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P5_6 How Many Turns Does a Coil Tattoo Machine Need?

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Abstract

We calculated how many turns a single solenoid of known dimensions in a coil tattoo machine would need to drive a needle at a frequency of 3000 strikes per minute at a voltage of 12 V. It was found around 18050 turns would be needed.

Introduction

A tattoo machine oscillates a needle to puncture skin between 50 and 3,000 times per minute [2] running between 4 V and 12 V [1]. The needle can either be oscillated using a rotary motor or an electromechanical relay. We calculated how many turns a single solenoid in an this relay would need to drive a tattoo needle at 12 V and a frequency of 3000 strikess per minute.

Theory and Results

A coil tattoo machine uses up to three solenoids to oscillate a needle. Initially, the spring plate is straight meaning the circuit is connected, causing the solenoid to produce a magnetic field which attracts the soft iron armature. The armature then moves down to the solenoid and the circuit becomes disconnected, discontinuing the magnetic field causing the armature to return to its original position.

We now find an equation which relates the number of coils in a solenoid required to drive the needle at 3000 strikes per minute with the machine working at 12 V. This relation is best found by starting with the long solenoid approximation then working through the unknown variables by substituting in other equations:

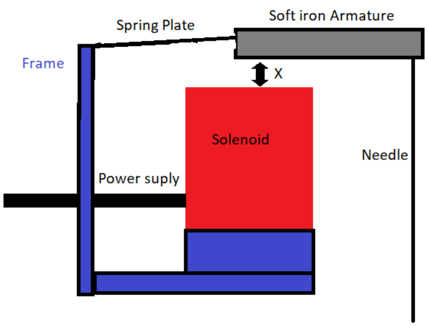

Figure 1: A coil tattoo gun.

$$B = \frac{NI\mu_o}{\ell}, \tag{1}$$

where B is the magnetic density, N is the number of turns, I is the current through the solenoid, ℓ is the length of the solenoid and μ_o is the permeability of free space. From looking at the dimension of a spool used to hold the coils of wire of the tattoo solenoid we know that $\ell = 28$ mm [4].

We know that V is 12 V, and a solenoid commonly has a resistance R of 20 Ω - 60 Ω [7], which we will take as 40 Ω for this paper. We can now use the relation:

$$V = IR, \tag{2}$$

to replace I in equation 1 later on.

Now we must find the magnetic density of the solenoid by considering Maxwell's pulling force formula [3] used for electromechanical relays:

$$F = \frac{B^2 A}{2\mu_o}, \tag{3}$$

where F is the force acting on the spring plate and A is the cross-sectional area of the solenoid. The spool used to hold the coiled wire of the solenoid in a tattoo machine has an inner diameter of 8 mm [4], so A is around 1.26 x 10 $^{-5}$ m^2, discounting the area gained from the width of the wire.

The force F can be found from the product of the bending stiffness k of the spring plate and the distance the needle moves when oscillating x:

$$F = kx. \tag{4}$$

A tattoo needle goes to depths of 1 mm - 2 mm into the skin [5], so we will take x as 1.5 mm.

The bending stiffness k of the spring plate is related to the mass of the tattoo needle m and the frequency of strikes, f_t, through the following equation:

$$\frac{1}{f_t} = 2\pi\sqrt{\frac{m}{k}}. \tag{5}$$

A tattoo needle has a mass roughly equal to 1 g and the soft iron armature is also around 1 g [6]. Now we can combine equations 1, 2, 3, 4 and 5 to show how all of our variables relate and solve for N:

$$N = \frac{2\pi f_t \ell R}{V}\sqrt{\frac{2mx}{\mu_o A}}. \tag{6}$$

Substitute all of our values into equation 6 to find $N = 18049.8$, so around 18050 turns.

Discussion

This is a high number of turns in a solenoid. By thinking about the dimensionality of the wires you would need wires of diameter 10 $^{-2}$ mm, which is exceedingly small. However, this is under the assumption the wire has the area of the inner spool, which it would not, and most tattoo machines use multiple solenoids meaning less coils would be needed. Also, this does not take into account that the tattoo machine works at different frequencies. By looking at equation 6 we can see by keeping the ratio of V and f_t constant we can use the same number of turns in the solenoid, which can be done using variable voltage. If we used a wire of a different resistance, say 60 Ω, then the number of coils would increase. Lastly, we took the oscillation of the needle to be like a spring, where in reality it would not be as the skin has elastic qualities which would perturb a perfect oscillation when puncturing.

Conclusion

We found 18050 turns were needed for the machine to run at 3000 strikes per minute at 12 V.

References

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