Research on influence of special-shaped honeycomb radar absorbing structure for wide-band absorbing design

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Abstract: To realise wide-band stealth of radar absorbing material, a special-shaped honeycomb radar absorbing structure within nested cone-shaped scattering configuration is designed. Based on the HS theory and the impedance matching design, the rule about the influence of the geometry parameter and electromagnetic parameter on the absorbing performance is analysed. In addition, the reflectivity performance is analysed on the condition of oblique incidence angles. By optimising the geometry parameters of the special-shaped honeycomb structure and designing the multilayer composite structure based on impedance matching theory, the results indicate that the two absorbing peaks can be formed for the special-shaped honeycomb radar absorbing structure, and the reflectivity is improved for both the vertical and oblique incidence angles.

1 Introduction

Honeycomb structure is a kind of common functional mechanics structure used for radar absorbing material. As the honeycomb structure is of good electromagnetics performance, especially by repetitiously reflecting electromagnetics wave inside the honeycomb structure, the absorbing band is widened. So, designing the honeycomb structure has great significance for wide-band stealth [1].

In order to research the influence parameters and the rules of radar absorbing performance for honeycomb radar absorbing structures, and to realise the wide-band stealth design, the equivalent electromagnetics parameters need to be distilled for honeycomb radar absorbing structure. The common electromagnetics equivalent methods include HS theory, SFT structure parameter by simplifying honeycomb hole as circle cross-section. Qiu K. P. [9] researches the influence of honeycomb shape parameter of honeycomb. In the paper, aiming at honeycomb radar absorbing structure, the electromagnetics parameters are archived based on HS theory. As a basic of wide-band absorbing design, a special-shaped honeycomb radar absorbing structure within nested micro-cone-shaped scattering configuration is designed. The influence rules of honeycomb hole geometry shape, structure thickness, electromagnetics parameters, and impedance matching parameter for multi-structure are researched for absorbing performance. By optimising design parameter of special-shaped honeycomb for the wide-band and wide-angle absorbing performance, the low reflectivity is archived for 2–14 GHz.

2 Theory for honeycomb equivalent electromagnetics parameter

The cross-section shape of honeycomb structure is shown in Fig. 1.

In Fig. 1, the element shape of honeycomb hole is standard hexagon, the geometry parameter is expressed as \( r \) in the \( y \) direction, and the parameter is expressed as \( \sqrt{3}r \) in the \( x \) direction. The simple honeycomb element is constituted of framework

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![Element shape sketch map of honeycomb structure](image)
The cube dimension rate $v_1$ for framework material and cube dimension rate $v_2$ for honeycomb-core material can be expressed as:

$$v_1 = \frac{w}{\tau} \left(2 - \frac{w}{\tau} \right)$$  
$$v_2 = \left(1 - \frac{w}{\tau} \right)^2$$  

In the HS theory, the upper limit and the lower limit expressive forms are adopted for the equivalent permittivity parameter. The forecast express is derived for describing the electromagnetic variety by comparing different limit cases. The upper limit express is shown as (3)–(5) in HS theory.

In order to realise the wide absorbing band and the low reflectivity of RAM from 2 to 12 GHz, in the meanwhile, to satisfy much stealth demand such as restraining the scattering for large oblique incident angle and weakening travelling wave, a special-shaped honeycomb structure within nested sub-miniature scattering configuration is designed. By designing the composite structure configuration for the honeycomb within cone-shaped scatter, and matching the impedance parameter for multi-structure materials, multi-wide absorbing bands are formed in the range of microwave.

The designed special-shaped honeycomb radar absorbing structure is shown in Fig. 3 in the paper. The special-shaped honeycomb radar absorbing structure is constituted of hexagon period element and cone-shaped scatter array. In where, the aramid resin material is used as the framework material of special-shaped honeycomb structure. The surface of structure is the radar wave absorbent, and carbon is used as absorbent. The cone, tetrahedron, pentahedron, and polyhedron can be all used as nested scatter shape. The period array follows the hexagon design. In the bottom, scatter is conjoint with hexagon framework. On the surface of scatter, the RAM is coated, and the absorbent is the same with absorbent on the wall of honeycomb hole.

