. (1991), they found that adding a hemisphere on a reflector could reduce the RCS of the reflector. In our reshaping methods, we adopt this philosophy and utilize sinusoidal equations to generate bump structures on the wind turbine tower surface to diverge the incident radar waves for the purpose of reducing the RCS of the wind turbine. The proposed methods are flexible. The number and height of the bump structures serve as the key parameters in the shaping methods. Users can tune these two parameters to produce optimal towers according to their needs.

BUMPY TOWER MODELLING

Assume the wind turbine tower is a cylinder and stands vertically in the z-direction. Then the surface of the tower can be modelled by:

$$\begin{aligned} x(h,\alpha) &= r\cos(\alpha), \\ y(h,\alpha) &= r\sin(\alpha), \\ z(h,\alpha) &= h. \end{aligned} \tag{1}$$

In (1), r, α and h are the radius and modelling parameters of the tower surface. Assume that the tower height is L, the ranges of the parameters are:

$$0 \le h \le L, -180 \le \alpha \le 180. \tag{2}$$

In our first modelling method, we revise (1) to generate bumps on the cylinder tower surface. The x and y coordinates of the tower surface are computed by:

$$\begin{aligned} x(h,\alpha) &= (D+r)\cos(\alpha), \\ y(h,\alpha) &= (D+r)\sin(\alpha). \end{aligned} \tag{3}$$

In (3), D is the perturbation of x and y coordinates for producing bumps on the tower surface. Assume that k bumps of height A meters are to be generated. The perturbation D is computed by:

$$D(\alpha) = A\cos(k\alpha). \tag{4}$$

Apparently D generates k waves of amplitude A meters between α=0 and α=2π radians. Nonetheless the resultant tower surface is composed of not only k bumps but also k concavities because of the intrinsic property of the cosine function. It was called a wavy tower in the article of Ueng and Chan (2015).

On the wavy tower surface, the bumps disperse the incoming radar waves so that the RCS in the radial directions of the bumps was reduced. However, the concavities concentrate the incoming radar waves. Thus the RCS in the radial directions of the concavities was increased. To alleviate the concentration of radar waves, we use the following strategy to eliminate the concavities:

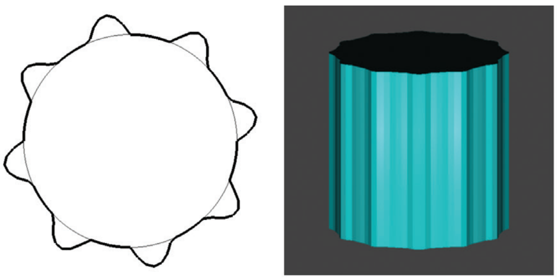
$$D(\alpha) = \max\,(A\cos(k\alpha), 0). \tag{5}$$

Equation (5) ensures that the perturbation D is always non-negative and thus the tower surface is composed of only k convex bumps. The tower modelled by (3) and (5) is called a bumpy tower in this article. The cross-section and 3D image of a short bumpy tower are shown in parts (a) and (b) of Figure 1. The bumps are parallel to the z-axis and orthogonal to the horizon. Users can modify A and k to change the height and the number of bumps.

BAMBOO TOWER MODELLING

Bamboo stems can support heavy loads, though they constitute less bio-mass. In the second reshaping method, we proposed to model the wind turbine tower as a bamboo-shaped structure so that both the stealth and strength of the tower were improved. Assume that k bumps of height A were to be generated, the geometrical modelling method of the perturbation D for the bamboo-shaped tower (the bamboo tower) is computed by:

$$\begin{aligned} \lambda &= L/k, \\ D(z) &= \max\left(A\cos\left(\frac{2\pi z}{\lambda}\right), 0\right). \end{aligned} \tag{6}$$



(a) cross-section of bumpy tower (b) 3D image of bumpy tower

FIGURE 1. Cross-section and 3D image of bumpy tower

In (6), L is the height of the tower and λ is the distance between two adjacent bump tips. The cosine function produces k waves between $z=0$ and $z=L$. Since D is a non-negative function of A and k, cavities were eliminated from the tower surface. Once D is computed, the tower surface is calculated by:

$$\begin{aligned} x &= (D+r)\cos(\alpha), \\ y &= (D+r)\sin(\alpha), \\ 0 &\le z \le L, \end{aligned} \tag{7}$$

