Device for the Implantation of Neural Electrode Arrays*

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***Abstract*— Electrode arrays used in neural recording and stimulation applications must be implanted carefully to minimize damage to the underlying tissue. A device has been designed to improve a surgeon's control over implantation parameters including depth, insertion velocity, and insertion force. The device has been designed to operate without contacting tissue and to respond to tissue movements in real time during insertion. This device uses an electrical motor to drive electrode arrays into tissue and allows for the monitoring of and response to electrode depth during insertion. A prototype device has been constructed and tests have been performed to determine the velocity and force characteristics of the motor when inside the device housing. Future versions of the device will use a custom-designed motor with longer linear travel, which will allow the insertion device to be held farther from tissue while still ensuring proper array insertion.**

I. INTRODUCTION

To maximize effectiveness and minimize damage to the surrounding tissue, cortical electrode arrays must be implanted in a carefully controlled manner. To aid this, a device has been designed that will allow the implantation velocity and depth of cortical electrode devices to be controlled while ensuring repeatability from one implantation to the next. This device uses an electronic actuator to propel the electrodes into neural tissue at a predetermined velocity.

The principal function of this device is to deliver electrode arrays into neural tissue with sufficient force and velocity to minimize damage to the underlying tissue. Previous devices [2][3] have accomplished this using a "nail gun" approach - the array is loaded into the device, then propelled a specific distance forward. This process relies on the tip of the insertion device to be placed a known distance away from the target tissue, usually requiring some portion of the inserter to press against the tissue. Due to the tendency of neural tissue to move during surgery, this contact can add significant complications and risk to the implantation procedure.

This insertion device is being designed with the goal of implanting neural electrode arrays without requiring the device to contact neural tissue. To accomplish this, the device must be able to sense when electrode arrays have been implanted to their desired depth and stall forward motion in response. In addition, the drive shaft of the motor should be retracted upon successful implantation to reduce the chance of damaging neural tissue by disturbing the arrays after they have been implanted.

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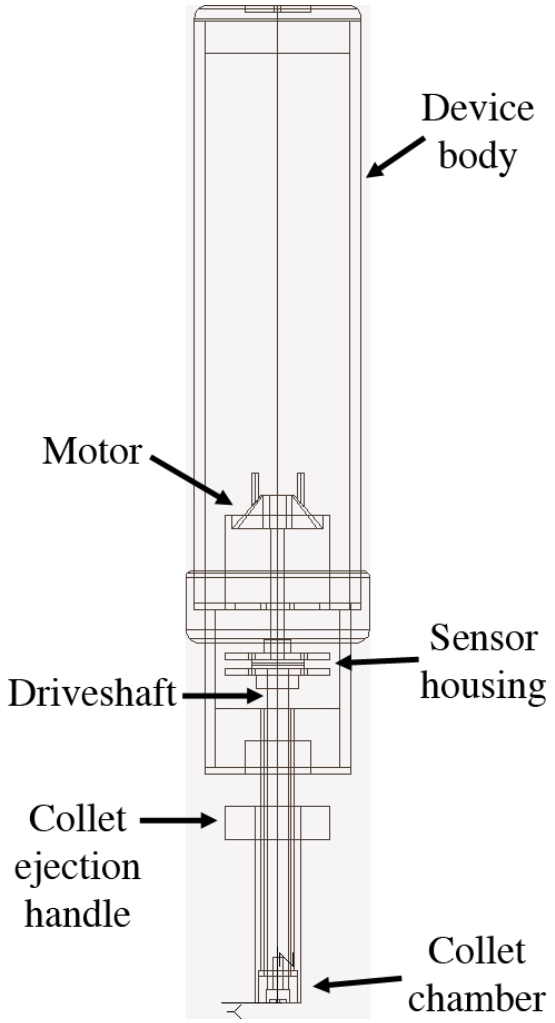

Fig. 1. Cross-section view of phase II prototype device.

To facilitate the rapid changes in movement direction necessary, a voice coil motor was selected to drive the insertion device. Motors of this type use an induction coil and a set of permanent magnets to create linear movement corresponding to the polarity of a voltage applied to the coil. Voice coil motors are lightweight and have low duty-cycle limits due to overheating, but are well suited to short bursts of speed and force and can have their direction and amount of travel specifically controlled.

As the design of this device has progressed, a series of prototypes have been constructed, each displaying design strengths and revealing weaknesses that were later improved upon.

