The hysteresis characteristics of a sensor with sensing memory function and linearization

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Abstract

With the emergence of a memristor, a new opportunity has been brought for further development of electronic information technology. The new memory devices with a self-contraction of hysteretic behaviour, as a sensor, it is usually required linearization, but the linearization result would make sensor to loss the memory function. In the study, the general character of memory sensor is summarized based on the characteristic analysis of a new analog memory device. And, as memristor to an example, according to the duality between the different types of devices, the linearization method is proposed for keeping memory. By theoretical analysis, the conditioning networks of linearization memristor sensor would be not only established a one-to-one correspondence relationship between the input and output of sensor, but also marked the history state of the memristor.

Keywords: Analog memory devices; Sensor; Hysteresist loop; Linearization

1 Introduction

May 2008, Hewlett-Packard (HP) company has successfully produced the world's first physical entity memristor[1] using nanotechnology, which confirmed that Professor Cai Shaotang have predicted the fourth electronic devices (memristor) exists in 1971 [2]. For having memory and perception function memristor [3] is concerned, the resistance has related to his history state. In recent years, the inherent nature characteristics compared with the memristor, the concept of other electronic devices (such as Memcapacitors, Meminductor, etc.) and systems with memory function, are proposed, and to become a hot topics [3-4].These elements have self-contraction hysteresis curve characteristics on constitutive variable. In its application, the hysteresis characteristics was been linearization for compensation its nonlinearity, but ignoring the characteristics similar memristor's analog memory function.

2 Analytical expression of analog memory devices constitutive variables

Generally, If $\dot{\chi}$ represents an N-dimensional vector. It is a description of the internal state of the system. $u(t)$ and $y(t)$ represent the relevant variables are the input and output of systems. g represents the general response. A class of memory system is defined by the following:

$$\begin{cases} y(t) = R(x,u,t)u(t) \\ \dot{x} = f(x,u,t) \end{cases}, \tag{1}$$

Where, $\dot{\chi}$ is the internal state variable about memory device, f is continuous N-dimensional vectors function. Suppose the initial state value is $u(t=t_0)$, at a certain time t_0. Formula (1) allowed special solution. Memristor system and meminductor system are actually a special case of equation (1). In terms of performance, the memristor resistance is specific expressed by the current - voltage:

$$\begin{cases} V_M(t) = R(x,I,t)I(t) \\ \dot{x} = f(x,I,t) \end{cases}, \tag{2}$$

where, $V_M(t)$ and $I(t)$ represent the device terminal voltage and the current flowing through the device. $\dot{\chi}$ is the internal state variable of memristor. R is a coefficient (that is memristor). In consideration of $I(t) = \frac{dq(t)}{dt}$, ($q(t)$ is the charge of directional movement in the device) the current-voltage relationship of memristor can be expressed as:

$$V_M(t) = R(q(t))I(t). \tag{3}$$

Moreover the meminductor is reflected by the relationship between the current and the magnetic flux:

$$\begin{cases} \phi(t) = L(x,I,t)I(t) \\ \dot{x} = f(x,I,t) \end{cases}, \tag{4}$$

where, R_{off} is meminductor's value, $\dot{x}$ is internal state variable of meminductor. In consideration of current control characteristics of meminductor, the flux $\phi(t)$ and current $I(t)$ relationship is:

$$\phi(t) = L\left[\int_{t_0}^{t} I(\tau)d\tau\right]I(t). \tag{5}$$

Literature [4] defines an n-order system that voltage control mencapacitors system:

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$$\begin{cases} q(t) = C(x, V_c, t)V_c(t) \\ \dot{x} = f(x, V_c, t) \end{cases} \quad (6)$$

Where, $q(t)$ is the charge of memcapacitor at the time t, $V_c(t)$ is expressed as the voltage across the memcapacitor, C is mencapacitors, x is the state of the system variables. The capacitor value of C depends on the state variables of system.

It is thus clear that there was both formal unity, but also the expression of personality alone for the memory-aware devices.

