Circuit theory for unusual inductor behaviour

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Abstract

The experiments of Osamu Ide showed that transformers exhibit current components hitherto unknown when switched on by steep pulses. This behaviour has been be explained by Einstein-Cartan-Evans Theory in a previous paper. In order to simplify calculations, an extended circuit theory is developed on this basis. Oscillations of the inductance are shown to account for the additional, exponentially decreasing current term. The circuit equation is first developed theoretically and studied analytically. Then precise solutions are obtained by simulation, showing that the experimental curves of the Ide effect can be reproduced very well. A mechanism for extracting energy is proposed.

Keywords: serial resonance circuit; transformer; initial current; circuit theory; variable inductance; simulation model.

1 Introduction

When a voltage is applied to a serial resonance circuit, it is known from classical electrodynamics that the current rises first linearly and then goes into saturation. The inductance of the circuit hinders the current to jump to its final value immediately. In a series of papers, Osamu Ide has described experiments revealing an extra current in this process [1]- [3]. Actually there are two effects. When voltage is switched on in a pulse, the current oscillates strongly for less than a microsecond, then rises beyond the classical (linear) value in an exponentially decreasing way. These effects can be seen in Fig. 1 which has been taken from [6] where the effect has been verified independently. In that paper, both effects could be explained as interactions with the background or spacetime potential, which becomes effective in non-continuous processes, in this case the hard switch-on of the voltage/current. In [6] the effects could be explained well by the so-called Einstein-Cartan-Evans theory [4]- [5], which provides an extensions of Maxwell-Heaviside theory on the electromagnetic sector.

A direct application of this theory is not easy for engineers, therefore we derive a simplified approach in this paper which is based on a slight extension of classical circuit theory. Both the experimental and theoretical results of [6]

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showed that the modulation of circuit behaviour due to spacetime effects results in a strong variation of the effective inductance. Therefore we will develop this approach in the following.

2 Analytic curcuit theory

The general serial resonance circuit with inductance L, capacitance C, Ohmic resistance R, obeys the circuit equation

$$\frac{d}{dt}(LI) + RI + \frac{Q}{C} = U_0 \tag{1}$$

where Q is the charge at the capacitor and I the current. Normally the device properties L, R and C are assumed constant in time. Then, by replacing $I = dQ/dt$, a second-order differential equation is obtained:

$$L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{Q}{C} = U_0. \tag{2}$$

However, if the inductance is not constant, from Eq.(1) follows:

$$\frac{dL}{dt}I + L\frac{dI}{dt} + RI + \frac{Q}{C} = U_0 \tag{3}$$

or, rewritten,

$$L\frac{d^2Q}{dt^2} + \left(\frac{dL}{dt} + R\right)\frac{dQ}{dt} + \frac{Q}{C} = U_0. \tag{4}$$

Comparing with Eq.(2), we see that the time change of the inductance behaves like an effective dynamic resistance

$$R_{\text{eff}} = \frac{dL}{dt} + R \tag{5}$$

which depends on time. Eq.(2) then reads

$$L\frac{d^2Q}{dt^2} + R_{\text{eff}}\frac{dQ}{dt} + \frac{Q}{C} = U_0. \tag{6}$$

This is the equation of a damped enforced oscillation as before. However, in the Ide experiment, we have a strongly oscillating current in the initial spike, indicating that the inductance oscillates heavily under the viewpoint of circuit theory. In particular dL/dt takes negative values for every second half-wave. Assuming that the Ohmic resistance is small and the inductance variation is high, we will have the case

$$R_{\text{eff}} < 0 \tag{7}$$

for about half of the time. The solution of the differential equation (6) then has a non-oscillatory form. For sake of simplicity, we assume a constant driving voltage U_0 and constant value R_{eff}. Then the analytical solution of (6) is

$$\text{Q}\,(t) = K_1 \exp\left(\omega_1\, t - \frac{R_{\text{eff}}\, t}{2\,L}\right) + K_2\, \exp\left(-\omega_1\, t - \frac{R_{\text{eff}}\, t}{2\,L}\right) + U_1\, C \tag{8}$$

with constants K_1 and K_2 and resonance frequency

$$\omega_1 = \frac{1}{2}\sqrt{\frac{R_{\text{eff}}^2}{L^2} - \frac{4}{C\,L}}. \tag{9}$$

