

Pulse Magnet Impedance Measurement and High-Frequency Modeling Based on Neural Network

Lantao. Huang¹, Ziheng. Huang¹, Zhuobin Liu¹, Boyu Lin¹, and Chenwei Zhang¹

¹Department of Instrumentation and Electrical, Xiamen University, 361000 China, lantaohuang@xmu.edu.cn

Pulsed high magnetic fields (PHMFs) have emerged as essential tools in scientific research. As the key to generating pulsed high magnetic field, the design and analysis of pulsed magnets has become the focus of scientific instrument research and development. Design methodologies for pulsed magnets involve a multidisciplinary approach, in which high-frequency circuit models are critical to the generation of magnetic fields. The model can be used to simulate the electromagnetic behavior of pulsed magnets and predict the discharge process. In this paper, we propose a high-frequency modeling method based on neural networks, which is developed through impedance measurements and neural network curve fitting. The impedance of the pulsed magnet was measured using a designed fixture adapter and a vector network analyzer (VNA), and high-frequency modeling and element value prediction were performed through a neural network. The method has high precision, good versatility and simple parameterization

Index Terms—Pulsed magnet, fixture adapter, high-frequency model, neural network

I. INTRODUCTION

WITH the development of power supply and control technology, the pulsed high magnetic fields (PHMFs) have achieved a high magnetic field strength in a certain period of time, which has broadened the practical range of the pulsed high magnetic field. These fields enable researchers to explore new physical phenomena, manipulate material properties, and advance our understanding of fundamental science in domains like condensed matter physics, materials science, and chemistry.

The pulsed magnet is the core component of the pulsed high magnetic field experimental device, and it is also the key to generate the pulsed high magnetic field. Design methodologies for pulsed magnets involve a multidisciplinary approach. Beyond mechanical and thermal considerations, the circuit model of the pulsed magnet is also critical to magnetic field generation. Computational models like finite element analysis (FEA) are commonly used to simulate the electromagnetic behavior of pulsed magnets, predicting discharge processes. However, these models are often based on simplified assumptions that may not fully capture the complex interplay of electromagnetic phenomena. Turn-to-turn capacitance and capacitance to ground are difficult to represent in simulation models, it can lead to discrepancies between predicted and actual performance. Actually, voltage and current undergo rapid changes within a short time in the pulsed magnetic field system, containing high-frequency components and exhibiting electromagnetic wave effects. Impedance mismatch between the cable and the magnet will result in voltage reflections, leading to over-voltage at the ports, which can cause aging or even insulation failure.

In this paper, we propose a high-frequency modeling method for pulse magnets based on neural networks, developed through impedance measurements and neural network curve fitting. The method derives the circuit model of the pulse magnet from its impedance data. Due to the incompatibility of the coaxial interface of the impedance measuring instrument with the pulse magnet terminal, a custom fixture adapter must be designed and

the parasitic parameters are extracted and incorporated to ensure precise impedance data. Once the impedance data is acquired, high-frequency modeling and element value prediction are performed using neural networks. The main contribution of this work is the development of a high-frequency modeling method for pulse magnets that is accurate, versatile, and straightforward to parameterize.

The rest of this paper is organized as follows. Section II introduces the measurement method of pulsed magnet impedance, including the specific design of the fixture adapter, the extraction of parasitic parameters, and the de-embedding of parasitic parameters. Section III introduces the high-frequency modeling methods for neural networks, including the construction of high-frequency models and neural network prediction. Finally, Section IV concludes the paper.

II. PULSE MAGNET IMPEDANCE MEASUREMENT

In this paper, the measurement of the pulse magnet is divided into three parts: the design of the fixture adapter, the extraction of parasitic parameters, the de-embedding of parasitic parameters and impedance measurement.

A. Design of fixture adapter

The pulsed magnet to be measured is directly installed on the designed fixture adapter and measured by a VNA. The whole design is carried out on a single-layer double-sided flame-retardant-4 (FR-4) board.

B. Extraction of fixture adapter's parasitic elements

In order to extract and de-embed parasitic parameters at high frequencies, the Q3D Extractor in ANSYS Electronic Desktop software is adopted. The conjugate gradient (CG) solver is used to extract the parasitic capacitance of copper traces and SMA connectors, while the AC RL solver is used to extract the parasitic resistance and inductance of copper traces and SMA connectors.

C. De-embedding parasitic elements and Impedance measurement

The VNA can be used to measure the scattering (S) parameters of the pulse magnet mounted on the fixture adapter. As shown in Fig.1, the equivalent circuit diagram is composed of parasitic resistance, parasitic capacitance, parasitic inductance, and pulsed magnet impedance. The parasitic parameters have been extracted in the previous section.

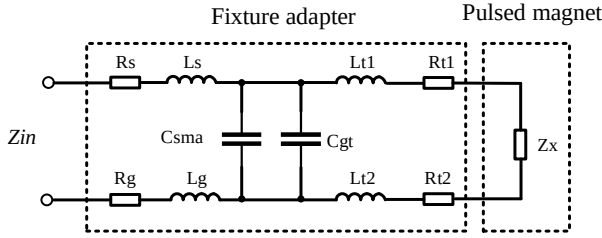


Fig.1. Equivalent circuits of fixture adapter.

