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The Exploration of Magnetization Curve Data at Arbitrary Temperature and Different Frequency

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Abstract

For the same material, in the material library, the manufacturer may only provide data at several special temperatures or frequencies, and data at other temperatures or frequencies cannot be obtained. This article uses the existing data to change the data at different temperatures. The frequency magnetization curve is converted into the magnetization curve data under the corresponding period, and the converted data is used to give the required temperature and frequency magnetization curve to obtain the fitting process and specific implementation results. It can be seen from the results that this method greatly reduces the non-linearity of the data and improves the stability. At the same time, the fitting process is simple and clear, and it is easy to realize the calculation formula.

Keywords

Magnetization curve; curve fitting ; interpolation.

1. Introduction

In the material library, a material generally corresponds to only one magnetization curve, One can only fit the magnetization curve from one piece of data and perform calculations ([1-5]),but in reality, the magnetization curve of the same material is different at different frequencies and temperatures. The manufacturer may only provide data at a few special temperatures or frequencies. How to use the existing data to fit the magnetization curve at the temperature and frequency we need is the problem to be solved in this part of the document.

2. Theoretical analysis

In practice, if you consider frequency or temperature at the same time, it is difficult to find the corresponding law with only this point of data, and compared with frequency, the difference of the same material at different temperatures is not very large, so it is decided start with frequency first.

The following are the magnetization curves of the two materials at different frequencies. It is obvious from Figure 1 that for the same material, as the frequency increases, the magnetic density value on the corresponding magnetization curve becomes smaller, especially in the middle area. The two ends have not changed much. This is related to the magnetization curve passing through the (0,0) point and magnetic saturation.

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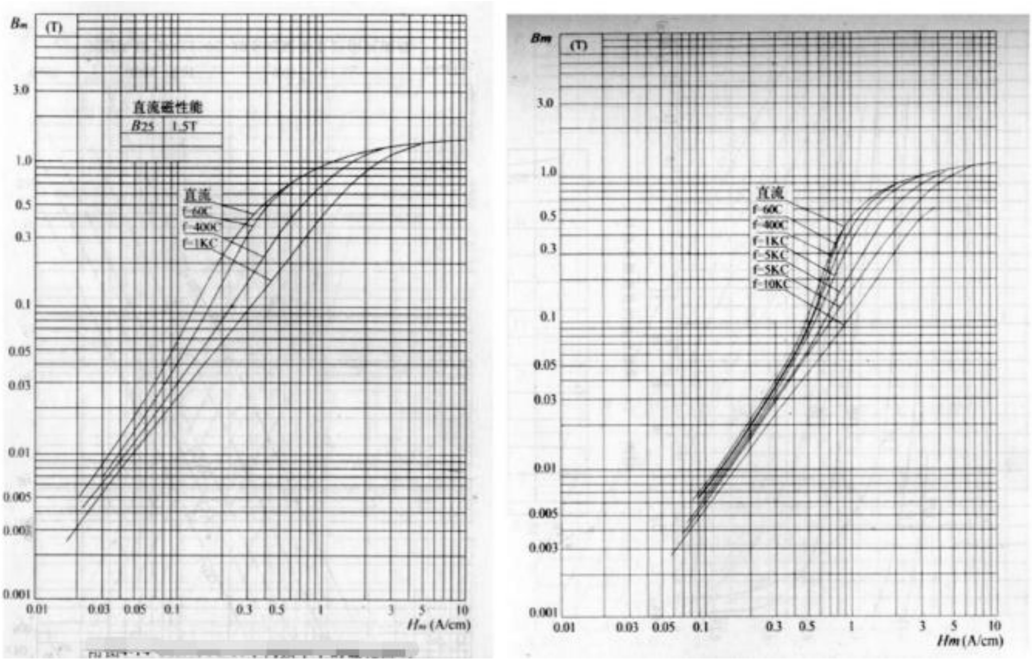

Figure 1:Magnetization curves at different frequencies (L: DR1750G-35, R: IJ6 (0.20mm))

In order to explore the changing trend of the data in more detail, we have obtained the B value corresponding to the same H value at different frequencies. Table 1 and Table 2 are the magnetic density discrete data values corresponding to the same H at different frequencies for the two cores. At the same time, in order to have a deeper understanding of the law of change, we have also added the change graph of the reciprocal frequency, that is, the curve under the period. Figure 2 and Figure 3 are the corresponding graphs. The number marked on the right end of the picture is the selected H value. Each H corresponds to a curve of magnetic density and frequency (period), the left figure is the frequency, the right figure is the period.