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A. Phase I

The first version of the device held the motor in a metal tube with the drive shaft extending down to the insertion tip. Since the device is intended to be used multiple times during each implantation surgery, a method to reload and insert multiple arrays was necessary. Each array can be placed into a collet which is held in the tip of the insertion device by a set of clamping arms. After implantation, the arms are retracted, releasing the empty collet and readying the device for another implantation.

In practice, the clamping arm design was found not practical and several ways were found by which the manufacturing time and cost of the device could be reduced, prompting the design of a second prototype.

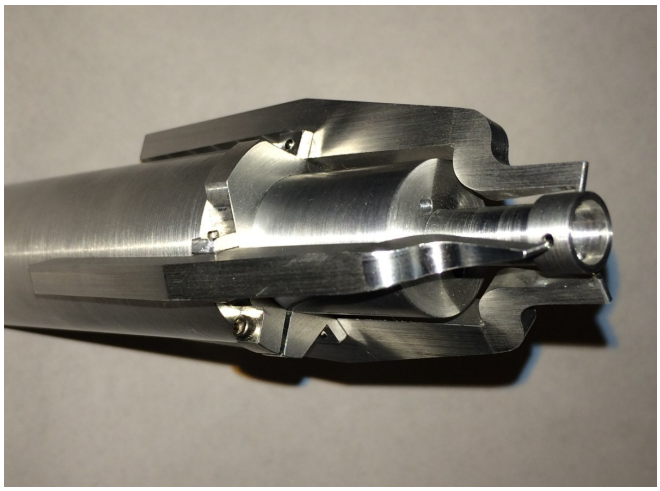

Fig. 2. Tip of Phase I version of device - three clamping arms to hold array collet in place.

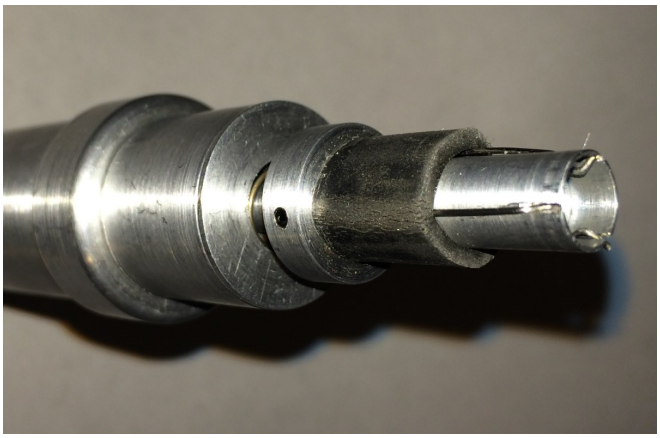

Fig. 3. Tip of Phase II device - array collet held in place by three spring clips.

Fig. 4. Tip of Phase II device showing array collet retention system. Clockwise from top left: electrode array held in a metal collet, tip before a collet is loaded, tip with a collet in place, and tip after ejection.

B. Phase II

While similar to the initial design, this version of the device includes an improved system to reload the device for each implantation. The array collets are held in place by springs which can be retracted by pulling upward on a handle near the tip of the device. Pulling this handle ejects an empty collet and allows for another to be loaded.

This version of the device also includes a chamber between the motor and the tip of the device that can be used to house sensors to aid in the accurate measurement of the velocity, position, and force output of the motor.

C. Phase III

After production of the Phase II prototype, it was determined that the drive motor in the device would need a longer travel than that provided but the commercially-available motor already in use. A third design of the device was then made that included a custom-made motor with similar specifications, but significantly larger displacement capability (25mm vs 5mm). This design allows the device tip to be suspended further abovethe target tissue, reducing the risk of tissue damage even further. In addition, it allows for greater flexibility in electrode length implanted by the device.

The Phase III device is currently under development. Future work on the device will include:

- Completion of longer-displacement motor.
- Comparison of parameters between custom-designed and comercially-available motors.
- Design and manufacture of integrated power supply and control circuitry.
- Testing of device efficacy in mock-surgery situations.

II. MATERIALS AND METHODS

The device body sections were machined from aluminum stock. Aluminum was chosen for its light weight and ease of machining. The final version of the tool may be machined from titanium to increase its durability for clinical use.

The motor used in Phase I and II was a voice coil motor from Geeplus Europe Ltd. (Model VM1614-100). The motor has a coil inductance of 4.0mH and a coil resistance of 43.0Ω.

The motor's movement is dependent on a DC voltage applied across its induction coil. The resulting current through

the coil generates a magnetic field which either attracts or opposes the permanent magnets inside the motor casing, depending on its polarity. During testing, a negative DC voltage was applied to the motor to hold it in a retracted position. When triggered, a positive voltage pulse was applied, causing the motor to drive forward. When this pulse ended, the total voltage across the coil returned to the original negative value, and the motor retracted.