This solution holds for

$$R_{\text{eff}}^2\,C - 4\,L > 0 \tag{10}$$

which is fulfilled when R_{eff} is large enough. From Eq.(8) can be seen that there is always an exponentially growing solution if $R_{\text{eff}} < 0$. The same holds for the current which is the time derivative of (8):

$$\begin{aligned} I = K_1 \left(\omega_1 - \frac{R_{\text{eff}}}{2\,L}\right) \exp\left(\omega_1\,t - \frac{R_{\text{eff}}\,t}{2\,L}\right) \\ -K_2 \left(\omega_1 + \frac{R_{\text{eff}}}{2\,L}\right) \exp\left(-\omega_1\,t - \frac{R_{\text{eff}}\,t}{2\,L}\right). \end{aligned} \tag{11}$$

Even if the constant K_1 is set to zero in order to avoid exponentially growing solutions as is often done in physical situations, the current (11) remains growing due to sign reversal by R_{eff}.

3 Simulation results

In the preceding section the effective resistance was made constant to be able to obtain analytic solutions. Now we investigate the full equation (4) with dynamic effective resistance (5). The capacitance has been omitted, i.e. we model the current onset of a coil only as in the original experiments. As suggested in [6] L is strongly oscillating in time with decreasing amplitude. We modeled this by a function

$$L(t) = L_0 \left(1 - \exp(-\frac{t}{T_1})\sin(\omega t)\right) \tag{12}$$

with a time constant T_1 and oscillation frequency ω. The derivative of $L(t)$ is extremely sharp and had to be confined to values less than 10^3 H/s in order to keep the simulation stable. The following parameters were used:

$$\begin{aligned} L_0 &= 0.04 \text{ H} \\ R &= 10\ \Omega \\ T_1 &= 800\ \mu\text{s} \\ \omega &= 2\pi \cdot 3 \text{ MHz} \\ U_0 &= 50 \text{ V} \end{aligned}$$

The simulations were carried out with the simulation program OpenModelica [7]. The results are shown if Fig. 2 and can be compared with the experimental curves of [6] presented in Fig. 1. A direct scaling of both curve sets was not attempted but would be possible. The exponentially decreasing additional current (green curve in Fig. 2) comes out quite exactly as in the experiment (black curve in Fig. 1). There is an additional offset in Fig. 1 whose origin is unclear but was observed by both Ide and Arenhold/Eckardt. This gives even an additional enhancement of the spacetime effect. The oscillations of inductance (modeled by 3 MHz) lead to an oscillatory fine structure of the current which may be in the order of precision of experimental measurement. As already explained, the amplitude of dL/dt was artificially limited in order to not distort the results. The effect is a kind of curve smoothing.

For making the Ide effect exploitable, the switching has to be repeated in a periodic way. We modeled this by switching the voltage U_0 on and off in rectangular pulses of 95% pulse width. Then the behaviour of Fig. 2 is repeated, see Fig. 3. In the off phases of the voltage the current starts going down as expected. It would drop to zero if the voltage were permanently switched off, but the decrease is minimal due to the short time interval. In total there is a current gain of about 60% at the end of the curve. After the first period, the gain is nearly 100%, but with low current amplitude. It can be seen that the additional current (green curve) does no more increase when the classical curve (red) changes from linear to exponential behaviour.

In Fig. 4 the time oscillation of the inductance model $L(t)$ has been graphed. The envelope of the oscillation decreases exponentially but does not drop to zero in the periodic time interval. Single oscillations cannot be resolved because of the scaling.

4 Discussion and conclusions

It has been shown that a circuit model with variable inductance works well for explaining the Ide effect. A rough analytical estimation could be verified by simulation and is in good qualitative agreement with measurements. Periodic repetition of the switching process should enable gathering energy from spacetime.