Table 1:The corresponding magnetic density data table of the same H value at different frequencies-core 1

	Period	0.03	0.04	0.05	0.1	0.2	0.3	0.4
DC	∞	0.012555	0.012555	0.017527	0.058921	0.226879	0.391771	0.531046
60C	0.0167	0.010321	0.010321	0.014192	0.041031	0.142169	0.312496	0.485151
400C	0.0025	0.008742	0.008743	0.011843	0.030349	0.081381	0.151543	0.231751
1000C	0.001	0.007633	0.007633	0.010034	0.023844	0.057533	0.093540	0.136722

Table 2 The corresponding magnetic density data table of the same H value at different frequencies-core 2

	Period	2	1	0.9	0.7	0.6	0.5
DC	∞	0.90406911	0.53780053	0.46350216	0.271336651	0.18429982	0.10948681
60C	0.0167	0.90406911	0.53780053	0.46350216	0.240861524	0.15644845	0.09294118
400C	0.0025	0.90406911	0.44314112	0.359833898	0.204467136	0.14096064	0.09021379
1000C	0.001	0.81455144	0.36514291	0.296498772	0.168474675	0.11966136	0.08128296
3000C	0.00033	0.63238060	0.22337323	0.186864329	0.119613215	0.09016942	0.06501074
5000C	0.0002	0.44233922	0.16583219	0.145069701	0.097102936	0.07886065	0.0612512
10000C	0.0001	0.30482811	0.11259276	0.098495949	0.071023561	0.05854611	0.04547286

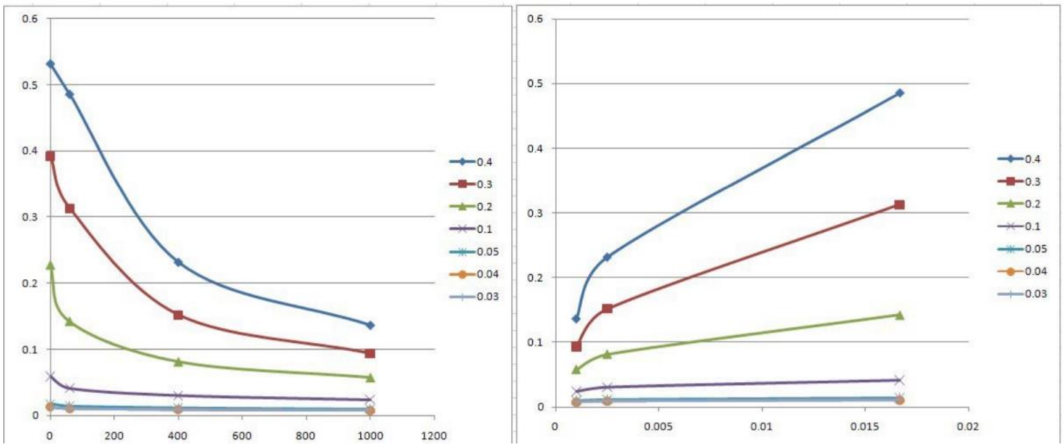

Figure 2: The magnetic density B value corresponding to the same H under different frequencies--core 1

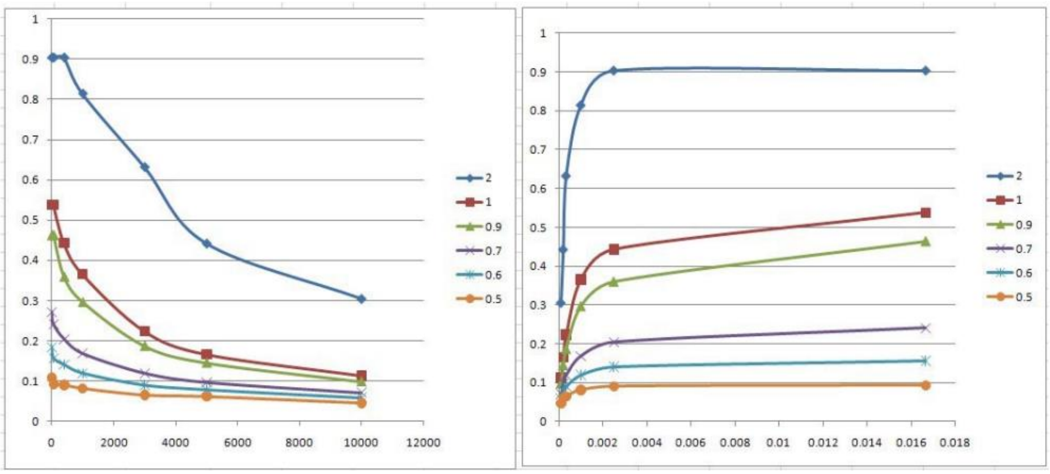

Figure 3: The magnetic density B value corresponding to the same H under different frequencies-core 2

