Electrical and current self-induction

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Abstract

The article considers the self-inductance of reactive elements

1. Electrical self-induction

To the laws of self-induction should be carried those laws, which describe the reaction of such elements of radio-technical chains as capacity, inductance and resistance with the galvanic connection to them of the sources of current or voltage. These laws are the basis of the theory of electrical chains. The results of this theory can be postponed also by the electrodynamics of material media, since. such media can be represented in the form equivalent diagrams with the use of such elements.

the motion of charges in any chain, which force them to change their position, is connected with the energy consumption from the power sources. The processes of interaction of the power sources with such structures are regulated by the laws of self-induction.

Again let us refine very concept of self-induction. By self-induction we will understand the reaction of material structures with the constant parameters to the connection to them of the sources of voltage or current. to the self-induction let us carry also that case, when its parameters can change with the presence of the connected power source or the energy accumulated in the system. This self-induction we will call parametric [1].

Subsequently we will use these concepts: as current generator and the voltage generator. By ideal voltage generator we will understand such source, which ensures on any load the lumped voltage, internal resistance in this generator equal to zero. By ideal current generator we will understand such source, which ensures in any load the assigned current, internal resistance in this generator equally to infinity. The ideal current generators and voltage in nature there does not exist, since both the current generators and the voltage generators have their internal resistance, which limits their possibilities.

If we to one or the other network element connect the current generator or voltage, then opposition to a change in its initial state is the response reaction of this element and this opposition is always equal to the applied action, which corresponds to third Newton's law.

if at our disposal is located the capacity C, and this capacity is charged to a potential difference U, then the charge Q, accumulated in the capacity, is determined by the relationship:

$$Q_{C,U} = CU . \tag{1.1}$$

The charge $Q_{C,U}$, depending on the capacitance values of capacitor and from a voltage drop across it, we will call still the flow of electrical self-induction.

When the discussion deals with a change in the charge, determined by relationship (1.1), then this value can change with the method of changing the potential difference with a constant capacity, either with a change in capacity itself with a constant potential difference, or and that and other parameter simultaneously.

If capacitance value or voltage drop across it depend on time, then the current strength is determined by the relationship:

$$I = \frac{dQ_{C,U}}{dt} = C\frac{\partial U}{\partial t} + U\frac{\partial C}{\partial t} .$$

This expression determines the law of electrical self-induction. Thus, current in the circuit, which contains capacitor, can be obtained by two methods, changing voltage across capacitor with its constant capacity either changing capacity itself with constant voltage across capacitor, or to produce change in both parameters simultaneously.

For the case, when the capacity C_1 is constant, we obtain known expression for the current, which flows through the capacity:

$$I = C_1 \frac{\partial U}{\partial t}. \tag{1.2}$$

When capacity with the constant stress on it changes, we have:

$$I = U_1 \frac{\partial C}{\partial t}. \tag{1.3}$$

This case to relate to the parametric electrical self-induction, since the presence of current is connected with a change in this parameter as capacity.

Let us examine the consequences, which escape from relationship (1.2). If we to the capacity connect the direct-current generator I_0, then stress on it will change according to the law:

$$U = \frac{I_0 t}{C_1}. \tag{1.4}$$

Thus, the capacity, connected to the source of direct current, presents for it the effective resistance

$$R = \frac{t}{C_1}, \tag{1.5}$$

which linearly depends on time. The it should be noted that obtained result is completely obvious; however, such properties of capacity, which customary to assume by reactive element they were for the first time noted in the work [1].

This is understandable from a physical point of view, since in order to charge capacity, source must expend energy.

The power, output by current source, is determined in this case by the relationship:

$$P(t) = \frac{I_0^{\,2} t}{C_1}. \tag{1.6}$$

The energy, accumulated by capacity in the time t, we will obtain, after integrating relationship (1.6) with respect to the time:

$$W_C = \frac{I_0^{\,2} t^2}{2C_1}.$$

Substituting here the value of current from relationship (1.4), we obtain the dependence of the value of the accumulated in the capacity energy from the instantaneous value of stress on it:

$$W_C = \frac{1}{2} C_1 U^2.$$

Using for the case examined a concept of the flow of the electrical induction

$$\Phi_U = C_1 U = Q(U) \tag{1.7}$$

and using relationship (1.2), obtain:

$$I_0 = \frac{d\Phi_U}{dt} = \frac{\partial Q(U)}{\partial t}, \tag{1.8}$$

i.e., if we to a constant capacity connect the source of direct current, then the current strength will be equal to the derivative of the flow of capacitive induction on the time.

Now we will support at the capacity constant stress U_1, and change capacity itself, then

$$I = U_1 \frac{\partial C}{\partial t}. \tag{1.9}$$

It is evident that the value

$$R_C = \left(\frac{\partial C}{\partial t} \right)^{-1} \tag{1.10}$$

plays the role of the effective resistance [1]. This result is also physically intelligible. This result is also physically intelligible, since. with an increase in the capacitance increases the energy accumulated in it, and thus, capacity extracts in the voltage source energy, presenting for it resistive load. The power, expended in this case by source, is determined by the relationship:

$$P(t) = \frac{\partial C}{\partial t} U_1^{\ 2} \tag{1.11}$$

from relationship (1.11) is evident that depending on the sign of derivative the expendable power can have different signs. When the derived positive, expendable power goes for the accomplishment of external work. If derived negative, then external source accomplishes work, charging capacity.

