Shielding Effectiveness Fitting of Local Electromagnetic Shielding Clothing Based on Human Figure

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Abstract— This study proposes a new method of shielding effectiveness (SE) based on NURBS curve, which aim is to address current non-effective method to describe the SE distribution of electromagnetic shielding (EMS) clothing. Moreover, the SE of local clothing can be fitted with the curve to observe the distribution. A testing method of key points is introduced to test the SE of the local clothing. Some concrete functions and program steps of curve fitting are listed. And then a distribution image of the SE on arm position is drawn. Results show that the proposed algorithm can accurately draw a 3D image of the SE of the local clothing and can reveal the distribution of electromagnetic wave on the local human body.

1. INTRODUCTION

All kinds of electromagnetic radiation exist in our modern life. Many researchers have proved that the electromagnetic radiation can produce adverse reaction, and even does harm to people's health [1]. The electromagnetic radiation has been listed as pollution and must be controlled by Human Environment Conference of Unite Nations, and many national governments have warned people against electromagnetic radiation [2]. Therefore, the study on electromagnetic shielding is becoming an urgent hotspot.

Most of the research of electromagnetic shielding clothing focuses on the development and application of the fiber and fabric. These materials include metal fiber, conductive fiber, metal coating fiber, multi-ion fabric, microwave-absorbing fabric and etc. [3, 4]. Report for describing the shielding effectiveness (SE) of clothing is almost inexistent, only research about SE of fabric was found in some literatures. These studies [5, 6] mostly focus the SE of fabric on a local plane, it cannot reveal the SE rule of electromagnetic clothing. Some scholars have been aware of this problem and present some testing methods for electromagnetic shielding clothing [7], but the SE description of local body has not been reported in detail.

It is also our viewpoint that SE research between clothing and fabric is very different. Surface shape must be considered when studying the SE of clothing. At present, universal method of describing 3D shape is NURBS curve which has been applied in some fields of electromagnetic [8]. Additionally, study of EM distribution considering human figure [9] has also been reported in some electromagnetic field problems. But, these researches have not discussed SE distribution of local clothing thoroughly.

Therefore, this paper explores the laws of the SE on the local clothing. At first, fitting formulas of the SE of key points on local clothing are deduced by analyzing electromagnetic and NURBS theories. Then, an example is demonstrated to verify the curve fitting method of the SE on the local body. At last, the distribution image of the SE is drawn to reveal the SE law of electromagnetic wave. Results show that this method is effective and can express the law of SE distribution on local clothing.

2. CONCRETE METHOD

2.1. SE Acquisition

We test the SE using shielding box. The shielding box is calibrated carefully to ensure it is leakproof. The antenna is calibrated in free space. The distant between antenna and local body model reaches the regular value. Signal receivers of the body model are connected with computer data receiving system. The electromagnetic shielding clothing is coated on the local model. We can obtain the testing results of the SE by computer. The local model is shown in Figure 1.

2.2. SE Calculation for Fitting

Suppose the impedance of electromagnetic wave in the air is $Z_1\,(\Omega)$, the characteristic impendence of shielding clothing is $Z_2\,(\Omega)$, the radiation field intensity of incident wave are $E_0(N/C)$ and $H_0(N/C)$. The incident wave produces the reflection when it arrives at the interface of the clothing, and the impedance of electromagnetic wave Z_1 is equal to impedance of a free space medium Z_0, then [10]

$$Z_1 = Z_0 = 377\,\Omega \tag{1}$$

$$Z_2 = \sqrt{\frac{2\pi f\mu_0\mu_r}{\sigma_0\sigma_r}} = 3.68\times 10^{-7}\sqrt{\frac{\mu_r f}{\sigma_r}} \tag{2}$$

$$R_{HN} = 20Lg\frac{Z_1}{4Z_2} = -119.07 + 10Lg\frac{fr^2\sigma_r}{\mu_r}\,(\text{dB}) \tag{3}$$

$$A = 20Lg\frac{E_0}{E_1} = 20Lg\frac{H_0}{H_1} = 15.4t\sqrt{f\mu_r\sigma_r}\,(\text{dB}) \tag{4}$$

$$B = 20Lg(1-e^{2t/\delta}) = 20Lg(1-e^{3.54t\sqrt{f\mu_r\sigma_r}})\,(\text{dB}) \tag{5}$$

Therefore, the theoretical model of the SE in near-field can be calculated as:

$$\text{SE}_{HN1} = R_{HN} + A + B = 14.6 + 10Lg\frac{fr^2\sigma_r}{\mu_r} + 1.31t\sqrt{f\mu_r\sigma_r} + 20Lg(1-e^{3.54t\sqrt{f\mu_r\sigma_r}})\,(\text{dB}) \tag{6}$$

where, t denotes the thickness of idea shield, μ_r denotes the relative magnetic permeability, σ_r denotes the relative conductivity, f denotes the frequency (H_z).