The silhouette and 3D image of a bamboo tower is shown in parts (a) and (b) in Figure 2. The bumps on the bamboo tower surface were parallel to the horizon unlike the bumps on the bumpy tower, which were orthogonal to the horizon. These bumps were generated to diverse the incident radar waves toward insignificant directions to reduce back-scatterings. The effectiveness and capacities of bamboo tower and bumpy tower in the reduction of RCS will be tested and discussed in the next section.

RESULTS AND DISCUSSION

BI-STATIC RCS COMPUTATION

In order to measure their scattering attributes, the bi-static RCS of these two tower models were computed by using a computer program, presented in Ueng and Yang (2009). The kernel algorithm is based on the Shooting and Bouncing Ray (SBR) method presented in Lin et al. (1989). In the setting of the simulation, the z-axis points vertically and the horizontal plane is spanned by the x and y axes. The zenith angle (θ) and azimuth angle (ϕ) of the x-axis are θ=90 and ϕ=0 degree and the direction of the y-axis is θ=90 and ϕ=90. The radar is 3000 meters away from the towers. The radar frequency is 3 GHz. The incident direction of the radar waves is fixed at θ=90 and ϕ=0 (in the direction of the x-axis). The zenith angle of the receiver is fixed at θ=90, but the azimuth angle of the receiver varies from ϕ = -90 to ϕ = 90 degrees. For each azimuth angle, the bi-static RCS of the towers detected by the receiver is computed and recorded.

THE BI-STATIC RCS OF THE BUMPY AND BAMBOO TOWER

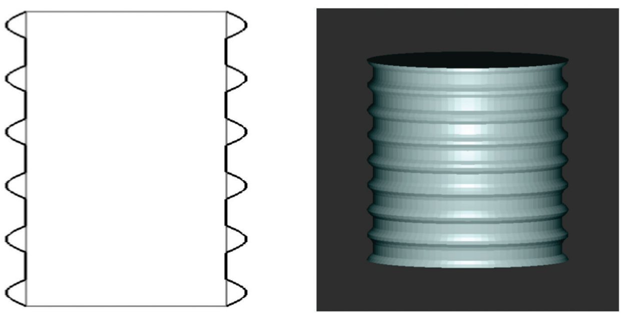
In the first test, we conduct simulations to explore the scattering capabilities of the cylinder, bumpy and bamboo towers. At first, we create a cylinder tower, a bumpy tower and a bamboo tower. The height of the 3 towers is 6 m and their radius is 1.5 m. Eight bumps of height 0.0333 m were created on the bumpy tower surface. The bamboo tower surface consists of the same number of bumps, but the bump height is increased to 0.1 m. The bi-static RCS of these two towers are shown in Figure 3. The bi-static RCS of the bumpy tower is displayed in 3(a) while that of the bamboo tower is shown in 3(b). For comparison, the bi-static RCS of the cylinder tower is also computed and depicted in green colour in the figures.

Based on the graphs shown in 3(a), we find that the back-scattering (about θ=90 and ϕ=0) of the bumpy tower is smaller than that of the cylinder tower by about 5 dB. The RCS between the azimuth angles of ϕ=-20 and ϕ=20 is also alleviated. Portions of radar returns in this region are reflected by a bump toward other directions, thus the RCS is decreased. However, the RCS in some other directions was increased, for example around ϕ=60 and ϕ=-60. These directions are radial directions of bump corners. Bump corners behave similar to dihedral reflectors. They concentrate on the incident radar waves and produce significant RCS in the radial directions. Therefore, to reduce the back-scatterings, the receivers should face bumps and avoid residing in the radial directions of the corners.

