Construction of a Wire-wound Inductor

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Abstract

This paper describes an experiment to construct a wire-wound inductor using copper wire and a stainless steel core. The inductor was wound by hand and then its inductance was measured (8.9 mH) by placing it in series with a 100 Ω resistor, observing the step response on an oscilloscope and measuring the time constant. The measured inductance is also compared with the expected value calculated using a standard formula for a long solenoid.

1. Introduction

In this experiment, a wire-wound inductor was constructed by wrapping enamel-insulated copper wire around a stainless steel core. The magnitude of the inductance depends on a number of factors, including the length and radius of the coil, the magnetic permeability of the core, and especially the number of turns.

The inductance of a long straight solenoid can be approximated using the following expression [1].

$$L = \frac{\mu N^2 A}{l} \tag{1}$$

where L is the inductance [H], μ is the magnetic permeability of the core [H/m], N is the number of turns, A is the cross-sectional area of the coil [m^2], and l is the length of the coil [m]. The permeability depends on what material the core is made of. The relative permeability of stainless steel typically falls in the range 750-1800 [2]. Although a predicted value for the inductance was calculated, the permeability of the specific steel used in this experiment is not known. Hence, there is a high level of uncertainty in the predicted inductance. The value used for the relative permeability was 750. This can be converted to an absolute permeability as follows.

$$\mu = \mu_r \mu_0 = 750 \times 4\pi \times 10^{-7} = 6.6405 \times 10^{-4}\, Hm^{-1} \tag{2}$$

where μ is the absolute permeability [Hm^{-1}], μ_r is the relative permeability [dimensionless], and μ_0 is the permeability of free space [Hm^{-1}].

The time constant of an RL circuit is given by the following expression.

$$\tau = \frac{L}{R} \tag{3}$$

Where τ is the time constant [s], L is the inductance [H] and R is the resistance [Ω]. Eq. 3 can be rearranged to give the following formula which allows the inductance to be calculated when the resistance and time constant are known.

$$L = \tau \times R \tag{4}$$

2. Method

The wire used in this experiment was Unistrand 35 SWG (diameter 0.2134 mm) copper wire with enamel insulation. The inductor core was formed by stacking the handles of 5 steel spoons. The resulting core had a square cross section with an area of approximately 1 cm^2. A winding with 80 turns and a length of 1.6 cm was wound by hand. The enamel insulation was stripped from the two ends of the winding using a sharp knife.

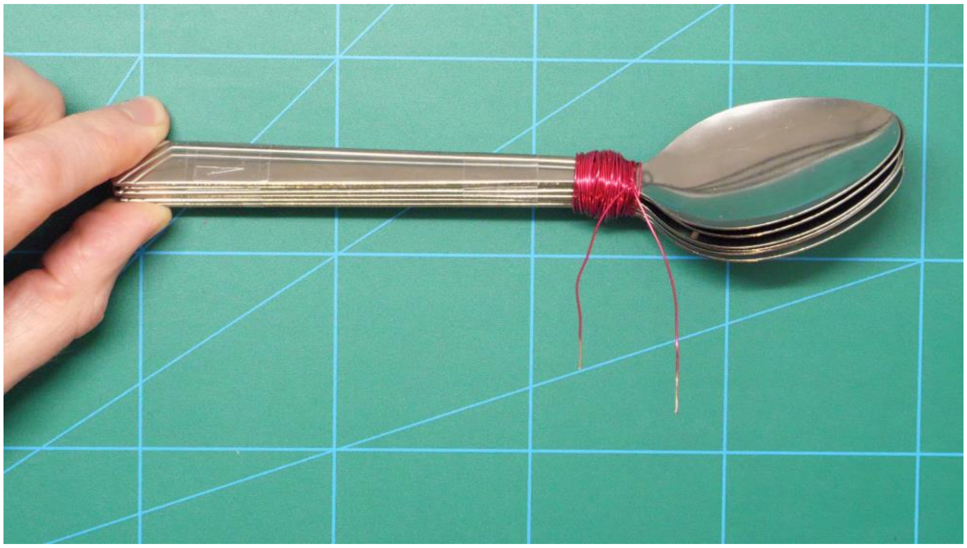

Fig. 1. The hand wound inductor comprises a length of enamel-insulated copper wire wrapped 80 times around a stainless steel core that was formed

from a stack of spoons. The insulating enamel has been stripped from the two ends of the wire to allow connection to the measurement circuit.