In a previous study [8], resonance of a field dependent solenoid was demonstrated. Simple but well founded arguments gave the material properties such as permeability as a parabolic function of the magnetic field. With reasonable simplifications, the non-linear hyperbolic partial differential equations were shown to reduce to a distorted wave equation which offered parabolic diffusion type solutions showing amplification effects similar to what was observed in this study. Heterodyning behaviour was also observed, corresponding to the resonance for the first standing wave in the solenoid core. At higher frequencies, the magnetic field becomes asymptotically linear in time, indicating some form of resonant growth as indicated in this paper.

The beauty of the method described in this paper, is that the calculation of field dependent device properties is separated from the resonant calculation. Rather than solve the difficult time dependent non-linear hyperbolic differential equation set generated by electromagnetism, we solve a single non-linear ordinary differential equation, such as equation (6) for the desired circuit. One then can use ECE solution techniques to design specific devices that would satisfy the parametric equations such as given by equation (12) for this specific example.

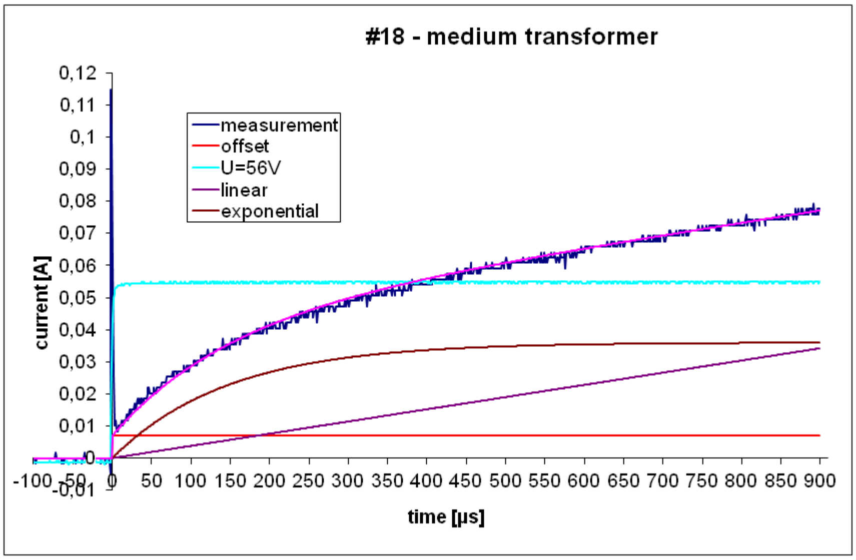

Figure 1: Measurements of Ide effect, taken from [6].

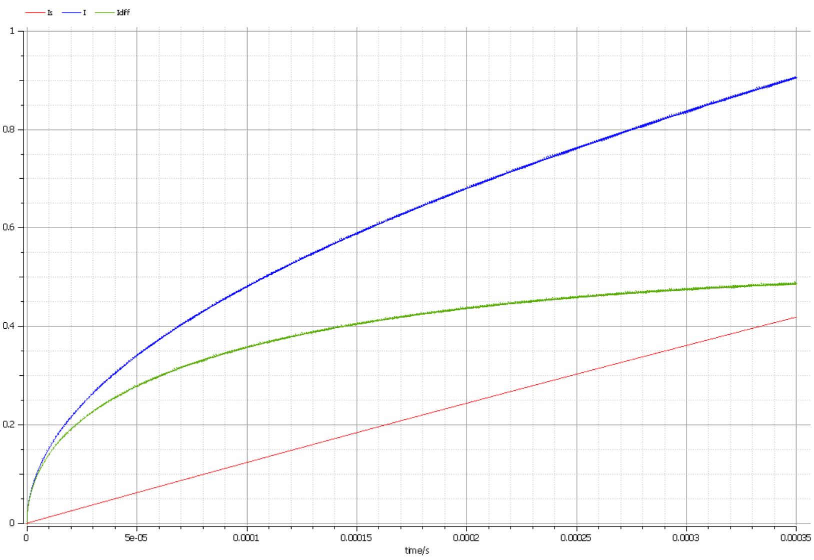

Figure 2: Simulation results. red: current from standard theory, green: additional current, blue: total current.