3 Commonality analysis of sensors with memory function

In fact, there was a class sensor with the memory function, such as capacitance weighing sensor, the vehicle in motion, vibration of the vehicle body can overcome the frictional resistance of the leaf spring, can significantly reduce the hysteresis. In stationary state, because the vehicle can't overcome the frictional resistance of the leaf spring, so that the characteristic curves of capacitive weighing sensor had showed significant hysteresis. When the load is loaded from zero load to full load, and then unloaded from full load to zero load, the characteristics of the sensor curve is shown in Figure 1. Where, the abscissa indicates the magnitude of the load, the ordinate represents the voltage value of the sensor output. Obviously, the loading curved trajectory does not coincide with the unloading, and exhibits hysteresis. This is a characteristic curve of typical memory sensor [6].

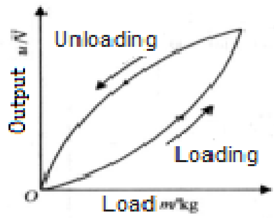


FIGURE 1 A capacitive weighing sensor hysteresis characteristics

Moreover, for some sensors, Output is not only related to the instantaneous value of the input and output variables are also concerned with history ,such as the temperature and the displacement of the shape memory alloy, input voltage and output displacement of micro-nano piezoelectric ceramic drives, and so on. They all have multi-valued of hysteresis and non-local memory mapping.

This hysteretic behaviour is often classic Preisach model described as follows:

$$f(t) = \iint_{\alpha \geq \beta} \mu(\alpha, \beta)\gamma[u(t)]d\alpha d\beta, \quad (7)$$

Wherein: $u(t)$ and $f(t)$ are respectively the input and output values for the system at time t; α and β are the start and end of input values, $\mu(\alpha, \beta)$ is Preisach model weight function value related on α and β, $\gamma_{\alpha,\beta}[u(t)]$ is the hysteresis operator.

It is thus clear that the memory function sensors are with common characteristics by formula (1) to (7), that exist the integral relationship between output and input and the status operator, that makes the output and input has nonlinear hysteresis characteristics.

In the application, this kind of memory function with hysteresis sensor is typically a linear processing. Efforts to make input and output of sensor appear one to one relationship, in order to obtain more accurate sensing results. But the result of this processing will make memory sensor amnesia.

4 The sensitive characteristics of memristor

4.1 THE BASIC CHARACTERISTICS OF A MEMRISTOR

The basic physical structure of HP labs's TiO2 memristor shows in Figure 2. It used to describe the relationship among the impedance, current and the ratio of doping. Moreover, the expression of memristor's basic characteristics is been simplifying mathematically [9].

$$R(q(t)) = R_0\sqrt{1 - \frac{2\eta \cdot \Delta R}{Q_0 R_0^2}\int_0^t u(\tau)d\tau}, \quad (8)$$

η represents the polarity of the memristor. Take "+l" when the memristor in the forward conduction, and when take "-l" memristor in the negative conducting.

$Q_0 = D^2 / \mu_D R_{ON}$; μ_D represents average mobility of impurity ions in a homogeneous field. D is the total length of the memristor. R_0 represents memristor's value at time $t = 0$.

$\Delta R = R_{ON} - R_{off}$, R_{ON} is the ON resistance, and that resistance value when $w(t) = D$, that condition is elements are all doping. R_{off} is the OFF resistance, and that resistance value when $w(t) = 0$, that condition is elements aren't doping.

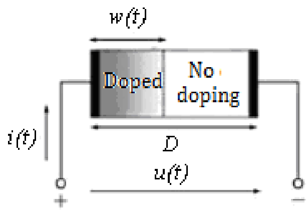


FIGURE 2 Memristor's physical structure

Due to doped and undoped region resistance is equal to the components of the total resistance $R(t)$. By study, it shows that current $i(t)$ through the memristor, and it to a linear relationship [1] with the rate of change $w(t)$. Memristor's mathematical model is follow [10].

$$u(t) = \left[R_{ON} \frac{w(t)}{D} + R_{off}\left(1 - \frac{w(t)}{D}\right)\right] i(t) = \left[R_{off} - \left(R_{off} - R_{ON}\right)\frac{w(t)}{D}\right] i(t), \tag{9}$$