Therefore, the calculation format of pulsed magnet impedance is as follows:

$$Z_{in} = Z_0 \frac{(1 + S_{11})}{(1 - S_{11})}$$

$$Z_{in} = j\omega(Ls + Lg + Lt1 + Lt2) + Z_x$$

$$Z_x = Z_0 \frac{(1 + S_{11})}{(1 - S_{11})} - j\omega(Ls + Lg + Lt1 + Lt2)$$

In the formulas, Z_{in} is the input impedance converted from the measured S parameters, Z_0 is the port reference impedance of 50 ohms, and Z_x is the impedance of the pulsed magnet.

The calculated impedance of the pulse magnet is presented, Fig.2 shows the impedance curves with and without the use of a de-embedding fixture adapter. It can be observed that there are significant differences in the curves after the high frequency of 10MHz.

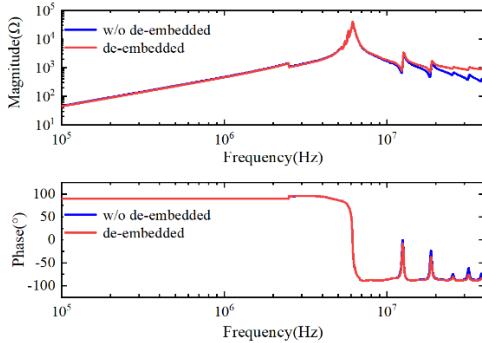


Fig.2. Measurement and de-embedded result

III. HIGH-FREQUENCY MODELING BASED ON NEURAL NETWORK

To obtain the values of circuit elements, MLP neural network is used in neural network prediction. As shown in Fig.3, the MLP neural network has six layers: one input layer, four hidden layers, and one output layer. Among them, the input is a random constant (C), the number of neurons in the four hidden layers is set to 50, 200, 200, and 50, and the output is the value of each circuit element that needs to be predicted.

For the impedance data prediction of this pulse magnet, the number of n frequency points is set to 868, the frequency range is 100kHz-40MHz, and the set training times are 1000. After training, the value of the loss function is $g1=0.0138$, where the

amplitude loss $g1(|Z|)=0.0263$ and the phase loss $g1(\angle Z)=0.0013$. Table III lists the estimated values for each element of the pulsed magnet high-frequency circuit model.

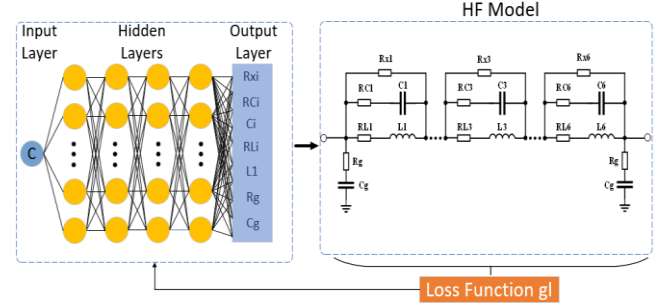


Fig.3. Element value prediction based on neural network

Table III

Estimated values of circuit elements			
element	value	element	value
Rx1/kΩ	40	Rx4/kΩ	0.15
RC1/Ω	3	RC4/Ω	0.15
C1/pF	9.55	C4/nF	0.799
RL1/Ω	3	RL4/Ω	0.15
L1/uH	69.3	L4/nH	49.15
Rx2/kΩ	8	Rx5/kΩ	0.2
RC2/Ω	1	RC5/Ω	0.1
C2/nF	0.15	C5/nF	0.45
RL2/Ω	1	RL5/Ω	0.1
L2/uH	0.108	L5/nH	56
Rx3/kΩ	3.5	Rx6/kΩ	0.1
RC3/Ω	0.5	RC6/Ω	0.1
C3/nF	0.228	C6/nF	0.86
RL3/Ω	0.5	RL6/Ω	0.1
L3/nH	308	L6/nH	20
Rg/kΩ	1.2	Cg/pF	70

Fig.4 shows the measured pulsed magnet impedance data and the predicted pulsed magnet impedance data across three frequency ranges. It can be observed that in all three frequency ranges, the predicted amplitude and phase of the pulsed magnet fit well with the measured results.

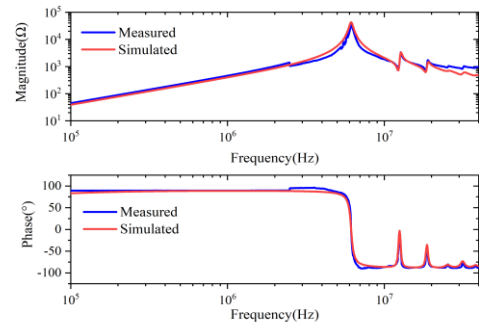


Fig.4. Impedance data for measured and predicted values

IV. CONCLUSIONS

In this paper, a high-frequency modeling method based on neural network is proposed. This method has good prediction accuracy in the range of 100kHz-40MHz, which can better simulate the electromagnetic behavior of pulsed magnets and predict the discharge process.