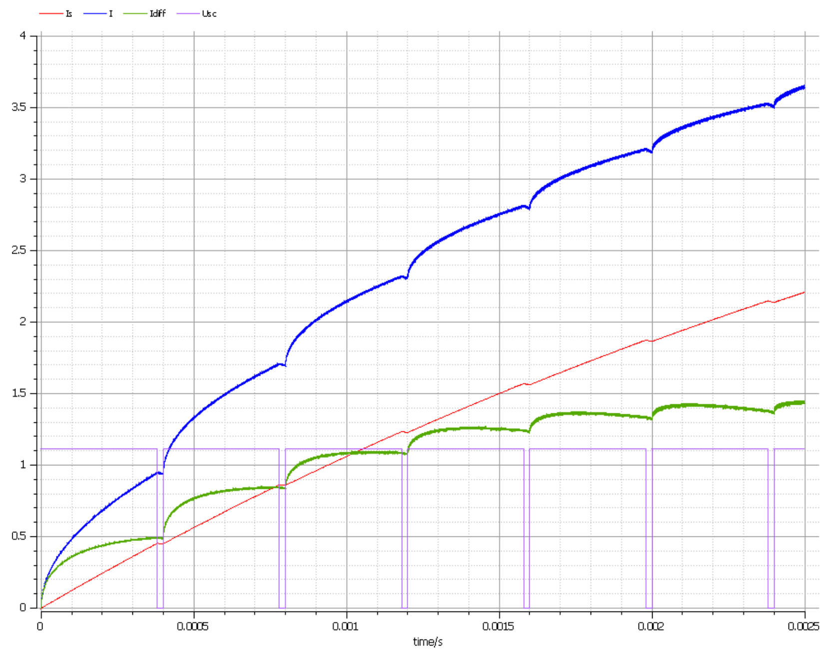

Figure 3: Periodic switching of device in steps of 400 μs. red: standard current, green: additional current, blue: total current, purple: voltage (scaled).

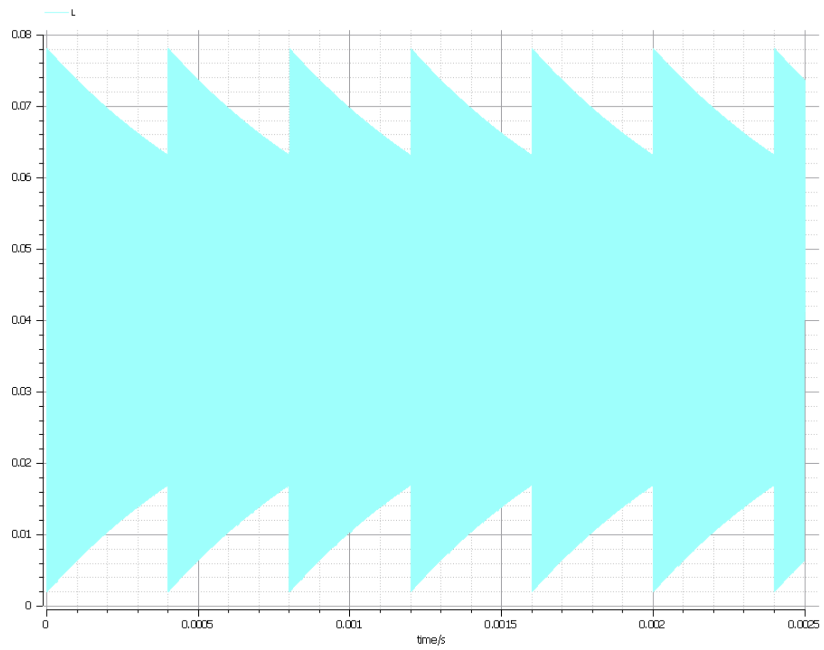

Figure 4: Time behaviour of inductance model for periodic switching (oscillating around 0.04 H).

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