On the basic of above design special-shaped honeycomb structure form, a multi-layer radar absorbing structure is made up of special-shaped honeycomb structure having different parameter, as shown in Fig. 4. For the each radar absorbing structure, geometry parameter and electromagnetic parameter are optimised. In addition, by designing the impedance matching between the three structures, the absorbing effect is archived simultaneity for multi-bands.

According to Fig. 4, the signs 1 and 7 are the outer high-transmission panel. Air is on the left of first layer, the electromagnetic wave incidents on the surface of first layer. PEC is on the right of seventh layer. The 2, 4, and 6 layers are special-shaped honeycomb structure within nested sub-miniature scattering, and the 3, 5, and 7 layers are hexagon framework and cone-shaped scatter array.

In the above expresses, the $\varepsilon_n$ and $\mu_n$ parameters are the equivalent permittivity and permeability.

### 3 Nested special-shaped honeycomb structure design

According to transmission line theory, when the electromagnetic wave pours into the multi-radar absorbing structure, shown in Fig. 2, the reflectivity is expressed as (9).

$$R = \frac{Z_n - 1}{Z_n + 1}$$  

where $Z_n$ is the input impedance of between the air and the nth RAM layer. It is the function of the thickness $d_n$, wave number $k_n$, characteristic impedance $\eta_n$, and the input impedance $Z_{n-1}$ of the $(n-1)$th layer.

$$\eta_n = j\omega\sqrt{\mu_n\varepsilon_n}/c$$  

$$Z_n = \frac{Z_{n-1} + \eta_n\varepsilon_n\eta_n}{\eta_n + Z_{n-1}\eta_n\varepsilon_n}$$  

$$\eta_n = \sqrt{\frac{\mu_n}{\varepsilon_n}}$$

In the above expresses, the $\varepsilon_n$ and $\mu_n$ parameters are the equivalent permittivity and permeability.
Table 1  Geometry parameters of the three special-shaped honeycomb structure layers

| Layer number | Thickness, mm | Hole size, mm |
|--------------|---------------|---------------|
| #2           | 1.93          | 2.75          |
| #4           | 1.98          | 1.2           |
| #6           | 1.98          | 1.8           |

Fig. 5 Influence of the first honeycomb hole size on reflectivity

Fig. 6 Influence of the second honeycomb hole size on reflectivity

Fig. 7 Influence of the third honeycomb hole size on reflectivity

shaped honeycomb structure. The high-transmission panel is located between honeycomb structure, signing as 3 and 5.

Table 1 lists the geometry parameters of the three special-shaped honeycomb structure layers.

4 Rule analysing for performance

The structure parameters of special-shaped honeycomb and electromagnetic loss of carbon material as radar absorbent can affect the electromagnetic performance for honeycomb structure; so, the absorbing performance of sandwich honeycomb structure is programmable. It has important significance for analysing and mastering the influence of structure parameters and electromagnetic loss on the absorbing performance.

In order to explore the wide-band and wide-angle design for thin stealth structure, the key influence factors and influence rule are researched, and the difference between special-shaped honeycomb and standard honeycomb is compared for the frequency respond characteristic. On the basic of analysing rule, the design parameters are optimised for the multi-radar absorbing structure. In the paper, reflectivity is simulated from 2 to 14 GHz. When the electromagnetic wave is incident perpendicularly on surface of the structure, the incident angle is denoted as 0°. The angle range for simulating reflectivity is from 0° to 90°. The permittivity is 3.8, and the permeability is 1 for the radar absorbent in the honeycomb structure.

4.1 Influence rule of hole size on reflectivity

By optimising the absorbing performance of the three special-shaped honeycomb structures, the influence rule of the hole size on reflectivity is analysed. The computed results are shown in Figs. 5–7.

According to Fig. 5, the influence rule of the first honeycomb hole size for reflectivity is summarised. There are two resonance absorbing wave crests in the reflectivity curve for the multi-absorbing structure, and the absorbing frequency is in the range from 3.4 to 5.3 GHz and 10.8 to 14 GHz. As the hole size increases, the two absorbing wave crests shift to the direction of higher frequency. Specially, it is better obvious that the hole size of #2 affects the absorbing wave crest on the higher frequency. In all, the absorbing performance is good and the reflectivity is lower than −10 dB for the frequency range from 3.8 to 5.7 GHz and the frequency higher than 11 GHz.

