A High-Speed Magnetostrictive Material Based Actuator for the Cutting and Resection of Biological Tissue

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Introduction

As technology advances, disadvantages of traditional open surgery become more apparent. Where patients are forced to stay in hospitals longer due to the longer recovery times brought on by the damaging surgery. Not only this, but the patient is subject to a **much higher risk** of infection and other complications [1].
Therefore, the bipolar electrosurgical device proposed uses ultrasonic energy, then converted to frictional energy, to generate heat at the tip of the blade. The heat generated will boil cells allowing for both cutting and resection of tissue.

Methodology

To create the high speed actuator, the circuit will first include a pulse generator. This will create a square wave to pulse the gate of the P and N channel MOSFETs, turning them on and off at high speeds to generate a positive and negative current flowing through the coil of wire surrounding the Terfenol rod.

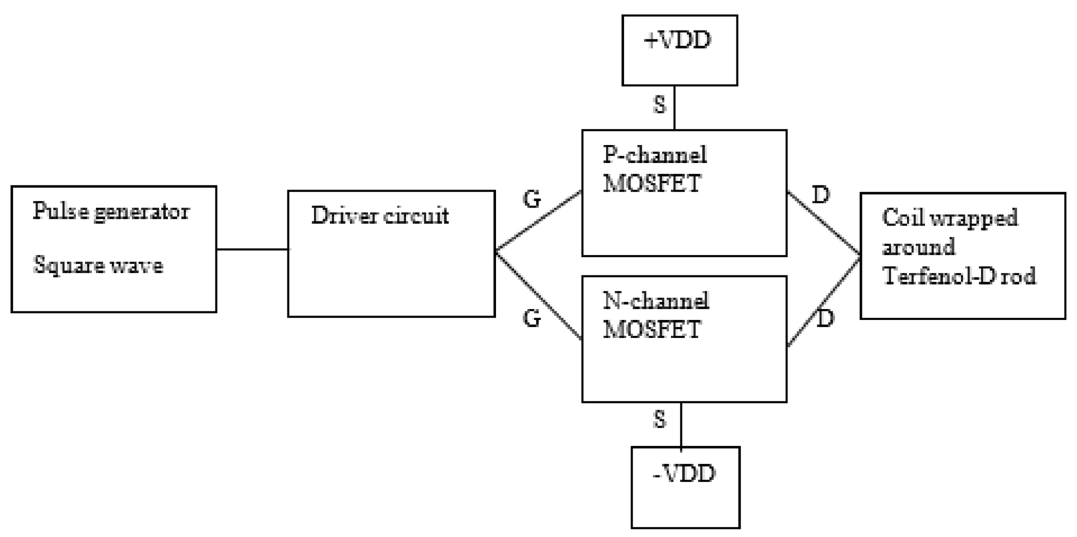

Figure 3: A basic circuit that will be used to power the coil of wire

Expanding the Terfenol rod will require a significant amount of magnetising force, therefore, the IRF840 and the IRF5210 were chosen due to their high drain current output, and large VDSMAX which will allow for the 8-12A required to induce the strain in the rod.

References

[1] T. N. Robinson and G. V. Stiegmann, "Minimally invasive surgery," 2004.

[2] B. A. Wills and J. A. Finch, "Magnetic and Electrical Separation," ch. 13, pp. 381–407, 8 ed., 2016.

Objectives

The main objective is to ascertain whether the proposed Terfenol actuator, provides better cutting and resection abilities when compared to the harmonic scalpel, whilst causing minimal damage to surrounding tissue. This breaks down into:

1. Research actuators & ferromagnetic materials
2. A literature review on alternative methods
3. Simulated design of solenoid coil circuit
4. Practical design and development of circuit
5. Refinement of circuit and prototype device

Statistical analysis

The following equations were used for statistical analysis:

$$H = NI/L \qquad B = H\mu_0\mu_r \qquad F = BIL$$

Where H is the magnetisation force, B is the magnetic flux density and F is the magnetic force [2].

By completing these formulas with the correct constants and accurate variables, the magnetic force can be calculated. First, calculating the formulas with low variables, where there will be 10 turns around the $1cm$ rod, and $8amps$. Then, high variables of 15 turns around the $1cm$ rod, and 12 amps passing through the coil.