Figure 3(b) shows the superiority of the bamboo tower. The bi-static RCS of the bamboo tower is smaller than that of the cylinder tower by about 10 dB in all azimuth angles. The bamboo tower possesses corners as the bumpy tower does. However, these corners face the horizontal direction. They reflect the incoming radar waves toward the sky or the sea. (In this work, we assume the wind turbine is stalled offshore.) No strong return is produced in any azimuth angle. Hence its performance is better than the bumpy and cylinder tower.

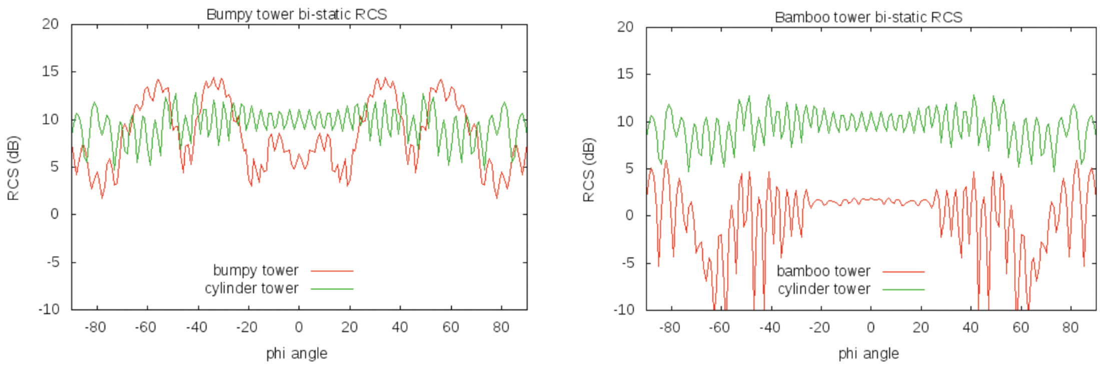
THE INFLUENCES OF THE BUMP HEIGHT

Ueng and Chan (2015) found that the bump height had a significant impact on the scattering characteristics of the



(a) silhouette of bamboo tower (b) 3D image of bamboo tower

FIGURE 2. Profile and 3D image of bamboo tower



(a) bi-static RCS of bumpy tower

(b) bi-static RCS of bamboo tower

FIGURE 3. Bi-static RCS of bumpy and bamboo towers, left: the bumpy tower, right: the bamboo tower

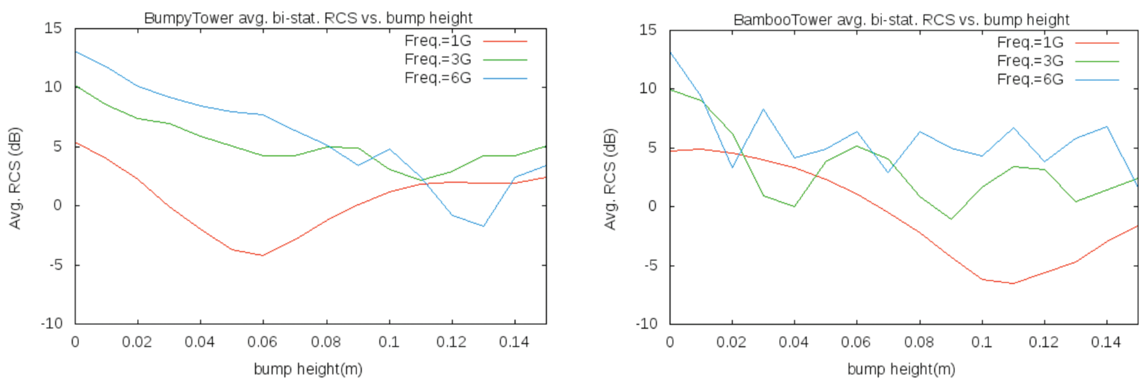
wavy tower, though no clear study was presented. In order to show the relation between the scattering behaviour of the towers and the bump height, we conduct a series of tests. In the tests, 8 bumps are created on the bumpy and bamboo tower surfaces, but the bump height is varied from 0 to 0.16 m. Three runs of simulation are conducted. The radar frequency is set at 1.0, 3.0 and 6.0 GHz in the simulations, but other parameters are kept the same as in the previous experiment. The average bi-static RCS of the bumpy tower and bamboo tower about the back-scattering direction (between ϕ=-10 to ϕ=10) is computed and depicted in Figure 4.