2.3. Computer Fitting

The SE of electromagnetic shielding clothing is changed with the change of the distance of signal recourse. Therefore, all SE data of clothing can be recorded by computer. The SE of each testing point is different because the position of the testing point is space distribution. We use NURBS algorithm to construct the 3D curve for the SE of key points to extract the distribution functions of the SE on the body surface. NURBS curve is described the curve and spline on the object surface using a mathematic method. It can be expressed as [11]:

$$S(u,v) = \sum_{i=0}^{i=m}\sum_{j=0}^{j=n} W_{ij}P_{ij}N_{\text{SE}}, p(u)N_j, u, v \in\ [0,1] \tag{7}$$

where, P_{ij} is the low of key point of the local body model, W_{ij} is the weight factor of key point, N_{SE}, p_u, N_j and $q(v)$ are the basis function of the spline B in the order p and the order q. Here, N_{SE} is defined as:

$$N_{\text{SE}} = 14.6 + 10\frac{pq(v)^2N_j}{u_{ij}} + 1.31\sqrt{pu_{ij}N_j} + 20\left(1-e^{3.54t\sqrt{pu_{ij}N_j}}\right)\,(\text{dB}) \tag{8}$$

where, u_{ij} is the permeability of the electromagnetic shielding fabric on the sequence point $p(i,j)$.

According to above Formulas, 3D NURBS curve fitting of the SE of the local body model is made using computer analysis software. The steps are as follows:

1) Class the key points according to the position of testing point and the SE and determine the sequence point with same classification.
2) Test SE of key points.
3) Iterate the sequence point with same classification and determine the fitting point.
4) Determine the values i and j of sequence point according to the fitting point.
5) Calculate the SE of other points not including key points by the Formula (6) according to the position of points.
6) Determine the basis function of B spline.
7) Fitting curves of SE distribution on the local clothing.
8) Draw a 3D sketch demonstrating distribution laws of SE on the local clothing.

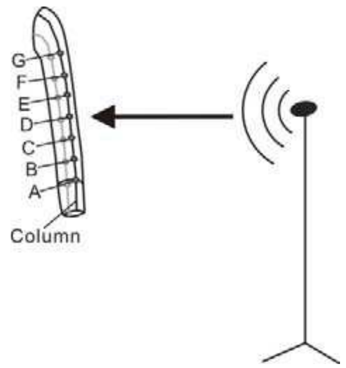

Figure 1: Local body model of SE testing.

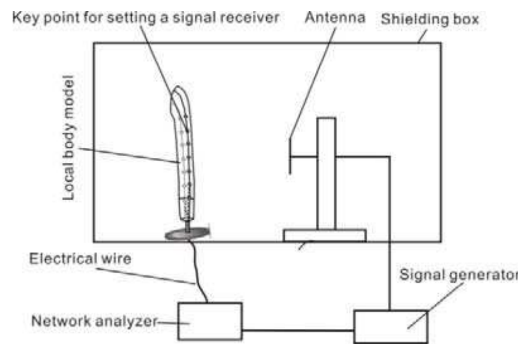

Figure 2: Experiment system for testing SE of key points in local body.

3. RESULTS AND ANALYSIS

3.1. Experimental Method

In order to test Computer Fitting method in this paper, an experiment is designed to get SE of key points in local arm. The emission frequency of signal is set as 500 MHz and the distance is set as 1 m. The testing points on the local body model are divided into six columns, three in the face of the arm, and three in the back. There are seven testing points in each column. We select ESFs with 38 dB manufactured by Shanghai Angel Textile Company as experimental samples, it were made of stainless metal fibers and cotton fibers. The experiment system is shown in Figure 2.

3.2. Results

The testing results of the SE when $f = 500$ MHz are listed in Table 1.

Table 1: The SE of each testing point on the local body model (500 MHz).