Reverse DC voltage was supplied by a high-current DC power supply powered by a General Radio Company Variac Autotransformer W5MT3. The forward voltage pulses were supplied by a Hewlett-Packard 214B pulse generator. Signals were recorded on a Tektronix TDS3034b oscilloscope.

III. PROCEDURE

To quantify the specifications of the drive motor within the device assembly and identify the input parameters necessary to properly drive the device, the motor's velocity at the end of its stroke (when the implant would contact tissue) and its force output were determined over a range of inputs. Velocity was measured while varying the forward voltage, reverse voltage, and forward pulse width. The forward input voltage required to move weights with a range of masses was also determined.

A. Velocity measurement

A test setup was constructed to measure the motor's velocity at the end of its stroke. A thin conductive spring was held 1mm away from a stable copper surface, with this assembly placed in the tool's path so that the copper plate was at the motor's full-stroke position. As the motor was activated, its drive shaft would contact the spring, then bend the spring into contact with the copper plate. The copper plate was held at 5V, the spring at 2.5V, and the drive shaft was connected to ground through a resistor. By recording the voltage across the resistor, the travel time across the 1mm spacing could be measured, yielding the motor's travel velocity.

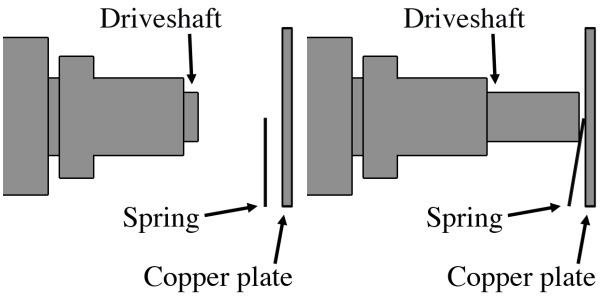

Fig. 5. Schematic of test setup for velocity measurements with motor in retracted (left) and extended (right) positions.

B. Force measurement

To measure the motor's maximum force output, the device was suspended vertically, with the normal forward direction of the motor facing upward. Weights were then hung from the moving element of the motor. First, a gradually-increasing DC voltage was applied to the motor in the forward direction. The applied voltage that caused the motor to overcome the weight was recorded.

Next, the applied voltage was gradually decreased until the motor could no longer support the weight. The voltage at this point was also recorded. Since there is greater overlap between the magnetic fields of the permanent magnets and the coil when the motor is in the forward position, it was expected that a lower voltage would be necessary to hold the weight in this position than to lift it from the retracted position.

IV. RESULTS

A. Velocity

The effects of forward pulse voltage, reverse voltage, and forward pulse width on the velocity of the motor were investigated. The velocity of the motor over the last 1mm of its travel was measured while those input parameters were changed.

Velocity increased with increasing forward pulse voltage and pulse width and decreased with increasing reverse voltage (figures 6, 7, and 8). This was expected, as the voltage across the coil is equal to the reverse voltage subtracted from the forward pulse voltage (1) and as pulse width increases, the coil has a positive voltage for a longer time period.

$$V_{coil} = V_{forward} - V_{reverse} \tag{1}$$

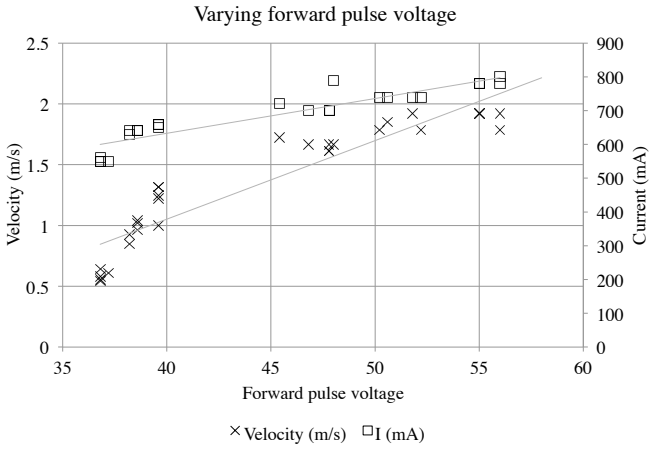

Fig. 6. Motor velocity and input current while varying forward pulse voltage. (Reverse voltage 15V, pulse width 7ms.)