First look at the graphs of magnetic density and frequency under the same H value, that is, the left graphs of Figure 2 and Figure 3. It clearly shows that with the increase of the frequency, the magnetic density value decreases successively, and the change in the middle area is obvious, and the decrease process is non-linear. Therefore, it can be seen that the change of the magnetization curve at different frequencies is also non-linear. The current data cannot accurately obtain this non-linear trend, but using the existing data, we can obtain the frequency of each H value at several known frequencies by using interpolation method. (Frequency reciprocal-period) and B value satisfy the equation, and then obtain the B value corresponding to the H value at the corresponding frequency. Continue this process to get the data pair of the corresponding H-B value at all frequencies, and fit it. Obtain the magnetization curve at this frequency.

In order to compare with the frequency, we have given the reciprocal of the magnetic density and frequency, that is, the relationship diagram of the period, that is, the right side diagrams of Figure 2 and Figure 3. It can be clearly seen that the magnetic density is a monotonically increasing function of the period. Since the numerical difference between the period and the magnetic density is not as large as the frequency, the fitting effect should be better than the frequency. Therefore, when interpolating the curve, the curve of the interpolated magnetic density with respect to the period can also be used. The interpolation methods are the same, but the abscissa is different. As for the method to be adopted, it can be more adopted in practical applications.

3. Case Analysis

Assuming that for a certain material, we already know its magnetization curve data at frequencies $f_1=0, f_2=60, f_3=400, f_4=1000$, as shown in Table 3, find the frequency $f_0=100C$ magnetization curve.

Step 1:

Obtain the $B_k, k=1,2,3..,7, f=0,60,400,1000$ values corresponding to $H_k, k=1,2,3..N$ in the order of increasing at a known frequency. It can be obtained in the following two ways: one is to directly obtain the discrete data provided by the existing database; the other is to obtain the fitting function based on the existing data of the database. After the fitting curve is obtained, it is substituted into the acquisition.

Table 3: Under the four frequencies, the corresponding B value under 7 H values.

	H_k	$H_k=0.03$	$H_k=0.04$	$H_k=0.05$	$H_k=0.1$	$H_k=0.2$	$H_k=0.3$	$H_k=0.4$
$f_3=0$	∞	0.01255 5	0.01255 5	0.017527 2	0.058921 1	0.22687 9	0.39177 1	0.53104 6
$f_3=60$	B_k, f_1	0.01032 1	0.01032 1	0.014192 9	0.041031 5	0.14216 9	0.31249 6	0.48515 1
$f_3=400$	B_k, f_2	0.00874 2	0.00874 3	0.011843 9	0.030349 8	0.08138 1	0.15154 3	0.23175 1
$f_4=1000$	B_k, f_3	0.00763 3	0.00763 3	0.010034 6	0.023844 4	0.05753 3	0.09354 0	0.13672 2

Step 2:

For each $H_k, k=1,2,3,...,N$, use the obtained data pair $(B_{k,f}, f), k=1,2,3,...,N$;

$f = f_1, f_2,..., f_n$, using spline interpolation to obtain a curve $B_k(f)$ about frequency *f*. As shown in Figure 2, each curve is about frequency f curve $B_k(f)$.

Step 3:

Substituting f_0 into $S_k(f)$, the magnetic density $B_k(f_0)$ corresponding to the frequency f_0 at the point $H_k, k=1,2,3,...,N$ can be obtained, and the data pair $(H_k, B_k(f_0)), k=1,2,3,...,N$.

Using the B-H curve fitting method, the corresponding magnetization curve at frequency f_0 can be obtained.

4. Selection of interpolation method

From Figure 2 and the theoretical analysis above, it can be seen that the two ends of the magnetization curve at different frequencies have small changes and large changes in the middle. Therefore, when there are more known data, in order to improve the accuracy and adjustability of the fitting, Cubic spline can be used to fit the curve. In this case, at least four magnetization curves at more than four frequencies need to be known. If the number of curves is less than three, only Lagrangian interpolation can be used.

