Research on microwave heating structure optimization of auxiliary material box of road maintenance vehicle

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Abstract. The arrangement and spacing of microwave comprehensive maintenance vehicle antenna array directly affect the heating efficiency and heating uniformity of asphalt mixture. In order to improve the heating uniformity of asphalt mixture, this paper proposes a microwave heating structure based on auxiliary materials box, and optimizes the microwave heating structure of auxiliary materials box of road maintenance vehicle through CST simulation platform. Firstly, in the way of side-by-side arrangement of the antenna array, the spacing of the antenna array is optimized, and the heating uniformity of the asphalt mixture in the auxiliary material box is the best when the spacing is 132mm×155mm under side-by-side arrangement. Then, under the optimal arrangement spacing, the orthogonal arrangement of antenna array was put forward, and it was concluded that under this arrangement, the heating uniformity of asphalt mixture increased by 12.1%, and the proportion of asphalt mixture increased by 8.7% at 80°C -160°C. This conclusion has certain reference value to the improvement of the heating effect of the auxiliary material box heating system.

1. Introduction

At present, the asphalt pavement is the most widely used pavement form in the highway. Due to the particularity of the asphalt material, the asphalt pavement is easy to maintain and renewable, and it is comfortable to drive on the asphalt pavement. However, the appearance of asphalt pavement cracks, ruts, pits and cracks seriously affects the comfort of driving and the convenience of transportation. It can be seen that the treatment of asphalt pavement diseases is of great significance. At present, many scholars at home and abroad have studied the regenerative heating of asphalt pavement in different ways [1]. Article [2] studied the hot air heating of asphalt mixture, and Reference [3] studied the heat balance of asphalt pavement by far infrared heating. Both hot air and infrared heating transfer heat from the surface of the heated object to the interior by using the principle of heat conduction or heat radiation, and it takes a long time to heat the asphalt mixture and the heating uniformity is not high. Compared with traditional hot air heating and infrared heating, microwave heating of asphalt mixture takes less time, the heating efficiency and heating uniformity are improved, and there are fewer coking and aging asphalt mixture during heating. Therefore, many scholars have studied the heating efficiency and heating uniformity of asphalt mixture by means of microwave heating [4]. Foreign scholar Hopstocky [5] found that asphalt has a poor ability to absorb microwaves, and the temperature rise of asphalt mixture under microwave radiation mainly comes from the conversion of microwave energy by aggregates. In [6] proposed a method of using the mean value and variance of the power loss density to evaluate the heating results according to the simulation results, but the mean power loss
density and the variance of the power loss density were not unified, and the determination coefficient of the heating quality was not derived. Articles [7] and [8] designed a horn radiant heater with Angle cone. By using HFSS simulation, it was found that the antenna length and the size of the horn mouth surface were important factors affecting the heating uniformity, and the design criteria of the horn mouth surface size and antenna length were established. All of the above researches are based on in-situ heating of heating wall and study different antenna structure and arrangement.

In order to improve the heating efficiency and uniformity of asphalt mixture, microwave heating of the auxiliary material box is proposed in this paper, which has certain influence on the heating efficiency and uniformity of asphalt mixture due to a series of reflection of microwave in the metal cavity of the auxiliary material box. Accessories box microwave heating is presented in this paper, the three-dimensional simulation model, based on the CST simulation platform, the auxiliary materials were analyzed, and the temperature of the asphalt mixture in the cloud and analyzes the orthogonal and side by side two different arrangement and the arrangement of different span of asphalt mixture, the influence of heating efficiency and heating uniformity, by microwave heating for road maintenance vehicle accessories box structure optimization, improve the material uniformity of the asphalt mixture is heated in the oven.