The following circuit was used to measure the inductance. The nominal value of the resistor was 220 Ω. Its resistance was measured with a digital multimeter and found to be 223.4 Ω.

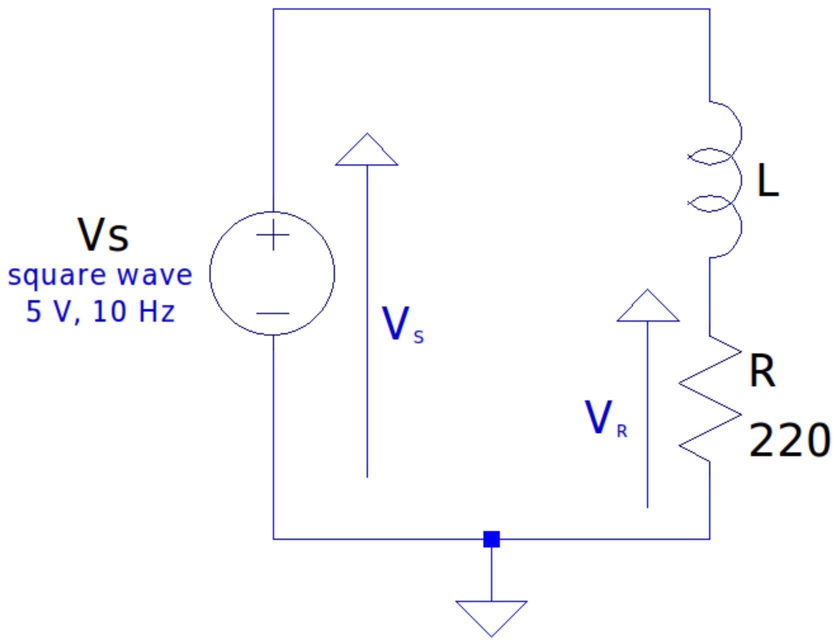

Fig. 2. Circuit used for inductance measurement. The inductor was placed in series with a known resistance to form an RL circuit. By measuring the time constant of the RL circuit, the inductance could be measured.

A square-wave voltage source with an amplitude of 5 V and a frequency of 10 Hz was connected to the circuit, repeatedly generating a step response that could be analysed using an oscilloscope. The time constant was measured from the oscilloscope screen and the inductance was then calculated using Eq. 3. For a positive-going step, the time constant is the time taken by the resistor voltage to reach 63.212% of its maximum value.

3. Results

The time constant measured from the circuit step response was 42.8 µs. The inductance was then calculated using Eq. 4.

$$L = \tau \times R = 42.8 \times 10^{-6} \times 223.4 = 9.566\, mH \tag{5}$$

For comparison, the predicted value was

$$L = \frac{\mu N^2 A}{l} = \frac{6.6405 \times 10^{-4} \times 80^2 \times 0.01^2}{1.6^{-2}} = 26.562\, mH \tag{6}$$

4. Discussion

Clearly, there is a significant difference between the measured and predicted inductance values. Several factors may account for this, but probably the most significant is the estimated value for the permeability of the steel. Different types of steel have widely varying permeability values and there was no reason to assume that the chosen value was a precise estimate. Hence, it should not be assumed that the measured value is incorrect simply because it is different from the predicted value.

Possible sources of error in this experiment include the following:

- The parasitic resistance of the inductor was not measured. This resistance appears in series with the RL circuit and affects its time constant. In retrospect, it would have been advisable to measure it and take it into account in the calculations.
- The source impedance of the voltage source was not taken into account. This resistance also affects the time constant and hence the inductance estimate.
- The time constant was measured by eye from the oscilloscope screen. Any inaccuracy in this measurement influences the calculated inductance.

5. Conclusions

The experiment produced a wire-wound inductor with an inductance of 9.566 mH, which was sufficiently large to facilitate observation and measurement of the time constant of the resulting RL circuit on the oscilloscope. Greater accuracy could have been achieved if additional sources of resistance in the circuit had been taken into account.

Bibliography

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2. S. W. Ellingson, “Permeability of Some Common Materials,” in *Electromagnetics*, Vol. 1 (Beta), Blacksburg, VA: VT Publishing, 2018, p. 214. [Online]. Available: https://vtechworks.lib.vt.edu/bitstream/handle/10919/84164/Electromagnetics_Vol1.pdf