Equation	Low variables	High variables
H	$8000A/m$	$18000A/m$
B	$0.0603T$	$0.136T$
L	$0.00483N$	$0.0163N$

Table 1: Table of variable values

This shows how the different values, namely 'number of turns' and 'current through coil', can alter the magnetic force on the material. Where an achievable increase in turns and current in a $1cm$ long terfenol rod can yield large returns. This however still shows that under these circumstances a visual elongation of the ferromagnetic rod may not be possible. Nevertheless, an audible hum should provide an adequate indication of whether the effect is working properly.

Results

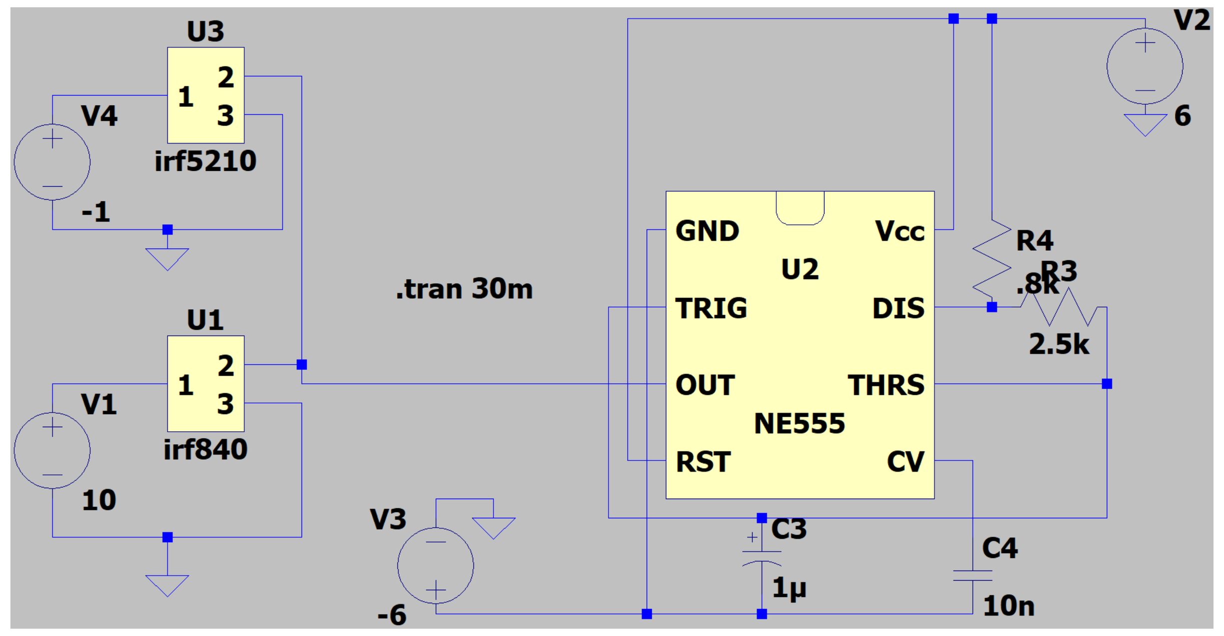

Figure 1: A circuit diagram of the pulse generator

Figure 1 shows a completed circuit that will be used to generate the alternating currents around the coil of wire. It uses an astable 555 timer circuit to generate a square-wave pulse to power the gate terminal of the MOSFETs. The astable 555 timer circuit was used instead of a regular pulse generator as it allows for faster, more accurate voltage switching. Also, the frequency can be adjusted by the RC circuit. The MOSFETs are comprised of the N-type MOSFET IRF840, and the P-type MOSFET IRF5210 as was in the specification to provide the optimal operating conditions.

The waveform in **figure 2** shows the output current from the drain terminals of the MOSFETs. Where the orange line shows the current output of the N-MOSFET IRF5210, and the blue line shows the current output of the P-MOSFET IRF840. Overall, it shows that the current peaks at $12A$ and again at $-12A$ which, as is shown in the calculations, should be enough to induce strain in the rod if combined with the correct amount of turns in the coil of wire. It will also be possible to then increase the output current by increasing the pulse voltage, as the NE555 timer is capable of handling upto $16V$ peak to peak.

