An Inductive Coil Simulation

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Abstract: - An inductive coil is one of the most widely used electrical circuit elements in a wide variety of devices. It is often necessary to consider the phenomenon of saturation of the magnetic core. There are a significant number of mathematical models and simulators of an inductive coil. Since each researcher is forced to work with its own specific set of input data and technical requirements, each model has its own field of application. In this article, the author offers the reader a description of his version of the mathematical model and simulators of an inductive coil, which makes it possible to take into account the nonlinearity of the magnetization curve basing on static inductance. The phenomenon of hysteresis is not considered.

Key-Words: - Choke; Reactor; Inductive Coil; Magnetic Core; Saturation; Simulation.

1 Introduction

For a more accurate correspondence to the reality of the results of modeling an electric drive and other electrical systems, one should use models of circuit elements, which describe physical processes as fully as possible. One of the most common elements in electrical circuits is an inductive coil in versions with or without a magnetic core. Depending on the functions performed, it has various names, of which the most common are the inductor, reactor and the choke [1]. In the technical literature, a number of satisfactorily working mathematical models and simulators of an inductive coil are described [2 - 4]. Since each researcher is forced to work with his own specific set of input data and requirements, each model has its own area of application. The author offers his own version of the mathematical model and simulators of the inductive coil.

2 Mathematical Model

As is known from [5], neglecting the intrinsic capacity of the winding and losses in insulation, it is possible to represent the equivalent circuit of an inductive coil in the form shown in Fig.1, where R_W - resistance of wire; $L(i_L)$ - coil inductance, which depends on the value of the current, other words, inductance with magnetic saturation account; R_C - resistance of losses in magnetic core; i_L - current though inductive branch; i_R - current though R_C; v - voltage between inductive coil terminals.

We can write the differential equations, describing mathematical model of an inductive coil, as:

$$\begin{cases} v + \Delta L(i_L)\dfrac{di_L}{dt} = L_{unsaturated}\dfrac{di_L}{dt} + (i_L + i_R)R_W; \\ R_C i_R = (L_{unsaturated} - \Delta L(i_L))\dfrac{di_L}{dt}, \end{cases} \quad (1)$$

where $L_{unsaturated}$ - unsaturated (largest) value of the inductance; $\Delta L(i_L) = L_{unsaturated} - L(i_L)$.

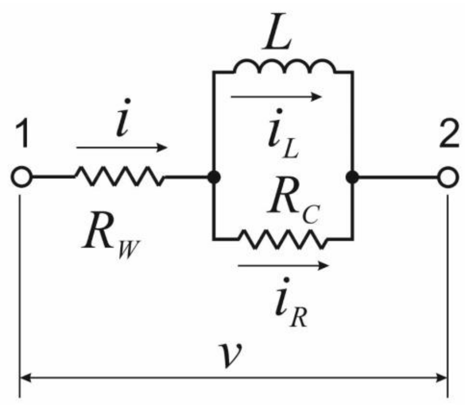

Fig.1. The equivalent circuit of an inductive coil

The term $\Delta L(i_L)\dfrac{di_L}{dt}$ on the left-hand side of the first equation of system (1) can be interpreted as some addition to the voltage applied to the terminals of an inductive coil, arising due to a decrease in inductance due to the phenomenon of saturation. It is possible to take into account the nonlinearity of the magnetization curve of core using the method described in [6]. Then the equations (1) are transformed to the form (2).

$$\begin{cases} v + L_{unsaturated}(1 - L^{**}(i_L))\dfrac{di_L}{dt} = \\ = L_{unsaturated}\dfrac{di_L}{dt} + (i_L + i_R)R_W; \\ R_C i_R = L_{unsaturated} L^{**}(i_L)\dfrac{di_L}{dt}. \end{cases} \tag{2}$$

3 Simulators

Using the OrCAD soft, the simulator of an inductive coil based on equations (2) in the form of an equivalent electrical circuit constructed (shown in Fig.2).

as a voltage $L_{unsaturated}\dfrac{di_L}{dt}$ value sensor. A voltage controlled voltage source E2 injects a voltage $\Delta L(i_L)\dfrac{di_L}{dt}$ into the circuit. The nonlinearity of the magnetization curve is specified by the TABLE block [6]. Resistors R2, R3 and R4 have a large values, for example 1 MΩ, and perform the function of ensuring stable operation of the model in the case of a pulse voltage v applied to the choke terminals. A similar solutions are described in [8, 9].

Also using the OrCAD soft, the simulator of an inductive coil based on equations (2) in the form of block diagram constructed (shown in Fig.3).