2. Analysis of auxiliary material box heating system

The choice of waveguide shape has a certain influence on the heating effect of asphalt mixture. Compared with the conventional rectangular waveguide, the two-fold horn waveguide [6] can form a compact antenna array with a large energy density, so the two-fold horn waveguide is selected.

| Disease touch location | 0~0.5 area (m^2) | 0.5~2 | 2~4 | Need to deal with depth (cm) |
|-----------------------|-----------------|-------|-----|---------------------------|
| Upper layer           | 179             | 61    | 20  | 5                         |
| Lower layer           | 188             | 59    | 22  | 5~15                      |
| total                 | 367             | 120   | 42  |                           |

For the repair of road potholes, the non-milling repair method is adopted when the potholes area does not exceed 4m^2 [9]. Relevant data are shown in Table 1. The average volume of potholes is calculated according to Equation 1:

\[ v_{av} = [(0.25 \times 179 + 1.25 \times 61 + 3 \times 20) \times 2.5 + (0.25 \times 188 + 1.25 \times 59 + 3 \times 22) \times 12.5] \times 100 \div (367 + 120 + 42) = 0.05 \text{m}^3 \] (1)

Therefore, the chamber size of the heater box type is 600mm*800mm*150mm. According to the relevant industry standard [10], relevant parameters of the asphalt mixture model are obtained as shown in Table 2. In combination with the heat calculation Equation (2), and substitute Equation (1) into Equation (2) to get the energy required to repair this pit is calculated to be 24161KJ.

\[ Q = \rho \cdot m \cdot \Delta T \] (2)

| density of asphalt mixtures kg/m^3 | Specific Heat Capacity KJ/°C/Kg | coefficient of loose paving material | Discharge temperature of mixture°C |
|-----------------------------------|---------------------------------|-----------------------------------|----------------------------------|
| 2350-2400                         | 1.39                            | 1.28-1.4                          | 160-170                          |

The power of magnetron used in related industries and researches is 1.0-1.6kw. Therefore, in this study, the magneto with 1.6kw and operating frequency of 2450MHZ is selected. When the electromagnetic conversion efficiency is 75%, at least 20 magnetrons are needed to meet the power demand. Therefore, in this paper, 20 magnetrons are selected to study the heating efficiency of asphalt mixture under different arrangement and spacing of the antenna array.
3. Modeling development in CST Microwave Studio

3.1. Establishment of antenna and auxiliary material box model
In CST Microwave Studio set up three-dimensional model of a single horn antenna, as shown in Figure 1(a), wall thickness is set to 2 mm, the antenna's material default to PEC (perfect electric conductivity), based on the study of antenna array configuration method, study the arranged side by side with the orthogonal configuration, two kinds of arrangement of the model configuration mode as shown in Figure 1(b), 1(c).

![Figure 1](image1.png)

**Figure 1.** The arrangement of the three-dimensional model of the two-fold horn and the antenna array: (a) shows a three-dimensional model of a single two-fold horn at the top, and at the bottom is the model of asphalt mixture; (b) antenna array arranged side by side; (c) antenna array arranged in an orthogonal way.

The influence of antenna array spacing and arrangement on the heating effect of asphalt mixture was studied by simulation, and 16 kinds of spacing arrangement were designed, with 4 kinds of spacing in vertical and horizontal directions, and the spacing of step length was 5mm. Spacing design is shown in Table 3 below:

| X direction(mm) | 147 | 142 | 137 | 132 |
|-----------------|-----|-----|-----|-----|
| Y direction(mm) | 165 | 160 | 155 | 150 |

**Table 3.** Spacing settings of antenna array in X direction and Y direction.

![Figure 2](image2.png)

**Figure 2.** Three-dimensional model of feed box.

![Table 4](image3.png)

**Table 4.** Parameters of asphalt mixture materials.

| coefficient of heat conduction | Loss tangent Angle $\tan\delta$ | relative permeability $\mu$ | relative dielectric constant $\epsilon$ |
|---------------------------------|-------------------------------|-----------------------------|---------------------------------------|
| 1.2W/$^\circ$C/m                 | 0.034                         | 1                           | 8.5                                   |
The three-dimensional model of the asphalt mixture material box is shown in Figure 2. The wall thickness of the asphalt mixture box is set to 4mm, and the material default is PEC. The basic parameters of the asphalt mixture material are shown in Table 4.