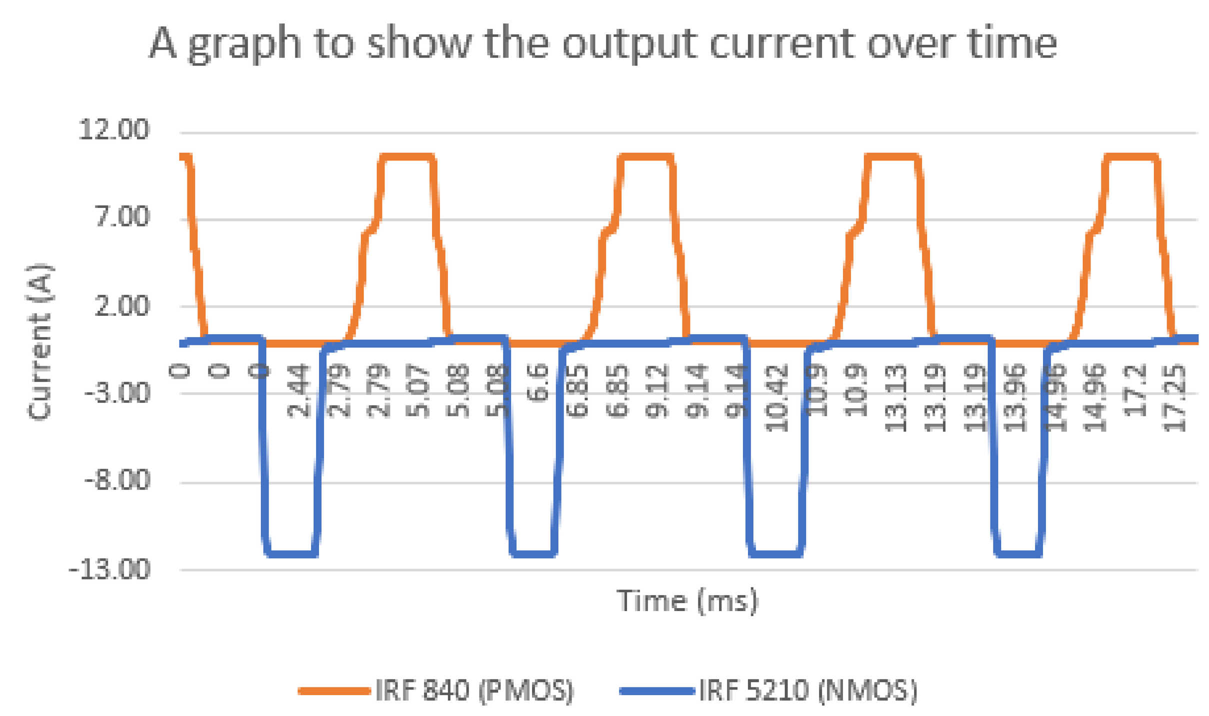

Figure 2: A graph to show the output current of the current pulse generator

Conclusion

Through the analysis of the calculations in the statistical analysis section and results section, it is possible to see that circuit that has been created has the means to generate a high enough current to be able to expand the Terfenol rod using the circuit shown in **figure 1** if the circuit uses the correct amount of turns in the coil.
In the case of an insufficient magnetic force being generated, alteration of current output may be necessary a the current will not be high enough to induce strain in the rod. In this case, a TS555 timer can be used instead of the NE555 timer, as it supports upto $18V$ peak to peak instead of the $16V$ peak to peak of the NE555.
The simulated results demonstrated in **figure 2** indicate that the designed circuit can be used as intended under practical conditions in order to generate feasible results, which can then be used as a benchmark comparison against the Harmonic Scalpel.

Future Research

Future work involves research into a prototype device that uses the circuitry and technology of the project, along with effective lenses and lighting methods. As most surgical laparoscopic tools are activated by a foot pedal, this too should be incorporated in the design of the prototype. This will then enable the tool to be better suited for the intense medical procedures in which it was designed.