4 Simulation Results and Conclusions

The simulation performed of time variation of the inductance of the RS38 choke as a function of the current i flowing through it. The dependence $L^{**}(|i_L{}^*|)$ for RS38 is approximated piecewise linearly according to [6] and is shown in Fig. 4. It is accepted $i_L \approx i$.

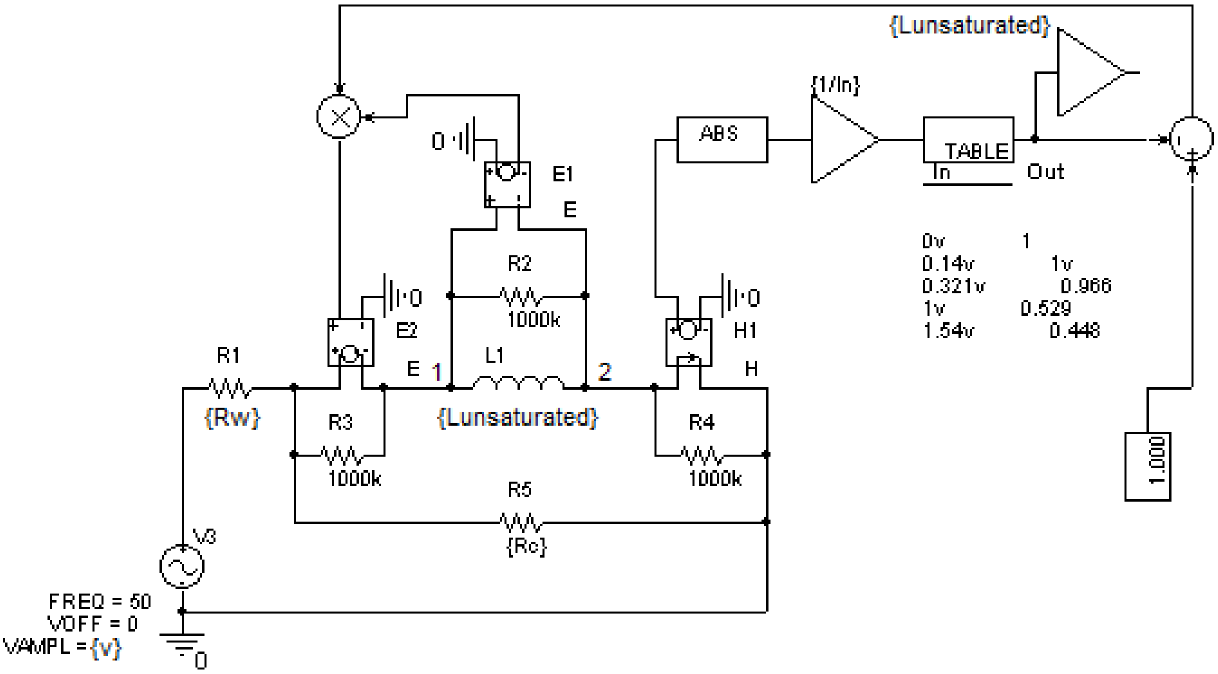

Fig. 2. Picture of the simulator of an inductive coil based on equations (2) in the form of an equivalent electrical circuit developed by means of OrCAD soft

Functions and designations of circuit elements in Fig. 2 are described in detail in [7]. The current controlled voltage source H1 serves as a i_L current sensor. Voltage controlled voltage source E1 serves

The point corresponding to the continuous current through the choke ($I_{continious} = 2860$ A) was taken as the basis for calculations in relative units.

In Fig.2 and Fig.3 $I_{continious}$ value corresponds to the I_n designation.

The choice of the R_C value is made under the condition of equality of losses in copper and losses in steel at $I = 150$ A and 50 Hz.