3.2. Setting of boundary conditions
CST Microwave Studio provides a variety of boundary conditions. According to the material setup of the model, since the box is an ideal conductor, the internal boundary conditions are solved by Maxwell's equation in integral form, such as Formula (3).

\[
\begin{align*}
\bar{e}_n \times (\bar{H}_1 - \bar{H}_z) &= \bar{J}_s \\
\bar{e}_n \times (\bar{E}_1 - \bar{E}_z) &= 0 \\
\bar{e}_n \cdot (\bar{B}_1 - \bar{B}_z) &= 0 \\
\bar{e}_n \cdot (\bar{D}_1 - \bar{D}_z) &= \rho_s
\end{align*}
\]

(3)

According to the results of Maxwell equation, the boundary conditions of asphalt mixture and the inner wall of the tank are set as \( E_t = 0 \).

4. Optimization of antenna array spacing
The arrangement and spacing of the antenna array have a certain influence on the heating efficiency and heating uniformity of the asphalt mixture. In this paper, Matlab programming is used to firstly select the way of side-by-side arrangement to heat the asphalt mixture, and four kinds of spacing are selected in X and Y directions. Relevant regulations [10] indicate that the minimum low pressure real temperature of asphalt mixture is between 70°C and 90°C. Considering that the time from baking to compaction of asphalt mixture is very short, it is considered that the temperature of asphalt mixture can reach 80°C. Experimental results [11] show that when the asphalt mixture is heated by microwave at more than 160°C, its elongation, penetration and softening point have negative changes, and the asphalt mixture is prone to aging and coking. Therefore, taking 80°C and 160°C as dividing points, the proportion of temperature segment of asphalt mixture was studied, and the amount of asphalt mixture conforming to the service temperature was analyzed under different arrangement and spacing. Using CST Studio suite software simulation, obtained the temperature of the asphalt mixture clouds X, Y direction in asphalt mixture surface of a value every 20 mm, each layer of export 1000 groups of data, every 20 mm thickness direction of a value, the data processing for asphalt mixture as a whole and the interlayer temperature mean value, standard deviation, coefficient of the discrete [12] and asphalt mixture proportion in 80°C to 160°C, its mathematical formula respectively (4) (5) (6).

\[
\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}
\]

(4)

\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2}
\]

(5)

\[
v_s = \frac{\sigma}{\bar{x}}
\]

(6)

\( n \) —total number of samples,
\( \bar{x} \) —average temperature,
\( \sigma \) —standard deviation of temperature,
\( v_s \) —discrete coefficient.
This section compares the discrete coefficient, the mean value and standard deviation of the overall temperature of the mixture and the proportion between 80°C and 160°C to analyze the heating simulation results of the asphalt mixture in the auxiliary material box. The size of the average temperature of the heating asphalt mixture will affect the use of asphalt mixture performance, as shown in Figure 3(a), the spacing in the X direction is constant, with the increase of Y direction arrangement spacing, the average temperature of the asphalt mixture increases after the first decreases, and the standard deviation increases gradually. Y direction when the distance is 150 mm, the average temperature, the other three kinds of arrangement of spacing, the average temperature difference is not big; When the Y direction is unchanged, the average temperature and standard deviation gradually increase with the increase of spacing in the X direction. Therefore, when the spacing is 147mm×150mm and X is arbitrary direction and Y direction spacing is 155mm, the heating effect of asphalt mixture is considered to be the best under 5 spacing.

As shown in Figure 3(b), the spacing in the Y direction is 150mm and 155mm, and the dispersion coefficient is almost equal and minimum, both around 0.35, indicating that the heating uniformity of asphalt mixture is the same and the best. However, the proportion of asphalt mixture between 80°C and 160°C decreases with the increase of spacing in the X direction. When the spacing is 132mm×155mm and 132mm×150mm, the heating temperature of asphalt mixture between 80°C and 160°C accounts for the largest proportion (70.8% and 69.7%), and the proportion over 160°C accounts for less, which is not easy to cause aging and coking phenomenon of asphalt mixture. Therefore, the heating effect of asphalt mixture is best when the spacing is 132mm×155mm and 132mm×150mm.