According to Fig. 6, as the hole size of #4 increases, the reflectivity curve is of better resonance absorbing effect in the neighbourhood of 4.5 GHz. In addition, above the 8 GHz, the absorbing wave crests gradually shift to the direction of higher frequency.

To reduce the reflectivity from 2 to 8 GHz, the hole size of #4 should be increased. By contraries, to reduce the reflectivity from 8 to 14 GHz, the hole size of #4 should be minimised. So, to synthesise the absorbing performance design for higher frequency and lower frequency in the microwave, the hole size of #4 is of key role. In all, the absorbing performance is good and the reflectivity is lower than −10 dB for the frequency range from 4 to 6 GHz.

According to Fig. 7, there are two absorbing wave crests in the reflectivity curve, and they are, respectively, located on the different band. As the hole size of #6 increases, the second absorbing wave crest shifts to the direction of higher frequency, and the reflectivity gets lower. In all, the absorbing performance is good and the reflectivity is lower than −10 dB for the frequency range from 3.5 to 6.2 GHz. When the frequency is higher than 10.2 GHz, the reflectivity is lower than −10 dB.

4.2 Influence rule of structure thickness on reflectivity

By optimising the thickness parameter of each special-shaped honeycomb structure, the influence rule of the structure thickness on reflectivity is analysed. The computed results are shown in Figs. 8–10.

According to Fig. 8, there are two absorbing wave crests in the reflectivity curve, and they are, respectively, located on the different band. As the hole size of #6 increases, the second absorbing wave crest shifts to the direction of higher frequency, and the reflectivity gets lower. In all, the absorbing performance is good and the reflectivity is lower than −10 dB for the frequency range from 3.5 to 6.2 GHz. When the frequency is higher than 10.2 GHz, the reflectivity is lower than −10 dB.
The variety rule for the thickness of #4 is different from the rule for #2.

According to Fig. 10, as the structure thickness of #6 increases, the two absorbing wave crests shifts to the direction of lower frequency. The thickness can mainly reduce the reflectivity from 3 to 6 GHz, and change the resonance frequency from 12 to 14 GHz.

In all, the absorbing performance is good and the reflectivity is lower than −10 dB for the frequency range from 3.5 to 6 GHz. As the frequency increases gradually, the reflectivity is lower than −6 dB. When the frequency is higher than 11 GHz, the reflectivity is lower than −10 dB, and the value can reduce from −10 to −18 dB.

By comparing the computed results in Figs. 8–10, when the thickness varies for each honeycomb, the resonance frequency will be changed. The variety relationship between the two absorbing wave crests and the thickness of each structure is different. So, by adjusting the thickness, it is realisable for controlling the resonance frequency value for absorbing wave crest.

4.3 Influence rule of scatter configuration on reflectivity

For the special-shaped honeycomb structure, nested micro-scatter configuration can choose cone-shaped and pyramid-shaped. Aim at the first special-shaped honeycomb, by FEM method, the influence of scatter configuration on reflectivity is analysed. Meanwhile, the reflectivity for special-shaped honeycomb within nested scatter is compared with that for standard honeycomb. In addition, aiming at the scatter configuration, the influence of RAM coating thickness on reflectivity is analysed. The RAM is carbon absorbent, and it is coated in the wall of special-shaped honeycomb.

According to Figs. 11 and 12, the cone-shaped scatter is subjoined in honeycomb structure, the absorbing performance is improved and the reflectivity can reduce about 7 dB. In Fig. 11, the cone-shaped scatter is used. In Fig. 12, the pyramid-shaped scatter is used, where standard honeycomb is structure without nested scatter configuration.

In addition, when the RAM coating thickness change from 0.2 to 0.6 mm, the absorbing peak is affected markedly, the reflectivity can reduce about 4 dB.

4.4 Influence rule of electromagnetic parameter on reflectivity

By optimising the electromagnetic parameter of honeycomb structure material, the influence rule of the RAM on reflectivity is analysed. The computed results are shown in Figs. 10–13.