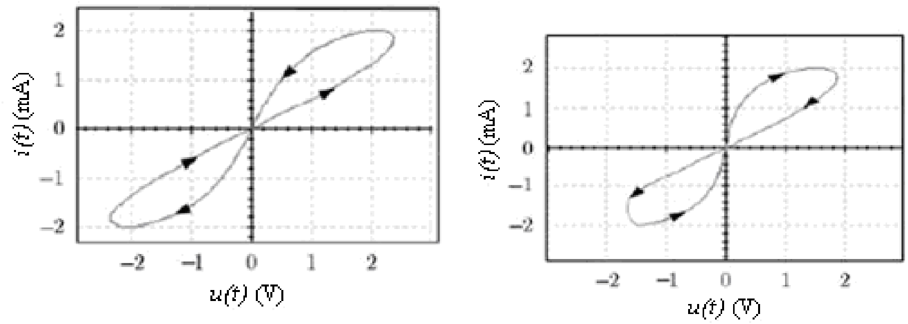
$$w(t) = \mu_D \frac{R_{on}}{D} i(t), \tag{10}$$

wherein $w(t)$ denotes the width of the element's doped region. The resistivity of the doped region is smaller than the resistivity of the undoped region.

4.2 TWO TYPES OF MEMRISTOR AND THEIR DUALITY

Due to mixed different impurities can form both positive and negative ions, so there are two memristor. $\mu_D > 0$ is P-type memristor, $\mu_D < 0$ is N-type memristor. Thus, the people have studied the characteristics of P-type and N-type memristors.

Memristor of P-type has both positive and negative bias mode. If doped section is widen when the current through the P-type memristor that is called as forward biased. If doped section is narrower that is called as reverse biased. Be concerned the P-type memristor forward biased, If $w(t) \in (0, D)$ and $u(t) > 0$, then $i(t) > 0$. Doped region to the right expand, $w(t)$ increase, and $R(t)$ diminution. When $u(t) < 0$ and $i(t) < 0$. Doped region is shrinked to the left. $w(t)$ decreased and $R(t)$ increased. In case of $u(t) = 0$, in that way $i(t) = 0$ and doped region $w(t)$ unchanged, $R(t)$ remains unchanged also. Under sinusoidal excitation voltage,the characteristics of reverse bias shows in Figure 3 (a).The resistance change of N-type memristor is contrast for P-type memristor's. Under sinusoidal excitation voltage, the characteristics of reverse bias shows in Figure 3 (b).



(a) P-type memristor's voltammetry characteristics (b) N-type memristor's voltammetry characteristics

FIGURE 3 The memristor's voltammetry characteristics

Figure 4 shows memristor's V-I characteristic curve in different frequencies. Therefore, with the frequency of the signal increases, the resistance change losing [11]. Transposed characteristic curve shown in Figure 4. This applies to testing the slowly varying parameters.

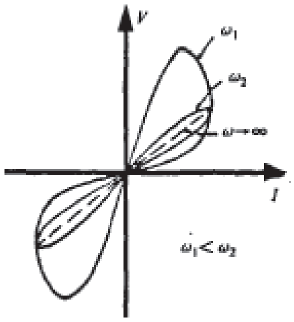


FIGURE 4 The memristor's transpose characteristic curve under the different frequencies

Because of the dual characteristics, between P-type and N-type memristor can through appropriate topology connect and parameter selection. Memristor external show a linear characteristic, and they have respective the inherent nature of the memristor.

4.3 MEMRISTOR SENSOR LINEARIZATION AND MEMORY IDENTIFICATION METHOD

Memristor sensor linearization is optional strictly dual P-type and N-type memristor to series, and get memristor sensing circuit .The input current is sensed and convered by the memristor sensor, respectively to obtain a linear voltage output and non-linear voltage output. Through the impedance conversion and keeping this instantaneous output voltage, obtain the output voltage V_{out} of linearly detected.

To mark linear detector output at the previous time status. The output voltage V_{out} is sampled for the half-value and compared with non-linear output voltage. The output level of comparator indicated variational trend of memristor resistance. That can be used as markers for the previous time status. The linearization conditioning and state marking method for memristor sensor is shown in Figure 5.