4.1. Lagrangian interpolation

Assuming that the magnetic density value and the frequency value (B_k, f_k),

$k=1,2,3,\ldots,n$ under n frequencies are known under H_k, for the convenience of the following writing, we assume that these n data pairs ,For $(x_i, y_i), i=1,2,3,\ldots,n$, the n-1 Lagrangian polynomial $L_{n-1}(x)$ with n nodes $x_1 < x_2 < \ldots < x_n$ can be expressed as:

$$L_{n-1}(x)=\sum_{k=1}^{n} y_k l_k(x)=\sum_{k=1}^{n} y_k \frac{\omega_n(x)}{(x-x_k)\omega_n'(x_k)}$$

among them

$$\omega_n(x)=(x-x_1)(x-x_2)\ldots(x-x_n)$$

When n=2, it is the linear interpolation formula:

$$L_1(x)=y_k\frac{x_{k+1}-x_k}{x_{k+1}-x_k}+y_{k+1}\frac{x-x_k}{x_{k+1}-x_k}$$

When n=3, it is the parabolic interpolation formula:

$$L_2(x)=y_{k-1}\frac{(x-x_k)(x-x_{k+1})}{(x_{k-1}-x_k)(x_{k-1}-x_{k+1})}+y_k\frac{(x-x_{k-1})(x-x_{k+1})}{(x_k-x_{k-1})(x_k-x_{k+1})}+y_{k+1}\frac{(x-x_{k-1})(x-x_k)}{(x_{k+1}-x_{k-1})(x_{k+1}-x_k)}$$

4.2. Cubic spline interpolation

The equation of the cubic spline curve passing through these n points is:

$$\begin{bmatrix} 2 & \mu_0 & & & & \\ \lambda_1 & 2 & \mu_1 & & & \\ & \lambda_2 & 2 & \mu_2 & & \\ & & & \ddots & & \\ & & & \lambda_{n-1} & 2 & \mu_{n-1} \\ & & & & \lambda_n & 2 \end{bmatrix}\begin{bmatrix} m_0 \\ m_1 \\ m_2 \\ \vdots \\ m_{n-1} \\ m_n \end{bmatrix}=\begin{bmatrix} C_0 \\ C_1 \\ C_2 \\ \vdots \\ C_{n-1} \\ C_n \end{bmatrix}$$

among them

$$\begin{cases} h_j = x_j - x_{j-1} \\ \lambda_j = \frac{h_{j+1}}{h_j+h_{j+1}} \\ \mu_j = 1-\lambda_j \\ C_j = 3[\lambda_j\frac{y_j-y_{j-1}}{h_j}+\mu_j\frac{y_{j+1}-y_j}{h_{j+1}}] \end{cases} \qquad j=1,2,3,\ldots,n-1$$

Both ends take the form of specifying the first derivative, namely

$$\begin{cases} C_0 = 2m_0 = 2\frac{y_2-y_1}{x_2-x_1} \\ C_n = 2m_n = 2\frac{y_n-y_{n-1}}{x_n-x_{n-1}} \end{cases}$$

After calculating m_j, $j=1,2,\ldots,n-1$, the equation of the interpolated cubic spline curve on the interval $[x_{j-1}, x_j]$ is obtained:

$$y(x)=m_{j-1}\frac{(x_j-x)^2(x-x_{j-1})}{h_j^2}-m_j\frac{(x-x_{j-1})^2(x_j-x)}{h_j^2}$$

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$$+y_{j-1}\frac{(x_j-x)^2[2(x-x_{j-1})+h_j]}{h_j^3}+y_j\frac{(x_-x_{j-1})^2[2(x_j-x)+h_j]}{h_j^3}$$

In this way, the aforementioned frequency curve $B_k(f)$ is obtained. Then the magnetic density value of any frequency in the interval $[0, f_n]$ can be obtained.

5. Summary

The magnetization data at different temperatures and frequencies are converted into data at the corresponding period, which greatly reduces the nonlinearity between the data. At the same time, the magnetization data curve is constructed by fitting and the interpolation method can be used to obtain other frequencies. The advantage of this method is that according to several known frequency curves, the magnetization curves of other frequencies within the frequency range can be obtained conveniently and quickly. The corresponding defect is that the magnetization curves outside the known frequency cannot be obtained, and the stability and Accuracy needs to continue to be studied.

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