![Figure 3](image-url)
Under different arrangement and spacing, through the analysis of three different aspects of asphalt mixture's performance, heating uniformity and whether it is easy to cause aging and coking of asphalt mixture, it is obtained that the heating effect of asphalt mixture in the auxiliary material box is the best when the antenna array is arranged in a side-by-side arrangement mode and the arrangement and spacing is 132mm×155mm.

**Figure 4.** Simulation temperature cloud map of asphalt mixture with different arrangement modes (a) Temperature cloud diagram of asphalt mixture at 4cm under orthogonal arrangement; (b) temperature cloud diagram of asphalt mixture at 4cm under side-by-side arrangement.

### 5. The influence of the optimal spacing arrangement on the heating effect

Under the optimal arrangement and spacing, the arrangement mode of the antenna is changed, and the arrangement mode of the antenna is orthogonal, that is, the two adjacent antennas are arranged perpendicular to each other (the arrangement mode is shown in Figure 1(c)), and the heating effect of
the asphalt mixture is compared with the side-by-side arrangement, as shown in Table 5, under the optimal arrangement spacing, the dispersion coefficient of the overall temperature of the asphalt mixture is 0.04 higher than that of the latter, indicating that the heating uniformity of the asphalt mixture increases by 12.1% when the antenna array is arranged in an orthogonal manner. In the case of orthogonal arrangement, the proportion of asphalt mixture temperature at 80°C -160°C is 77.0%, and the proportion is small when the temperature exceeds 160°C, which is not easy to cause aging and coking of asphalt mixture. The orthogonal layout and parallel layout were simulated by CST Studio suite software. The temperature cloud images in the top view, left view and main view of the asphalt mixture were taken under different arrangement modes at the thickness of four centimeter, as shown in Figure 4. Therefore, it is considered that the heating effect of asphalt mixture is the best when the array of antenna array is 132mm×155mm under the orthogonal arrangement.

Table 5. Temperature statistics of asphalt mixture and the proportion of temperature segment between 80°C and 160°C under different arrangement modes.

| arrangement mode | arrangement space | 80°C -160°C | mean value | standard deviation | coefficient of dispersion |
|------------------|------------------|-------------|------------|-------------------|--------------------------|
| side by side     | 132mm×155mm      | 70.8%       | 134.2      | 45.0              | 0.33                     |
| orthogonal       | 132mm×155mm      | 77.0%       | 114.9      | 33.7              | 0.29                     |

6. Conclusions

This paper introduces the heating method of asphalt mixture under different antenna arrangement based on auxiliary material box, in order to improve the heating efficiency and heating uniformity of asphalt mixture, after the optimization of antenna array arrangement spacing, an orthogonal arrangement method of antenna array was proposed to improve the heating uniformity of asphalt mixture at one time. In this paper, the following conclusions were obtained by studying the heating efficiency and heating uniformity of asphalt mixture:

1. When the antenna array is arranged side by side, and the spacing is 132mm×155mm, the heating effect of asphalt mixture in the auxiliary material box is the best.

2. Under the optimal arrangement spacing, the dispersion coefficient of orthogonal arrangement is 0.04 smaller than that of side-by-side arrangement. When the antenna array is orthogonal arrangement, the heating uniformity of asphalt mixture is 12.1% higher than that of side-by-side arrangement.

3. Under the optimal arrangement spacing, the proportion of asphalt mixture between 80°C and 160°C in the orthogonal arrangement is increased by 8.7%, and the phenomenon of coking and aging of asphalt mixture is reduced.

In this paper, the CST simulation platform is applied, and the conclusion of the simulation experiment has certain reference value for improving the heating effect of the auxiliary material box heating system.

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