By examining Figure 4(a), we found that the bump height did affect the average bi-static RCS of the bumpy tower. At first, the RCS value declines as the bump height grows. However, after reaching the minimal point, the RCS value increases as the bump height grows. We also find that the optimal bump height is affected by the radar frequency. The smaller the radar frequency becomes, the shorter the optimal bump height is.

Figure 4(b) uncovers the relation between the bump height and the average bi-static RCS of the bamboo tower. When the radar frequency is 1 GHz, the influence of the bump height on the scattering behaviour of the bamboo tower is similar to that of the bumpy tower. As the bump height increases, the average bi-static RCS declines at first but grows after the bump height becomes taller than the optimal height. However, when the radar frequency is raised to 3.0 and 6.0 GHz, the impact of the bump height on the average bi-static RCS is different. The average bi-static RCS fluctuates as the bump height increases. Several optimal bump heights show up in the graphs. The distance between the optimal bump heights is proportional to the radar wavelength. In case the radar frequency is 3.0 GHz, the distance is about 5 cm, which is one half of the radar wavelength (10 cm). Similarly, the distance is about 2.5 cm when the radar frequency is 6.0 GHz (the radar wavelength is 5.0 cm).

THE INFLUENCE OF THE NUMBER OF BUMP

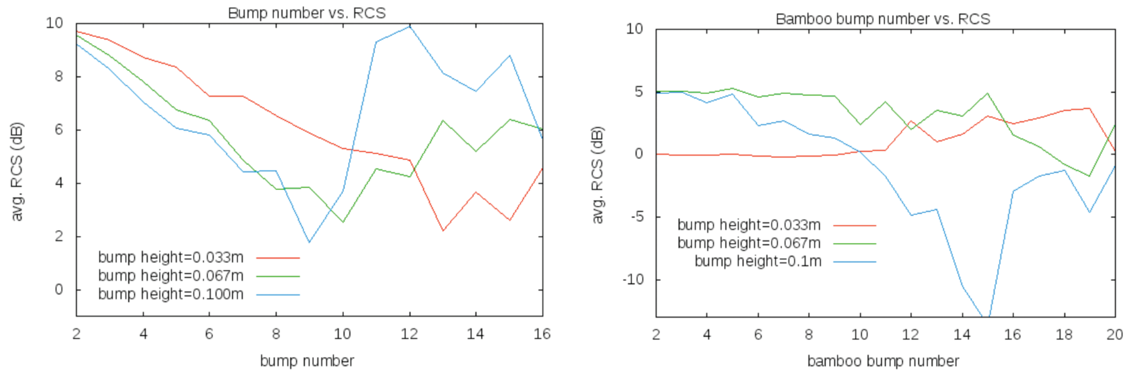
The number of bump also plays an important role in deciding the scattering patterns of the towers. In another experiment, we carry out tests to explore the influence of the number of bumps on the average bi-static RCS value. In these tests, the radar frequency is fixed at 3 GHz, but the number of bump is varied from 2 to 20. The bump height is set to 3.33, 6.67, and 10 cm. The average bi-static RCS



(a) bumpy tower, bump height vs. RCS

(b) bamboo tower, bump height vs. RCS

FIGURE 4. Relation between bump height and RCS, left: the bumpy tower, right: the bamboo tower



(a) bumpy tower, bump number vs. RCS (b) bamboo tower, bump number vs. RCS

FIGURE 5. Relation between bump number and RCS, left: the bumpy tower, right: the bamboo tower

between ϕ=-10 and ϕ=10 is computed and displayed in Figure 5.

By examining Figure 5(a), we find that the optimal number of bump for the bumpy tower is 9 when the bump height is 10 cm. The optimal number of bump for the bumpy tower of bump height=6.67 cm is 10. As the bump height is decreased to 3.33 cm, the optimal bump number becomes 13. In conclusion, as the bump height increases, the optimal bump number decreases for the bumpy tower. The test results of the bamboo towers are shown in 5(b). When the bump height is 3.33 cm, the optimal bump number is not clear. As the bump height increases to 6.67 cm, the optimal number of bump is 19. If we increase the bump height to 10 cm, the optimal number of bump declines to 15.

