Composites Lab

Design Considerations for Shape Memory Alloy Actuator based Active Steerable Needle

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Sharad Raj Acharya, Parsaoran Hutapea, Ph.D.
Department of Mechanical Engineering, Temple University

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Project Objectives and Goals

The objective of this project is to present a design of active steerable surgical needle that can actively and controllably bend during tissue insertion to reach target location with accuracy. A design consideration on the nitinol actuator in the active needle will be explained, a prototype is fabricated and tested and a computational study will be discussed

Background

Active steerable surgical needles can achieve steerability and maneuver in minimal invasive medical procedures like biopsy and brachytherapy (Fig. 1) by bending during insertion. These medical procedures require the needles to insert and reach cancerous regions with high accuracy for radioactive seed implantation or drug delivery. Current method requires that a therapist perform multiple insertions and rotation of the passive needles for adjustment in order to reach a target which is not desirable Fig. 2 (top). Nitinol shape memory alloy wire actuators have been studied extensively as candidates for actuators in active needles because of their high strain per weight ratio and biocompatibility.

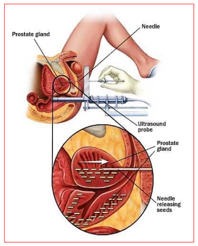


Fig. 1: Radioactive Seed Implantation in Prostrate Brachytherapy

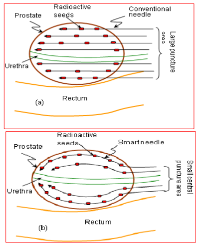


Fig. 2: Conventional Needle in Straight Path (Top) Smart Needle Bending to Take Curved Path (Bottom) [1]

A design of active needles for minimally invasive percutaneous needle based procedures like brachytherapy, biopsy and tissue ablation has been studied experimentally and computationally using Brinson model [2]. This project uses built in Lagoudas model in COMSOL Multiphysics [3] to study the simulation of nitinol actuator bending the needle using a 3D solid physics.

Methods & Procedures

- For fabricating a prototype, a nitinol actuator wire is pre-strained by loading and unloading (State B to D) as shown in Fig. 3 (b) and attached to a needle core end to end as shown in Fig. 4.
- The ends of the actuator wire is connected to DC power for resistive heating for actuation.
- Temperature in the actuator wire due to DC power supply is recorded.
- The nitinol wire when heated to a temperature above its Austenite Start Temperature undergoes shape memory effect, causing contraction (Fig. 3 (b) red curve) and resulting needle bending is measured in terms of needle tip deflection using an electromagnetic tracker.
- A 3D solid model is created in COMSOL Multiphysics resembling needle core and nitinol wire as shown in Fig. 5 for stationary analysis.
- The pre-straining procedure if performed which will be followed by raising temperature of the actuator above Austenite finish temperature.
- Nitinol SMA properties [4] were used for modelling.

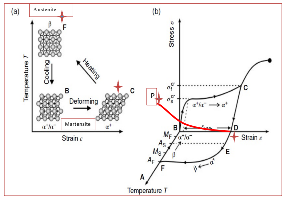
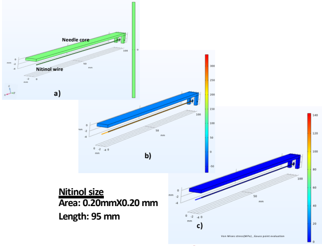


Fig. 3: Phase change (a) and Stress-Strain-Temperature Curve (b) for Nitinol-Shape Memory Alloys

Fig. 4: A Nitinol Actuator (Top), Nitinol Actuator Attached to The Needle Core (Bottom)



Nitinol size
Area: 0.20mmX0.20 mm
Length: 95 mm

Fig. 5: A 3D solid model of nitinol attached to needle core. a) before loading b) during full loading c) after loading. Needle core kept fixed during pre-straining

Data and Results

- For prototype testing, a DC power is supplied to nitinol actuator. Data collected in Fig. 6 shows the increase in temperature of nitinol actuator and thus the needle tip deflection. When power is cut off temperature of actuator as well as needle tip deflection decreases.
- A stationary structural modelling for pre-straining nitinol wire is performed which will be followed by raising temperature to recover the strain as a future work.
- The stress-strain plot for the nitinol pre-straining in COMSOL is presented in Fig.7 . The loading unloading was done by load ramping technique.
- Raising the temperature of nitinol will produce shape memory effect to recover the transformation strain shown in Fig 6 which will be future work.

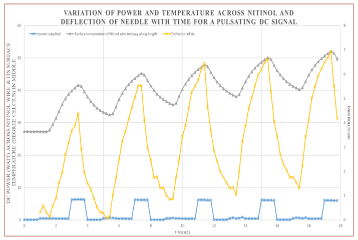


Fig. 6: Experimental results on nitinol wire actuated needle tip displacement with DC Power Supply and corresponding nitinol surface temperature

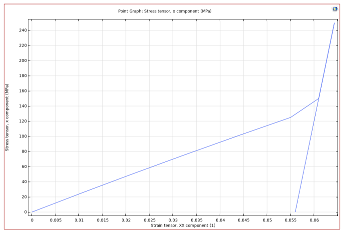


Fig. 7: Stress-Strain plot on a Nitinol wire model loading and unloading in COMSOL (Nitinol property: Maximum recoverable transformation strain=0.056)

Conclusions

This project presents nitinol wire as a feasible actuating component in designing active steerable needles. A thermomechanical constitutive relation for shape memory alloys built in COMSOL as 'Lagoudas' material model can be used to perform stationary as well as time dependent structural analysis.

Future Studies / Recommendations

A time dependent simulation of needle bending will be performed using Multiphysics coupling of Electrical, thermal and structural physics to obtaining a realistic response

Adding multiple actuator wires to study needle bending in multiple directions experimentally and using computational techniques is recommended for future study.

Acknowledgments

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