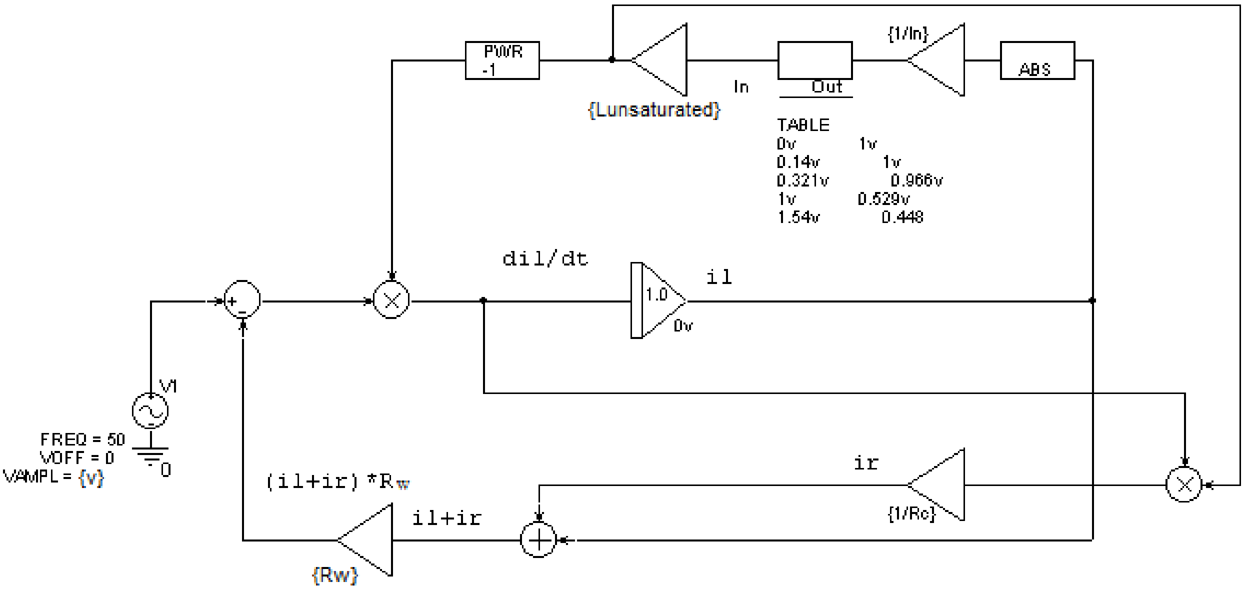

Fig. 3. Picture of the simulator of an inductive coil based on equations (2) in the form of block diagram developed by means of OrCAD soft

In accordance with the RS38 passport data, the inductance at an alternating current of up to 150 A (effective value) of a frequency of 50 Hz is at least 3.5 mH, and when magnetized by a direct current of 3270 A, at least 1.7 mH. When calculating the curve in Fig. 4 it is necessary to take into account that on alternating current it is necessary to operate with its amplitude values [6].

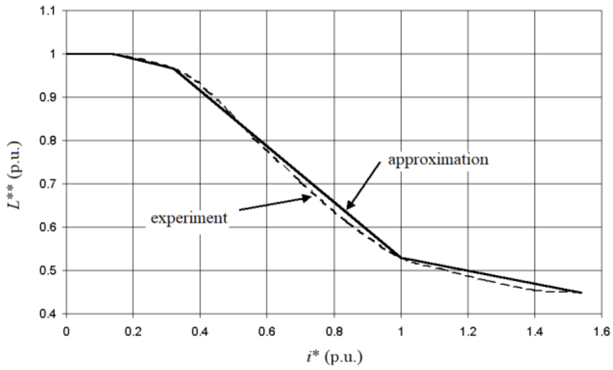

Fig.4. The approximation of $L^{**}(|i_L{*}|)$ dependence for RS38 choke

The simulation results in Fig.5 achieved at following conditions: $v = 1800\sin(314t)$; $L_{unsaturated} = 3.57$ mH; $R_C = 200$ Ω; $R_W = 0.00607$ Ω; temperature of coil wire 90◦C.

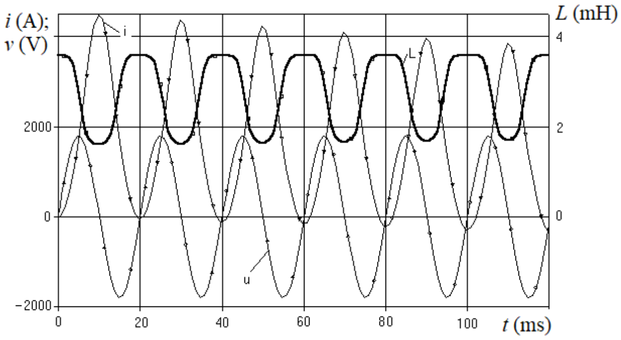

Fig.5. Simulation results for RS38 choke under applying to terminals sinusoidal voltage condition

The both developed simulators give identical simulation results. The simulation results (Fig.5) are in good agreement with the RS38 passport data.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Mikhail Pustovetov developed mathematical model and implemented it in form of OrCAD-based simulators, then carried out the simulation and analysis of simulation results in comparison with data of experiment. Thus, his contribution to the creation of a scientific article is to: conceptualization, formal analysis, methodology, investigation and validation.