B. Force

Following (2), the force produced by the motor's induction coil is proportional to the square of the current through the coil. It was expected that as the voltage across the coil increased, the maximum force generated by the motor would also rise. It was also expected that the voltage necessary to generate a given force would decrease as the motor went from its retracted to its extended position due to the increasing overlap of the magnetic fields created by its

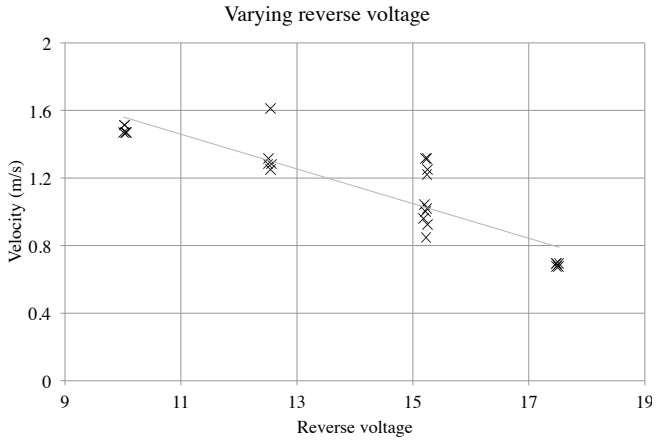

Fig. 7. Motor velocity while varying reverse voltage. (Forward voltage 39V, pulse width 7ms.)

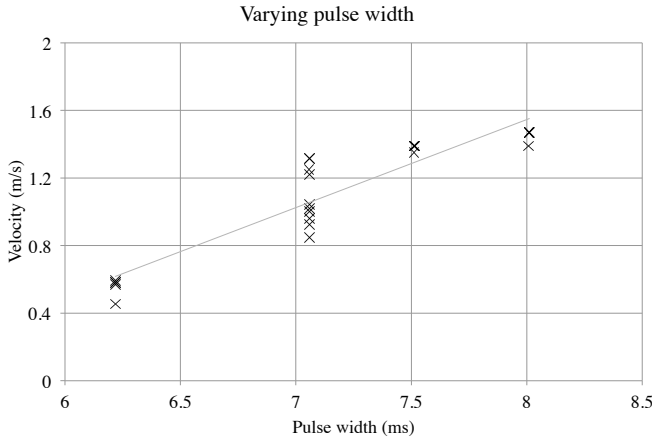

Fig. 8. Motor velocity while varying forward pulse width. (Forward voltage 39V, reverse voltage 15V.)

coil and permanent magnets. Figure 9 shows both of these phenomena occurring as expected.

$$F = \frac{(NI)^2 \mu_0 A}{2g^2} \tag{2}$$

V. CONCLUSIONS

The phase II device shows promise and has performed well in initial trials. As testing progresses, the input and drive characteristics will be more extensively characterized, which will allow the phase III device to be designed to more demanding specifications. Once the device has the longer

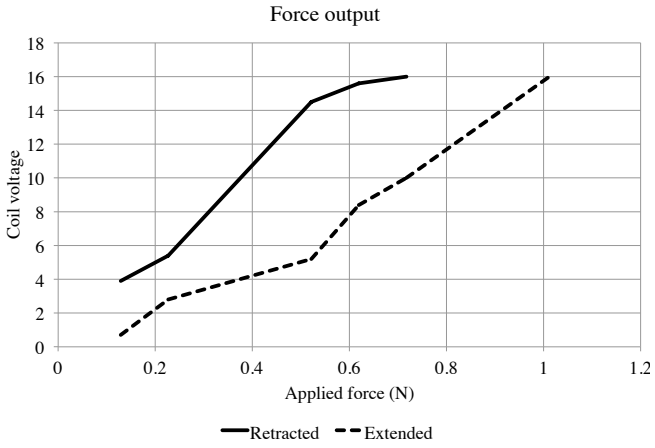

Fig. 9. Voltage required to lift an applied force with motor starting at retracted (solid) and extended (dashed) position.

linear travel that will be provided by the custom-designed voice coil motor in phase III, tests will be performed with arrays to test the practical performance of the insertion device.

Phase III will also add sensing functionality that will allow for an electrode array's position relative to the tissue surface to be known as it is inserted. By measuring the resistance force on the motor, the time at which the electrode tips contact the tissue surface, puncture it, and when the array substrate contacts the surface can each be determined. This information will then be used to control the motor's forward drive - when the array substrate has contacted the tissue surface, forward motion will be stopped and the motor will reverse to minimize its contact time with the neural tissue.

ACKNOWLEDGMENT

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