Column No. of local body	Shielding effectiveness (dB) of each key point						
	A	B	C	D	E	F	G
1	37.16	36.99	35.27	34.34	35.59	36.89	37.27
2	36.23	35.74	34.90	34.47	35.06	36.23	36.82
3	35.89	35.06	34.51	33.91	34.89	35.33	35.97
4	36.18	35.48	34.44	33.86	34.53	35.26	36.16
5	36.79	35.82	35.07	34.43	34.98	35.72	36.38
6	37.20	36.89	35.32	34.89	35.67	36.78	37.21

4. COMPUTER CURVE FITTING

4.1. Fitting According to SE of Key Points

According to Formula (7) and Formula (8), we use the MATLAB7.0 to compile a program and classify and schedule the data in Table 1. Figure 3 and Figure 5 are SE of key points according to different directions of array in Table 1. Then, we fit their SE curves by computer, as shown in Figure 4 and Figure 6.

4.2. Analysis

After the experimental verification and data analysis, we find that the SE changes have some regular changes. The SE shows linear changing along the arm axial direction. The initial value of increasing is the point of the arm model that is the nearest the radiation recourse. Otherwise, the distance from key point to emission source influences the SE distribution of the arm model. The bigger the distance is, the weaker the SE is. With the NURBS curve fitting, the farther part in the arm model is the strong SE area.

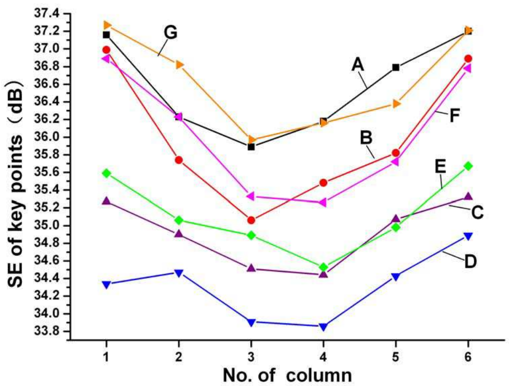

Figure 3: SE of key points with same identifier in the columns.

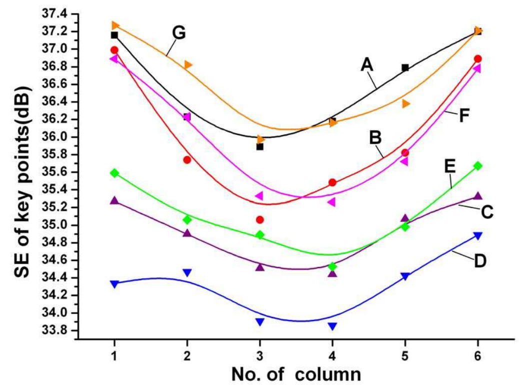

Figure 4: Fitting result of Figure 3.

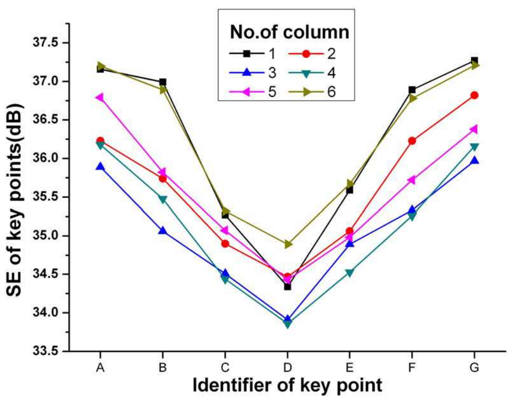

Figure 5: SE of key points in each column.

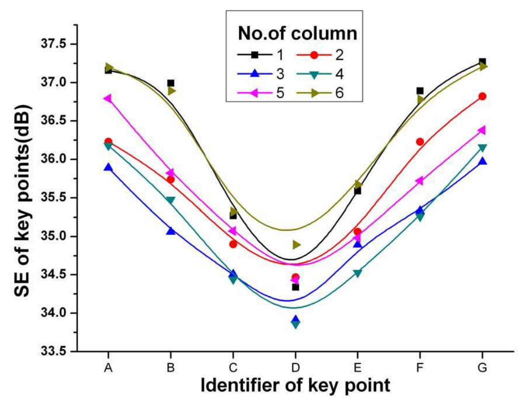

Figure 6: Fitting result of Figure 5.

5. CONCLUSION

A SE fitting analysis method on NURBS curve is proposed in this paper. With this method, the local testing points of electromagnetic shielding clothing can be classified and scheduled. A curve fitting is made by the SE of each testing point, and the 3D SE distribution of the local clothing is drawn. This image can show directly the distribution of electromagnetic wave on the body, and can provide the theoretical basis of the SE of local electromagnetic shielding clothing.

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