Again, introducing concept the flow of the electrical induction

$$\Phi_C = CU_1 = Q(C),$$

obtain

$$I = \frac{\partial \Phi_C}{\partial t}. \tag{1.12}$$

Relationships (1.8) and (1.12) indicate that regardless of the fact, how changes the flow of electrical self-induction (charge), its time derivative is always equal to current.

Let us examine one additional process, which earlier the laws of induction did not include, however, it it falls under for our extended determination of this concept. From relationship (1.7) it is evident that if the charge, left constant (we will call this regime the regime of the frozen electric flux), then stress on the capacity can be changed by its change. In this case the relationship will be carried out:

$$CU = C_0 U_0 = const\,,$$

where C and U - instantaneous values, and C_0 and U_0 - initial values of these parameters.

The stress on the capacity and the energy, accumulated in it, will be in this case determined by the relationships:

$$U = \frac{C_0 U_0}{C}, \tag{1.13}$$

$$W_C = \frac{1}{2}\ \frac{(C_0 U_0)^2}{C}\ .$$

It is natural that this process of self-induction can be connected only with a change in capacity itself, and therefore it falls under for the determination of parametric self-induction.

Thus, are located three relationships (1.8), (1.12) and (1.13), which determine the processes of electrical self-induction. We will call their rules of the electric flux. Relationship (1.8) determines the electrical self-induction, during which there are no changes in the capacity, and therefore this self-induction can be named simply electrical self-induction. Relationships (1.3) and (1.9-1.11) assume the presence of changes in the capacity; therefore the processes, which correspond by these relationships, we will call electrical parametric self-induction.

2. Current self-induction

Let us now move on to the examination of the processes, proceeding in the inductance. Let us introduce the concept of the flow of the current self-induction

$$\Phi_{L,I} = LI \,.$$

If inductance is shortened outed, and made from the material, which does not have effective resistance, for example from the superconductor, then

$$\Phi_{L,I} = L_1 I_1 = const \;,$$

where L_1 and I_1- initial values of these parameters, which are located at the moment of the short circuit of inductance with the presence in it of current. This regime we will call the regime of the frozen flow [1]. In this case the relationship is fulfilled:

$$I = \frac{I_1 L_1}{L}\,, \qquad (2.1)$$

where I and L - the instantaneous values of the corresponding parameters.

In flow regime examined of current induction remains constant, however, in connection with the fact that current in the inductance it can change with its change, this process falls under for the determination of parametric self-induction. The energy, accumulated in the inductance, in this case will be determined by the relationship

$$W_L = \frac{1}{2}\frac{\left(L_1 I_1\right)^2}{L} = \frac{1}{2}\frac{(const)^2}{L}\,.$$

Stress on the inductance is equal to the derivative of the flow of current induction on the time:

$$U = \frac{d\Phi_{L,I}}{dt} = L\frac{\partial I}{\partial t} + I\frac{\partial L}{\partial t}.$$

let us examine the case, when the inductance of is constant. L_1

$$U = L_1\frac{\partial I}{\partial t}. \qquad (2.2)$$

designating $\Phi_I = L_1 I$, we obtain $U = \frac{d\Phi_I}{dt}$. After integrating expression (2.2) on the time, we will obtain:

$$I = \frac{Ut}{L_1}. \qquad (2.3)$$

Thus, the capacity, connected to the source of direct current, presents for it the effective resistance

$$R = \frac{L_1}{t}, \qquad (2.4)$$

which decreases inversely proportional to time.

The power, expended in this case by source, is determined by the relationship:

$$P(t) = \frac{U^2 t}{L_1} . \qquad (2.5)$$

This power linearly depends on time. After integrating relationship (2.5) on the time, we will obtain the energy, accumulated in the inductance of

$$W_L = \frac{1}{2}\frac{U^2 t^2}{L_1}. \qquad (2.6)$$

After substituting into expression (2.6) the value of stress from relationship (2.3), we obtain:

$$W_L = \frac{1}{2}L_1 I^2.$$

This energy can be returned from the inductance into the external circuit, if we open inductance from the power source and to connect effective resistance to it.

Now let us examine the case, when the current I_1, which flows through the inductance, is constant, and inductance itself can change. In this case we obtain the relationship

$$U = I_1 \frac{\partial L}{\partial t}. \tag{2.7}$$

Thus, the value

$$R(t) = \frac{\partial L}{\partial t} \tag{2.8}$$

plays the role of the effective resistance [1]. As in the case the electric flux, effective resistance can be (depending on the sign of derivative) both positive and negative. This means that the inductance can how derive energy from without, so also return it into the external circuits.

Introducing the designation $\Phi_L = LI_1$ and, taking into account (2.7), we obtain:

$$U = \frac{d\Phi_L}{dt}. \tag{2.9}$$

Of relationship (2.1), (2.6) and (2.9) we will call the rules of current self-induction, or the flow rules of current self-induction. From relationships (2.6) and (2.9) it is evident that, as in the case with the electric flux, the method of changing the flow does not influence eventual result, and its time derivative is always equal to the applied potential difference. Relationship (2.6) determines the current self-induction, during which there are no changes in the inductance, and therefore it can be named simply current self-induction. Relationships (2.7,2.8) assume the presence of changes in the inductance; therefore we will call such processes current parametric self-induction.

1. Менде Ф. Ф. Новая электродинамика. Революция в современной физике. Харьков, НТМТ, 2012, – 172 с.