Based on the test results, we find that the optimal bump number of the bumpy tower inclines while the bump height increases. The reason can be explained as follows: Larger bumps scatter radar waves better than smaller bumps. Thus using a few larger bumps can produce better results. As the number of bump increases further, the gaps between the bumps become narrower. These gaps concentrate radar waves and produce larger RCS in the back-scattering direction. Thus the average bi-static RCS increases. This relation is not obvious for the bamboo tower when the bump height is low. In case that the bump height is raised, the bamboo tower shares similar property with the bumpy tower: As the bump height increases, the optimal bump number decreases.

CONCLUSION

In this paper, we present two parametric surface modelling methods for reshaping wind turbine towers. In the modelling algorithms, horizontal and vertical bump structures were created on the surfaces of the conventional cylinder tower to scatter incident radar waves. The experimental results verify that adding these bump structures reduces the average bi-static RCS value in the back-scattering direction. The test results also showed that the effectiveness of the proposed methods is affected by the number and height of bumps. Thus optimal tower shapes are possible to achieve by tuning the bump number and height. The scattering behaviours of these towers are also influenced by the radar frequency. When the radar frequency is high (=9 GHz), higher bumps (=13 cm) are preferred for the bumpy tower. However, the behaviour of the bamboo tower is different. The optimal bump height of the bamboo tower is periodic. Multiple optimal bump heights, separated by a half of the radar wavelength, are applicable for the bamboo tower. The experimental results also indicate that the bamboo tower possesses the least bi-static RCS than the bumpy tower and cylinder tower. It is the superior design.

ACKNOWLEDGEMENTS

This work was partially supported by Green Energy and Environment Research Laboratories, ITRI, Taiwan.

REFERENCES

Baldauf, J., Lee, S.W., Lin, L. & Jeng, S.K. 1991. High frequency scattering from trihedral corner reflectors and other benchmark targets: SBR versus experiment. *IEEE Transactions on Antennas and Propagation* 39(0): 1345-1351.

Ling, H., Chou, R.C. & Lee, S.W. 1989. Shooting and Bouncing Rays: Calculating the RCS of an arbitrarily shaped cavity. *IEEE Transactions on Antennas and Propagation* 37: 194-205.

Matthews, J.C.G., Sarno, C. & Herring, R. 2008. Interaction between radar systems and wind farms. *Proceeding of Loughborough Antennas and Propagation Conference*. pp. 461-464.

Matthews, J.C.G., Pinto, J. & Sarno, C. 2007. Stealth solution to solve the radar-wind farm interaction problem. *Proceedings of Loughborough Antennas and Propagation Conference*. pp. 101-104.

Matthews, J.C.G., Lord, J.A. & Pinto, J. 2006. RCS prediction for stealthy wind turbines. *Proceedings of EuCAP 2006*. pp. 6-10.

Pinto, J., Matthews, J.C.G. & Sarno, C. 2009. Radar signature reduction of wind turbines through the application of stealth technology. *Proceedings of EuCAP 2009*. pp. 3886-3890.

Ueng, S.K. & Chan, Y.H. 2015. A reshaping method for wind turbine RCS reduction. *Applied Mechanics and Materials* (in press).

Ueng, S.K. & Yang, F.S. 2009. Visual computing for scattered electromagnetic fields. *Advances in Visual Computing, Lecture Notes in Computer Science* 5876: 899-908.

Shyh-Kuang Ueng* & Yao-Hong Chan
Department of Computer Science & Engineering
National Taiwan Ocean University, Keelung City 202
Taiwan

Wei-Hsien Lu & Heng-Wen Chang
Green Energy and Environment Research Laboratories
ITRI, Chung Hsin Rd., Chutung, Hsinchu
Taiwan

*Corresponding author; email: skueng@mail.ntou.edu.tw

Received: 11 August 2014
Accepted: 23 June 2015