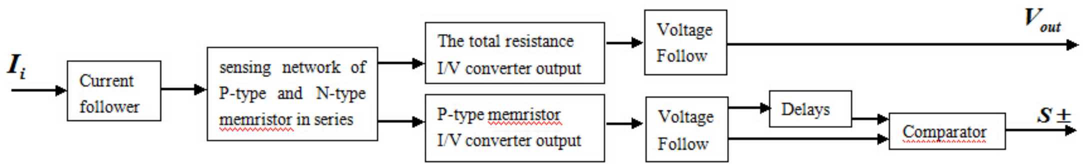


FIGURE 5 The block diagram of linearization conditioning and state marking for memristor sensor

Used four-terminal floating ground zero (FTFN) with the current gain adjustable function do the ratio operation to input current, and to drive the memristor sensing network. In Figure 6, Memristor sensing network are constituted by P-type and N-type memristors in series. Since the P-type and N-type memristor, Mp and Mn, are strict duality, so $Mn + Mp = R_{ON} + R_{off}$ is a constant resistance. Voltage and input current are linear relationship:

$$Vout = (R_{ON} + R_{OFF})kI_i \,, \tag{11}$$

(k is a current transfer ratio of current gain adjustable FTFN).Output voltage and terminal voltage of memristor are respectively by A1 and A2 two voltage followers to isolate sensing circuit and the processing circuit, and the output signal processing circuit will not affect the Sensed current.

Current follower, as an amplifier, composed by FTFN with current gain adjustable function. The output current is proportional to the input current. The amplifier of output current used is a current-mode amplifier. The current gain is adjusted into k times by $Mp + Mn$ converter to be output voltage. Memristor's (Mp) terminal voltage (V_{Mp}) through the delay circuit $R2$, C_1 to obtain V_{Mp_d}, then it's through comparator C and itself (V_{Mp}) to compare. Noted orientations of memristor arranged. When $V_{MPd} > V_{Mp}$, comparator output is low, denoted by $S_{(t^-)}$, represents Mp value in reducing, corresponds to direction of Iz is inflow Z terminal of FTFN. When $V_{MPd} < V_{Mp}$, comparator output is high, denoted by $S_{(t^+)}$, meaning Mp value in increasing, corresponds to direction of Iz is flow into Z terminal of FTFN. The change range of Mp is between $R_{ON} \sim R_{OFF}$. This shows that memristor sensor circuit, as a detector, not only to achieve the input current following voltage output was varies linearly, but also marking variation trend of the voltage. That is to say it have a linear memory testing function.

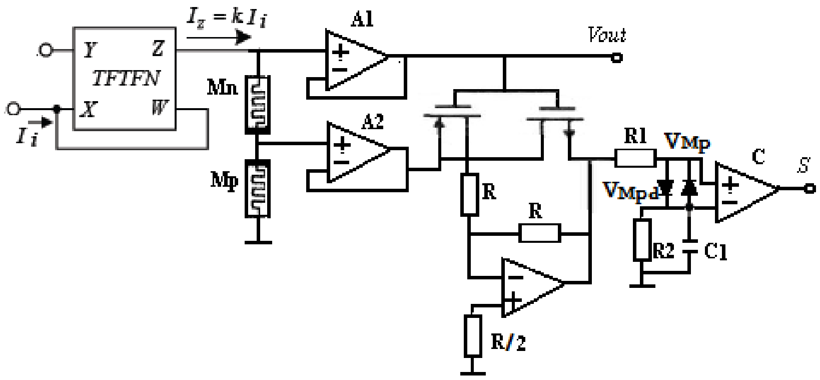


FIGURE 6 The circuit diagram of linearization conditioning and state marking to memristor sensor

5 Summary

The sensors with memory function have nonlinear hysteresis characteristics. Memristor sensor is one of them, except having a hysteresis loop characteristics, the two types of memristor sensors have duality on the characteristics. Using this "duality" can be changed the nonlinear characteristics into linear characteristics for memristor sensor. And to avoid a general linear process caused amnesia of memory sensor. Therefore, it's applies to linear memory testing for the slow change current signal.

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