According to Fig. 13, as the conductance of carbon material for #2 increases, the first absorbing wave crest on 4 GHz do not shift, but the reflectivity can reduce markedly about 10 dB. In addition, the second absorbing wave crest on the frequency from 10 to 14 GHz can shift to the direction of higher frequency. So, the reflectivity peak value can be affected markedly by the conductance of RAM.

According to Fig. 14, as the conductance of carbon material for #4 increases, the reflectivity of first absorbing wave crest on 4 GHz can be reduced more.

Fig. 8 Influence of the first honeycomb thickness on reflectivity

Fig. 9 Influence of the second honeycomb thickness on reflectivity

Fig. 10 Influence of the third honeycomb thickness on reflectivity

Fig. 11 Influence of the cone-shaped scatter on reflectivity

Fig. 12 Influence of the pyramid-shaped scatter on reflectivity

Fig. 13 Influence of the conductance for #2 on reflectivity
reduces markedly, the reflectivity value changes from $-13$ to $-22$ dB.

In all, it is advantaged to the absorbing performance from 3 to 5 GHz that adjusting the conductance of RAM for #4.

According to Fig. 15, as the conductance of carbon material for #4 increases, the reflectivity of first absorbing wave crest on 4 GHz do not vary, but the reflectivity of second absorbing wave crest on 13 GHz reduce markedly. So, it is advantaged to the absorbing performance for higher frequency that adjusting the conductance of RAM for #6.

In a word, by adjusting the electromagnetic parameter of #2, the two absorbing wave crests can be changed simultaneously. By adjusting the electromagnetic parameter of #4, it is advantaged to the absorbing performance for lower frequency. By adjusting the electromagnetic parameter of #6, it is advantaged to the absorbing performance for higher frequency.

5 Wide-band absorbing designing and oblique incident performance analysing

Based on nine common size for honeycomb, the special-shaped honeycomb structure form within nested cone-shaped scatter is used, the wide-band absorbing performance is optimised by impedance matching for multi-structure.

Aiming at the multi-honeycomb structure in Fig. 4, according to the transmission line theory, optimisation method can be adopted to design multi-absorbing structure. The object function is defined as $R = R(d_1, m_1, d_2, m_2, ..., d_n, m_n, f)$, where, $d_i$ is the geometry parameter including thickness and hole size.

On the basic of influence rules, by optimising design, the reflectivity is shown in Figs. 16 and 17.

The reflectivity result for perpendicularly and obliquely incidence is shown in Figs. 16 and 17. By increasing the thickness of #2, and reducing the thickness of #6, and adjusting the hole size for each layer, the whole absorbing performance is improved in microwave band. The reflectivity is lower than $-10$ dB from 3 to 14 GHz. In addition, in the case of oblique incidence, the low reflectivity can be kept.

6 Conclusion

Aiming at the special-shaped honeycomb absorbing structure, the simulation arithmetic, the influence rule of key parameters, and wide-band absorbing optimisation designing are researched. The research conclusions include the five aspects.

i. The equivalent electromagnetic parameter of special-shaped honeycomb is not only related with RAM and cubage dimension rate but also related with nested scatter configuration, hole size, and thickness.

ii. When the cone-shaped scatter is subjoined within the honeycomb, the reflectivity can be reduced about 7 dB.

iii. The influence of hole size for absorbing wave crests is obvious. When the hole size increases, the resonance peak will shift to the direction of higher frequency, and the reflectivity peak value can vary about 10 dB.

iv. As the thickness increases, the resonance peak will shift to the direction of lower frequency and the reflectivity peak value can vary to some extent.

v. The electromagnetic loss parameter is key and basic for impedance matching. As the RAM coating thickness increases, the reflectivity can be reduced about 4 dB.

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Fig. 14 Influence of the conductance for #4 on reflectivity

Fig. 15 Influence of the conductance for #6 on reflectivity

Fig. 16 Reflectivity of perpendicularly incident angle for the optimised multi-absorbing structure

Fig. 17 Reflectivity of obliquely incident angle for the optimised multi-absorbing structure

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