MODELING OF AN ACTIVE SURGICAL NEEDLE FOR PROSTATE BRACHYTHERAPY

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Abstract

- Needle insertion is a common surgical technique being used in many diagnostic and therapeutic percutaneous procedures
- Prostate brachytherapy: accurate implantation of radioactive seeds
- Assist the maneuverability of the needle to reach target locations
- Actuation forces provided to the needle body by the attached shape memory alloy
- Development of a 3D finite element model of the SMA actuated steerable needle
- Validation by prototype to show the feasibility of the proposed active surgical needle

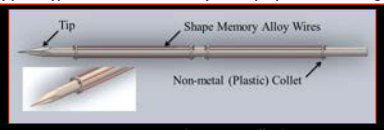


Fig. 1. Proposed smart needle design

Objective

- Characterization of Nitinol wires as actuators
- Develop a FE model of the active needle
- Showing the feasibility of the design
- Developing a prototype of the active needle for validation purposes
- Investigation of the influencing design parameters on the deflection of the needle

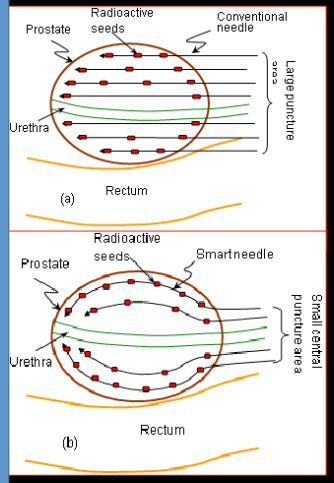


Fig. 3. (a) conventional rectilinear approach of prostate brachytherapy needle insertion pattern with straight needles, (b) proposed curvilinear conformal smart needle insertion

Fig. 1. Proposed smart needle design

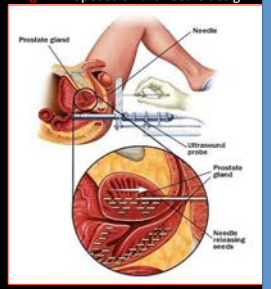


Fig. 2. Prostate brachytherapy approach

Critical aspect in modeling the active needle:
Incorporation the shape memory effect of the Nitinol actuator [1,2]
Brinson model [3] takes into account the twined/detwined martensitic transformation
Both the pseudoelastic effect and the shape memory effect

Method

Characterization of SMA wires:

Experiment:
- Strain response: constant stress experiment
  Figure 5 (Left)
  Dead weight, LVDT, Thermocouple
- Stress response: constant strain experiment
  Figure 5 (Right)
  Load Cell, Thermocouple

Model:
- Brinson model was used to find the response of the SMA wires under different loading conditions

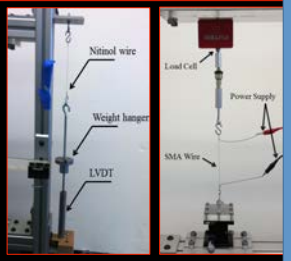


Fig.5. Constant stress (Left), Constant strain experiment (Right)

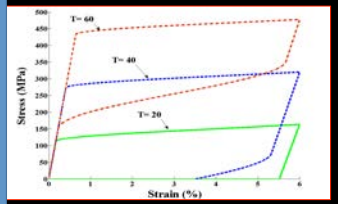


Fig. 6. Isothermal stress-strain curve for SMA

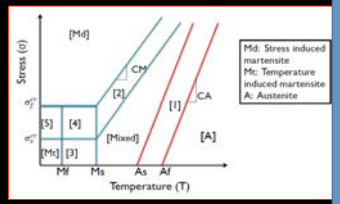


Fig. 7. Phase diagram for SMA

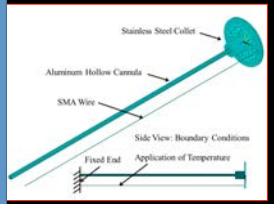


Fig.9. FE model of the smart needle

- 3D FE model of the active needle in ANSYS
- SOLID65 element for both actuator and needle
- Birth and death capability of ANSYS was used to have a prestrain condition on the Nitinol wire
- Increasing the wire temperature from room temperature to 80ºC
- Nitinol wire contracts and needle bends

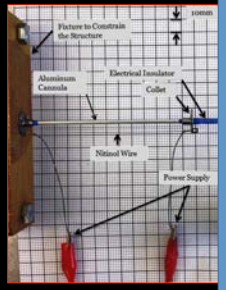


Fig.9. Smart needle prototype

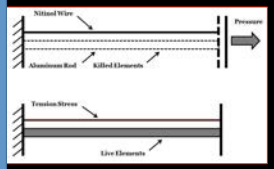


Fig.8. Birth and death method to set the pre-strain condition on SMA wire: application of pressure at one end at the first step (shown at top) and equilibrium position after removing the pressure at the second step of solution (shown at bottom)

- Aluminum hollow cannula: (*Din=0.88mm, Dout=1.59mm*)
- Actuated by FLEXINOL SMA wire
- Stainless steel holder (*D=18mm*)
- Vision based method for deflection measurement: high speed camera, ImageJ software
- Joule heating by applying current as a ramp function

Results

Figures 4-7 [4] show the behavior of the shape memory alloy under certain conditions such as constant stress/strain or isothermal, all produced considering Brinson's approach. Figures 8 and 9 show the smart needle which is designed for finite element preliminary study. Figure 10 shows the active needle deflected by actuating the Nitinol wire with the prototype and FE model, respectively. Preliminary results show negligible difference in needle deflection between the experiment and the FE model; 5 mm from experiment and 4 mm from the FE model. Therfore, validating the FE model in predicting needle deflection.

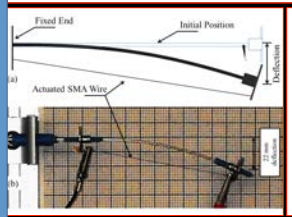


Fig.10. Deflection of the actuated smart needle prototype

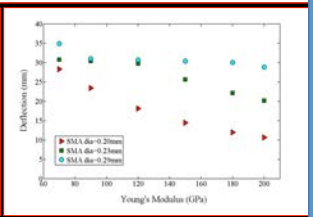


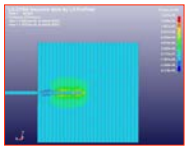
Fig.10. Deflection of the actuated smart needle prototype

Conclusions

A 3-D finite element model for an active needle has been developed based on the Brinson model. Both the FE model and the Brinson model have been validated with experiments. Future work will focus on using the FE model to study the effects of needle and actuator dimensions on the needle deflection

Parallel Studies

Needle tissue interaction FE analysis



Phantom material development

Needle insertion test

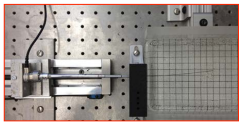


Fig. 6. Other related studies

Acknowledgment

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References

[1] Liang, C. and C. A. Rogers. 1990. "One-Dimensional Thermomechanical Constitutive Relations for Shape Memory Materials", Journal of Intelligent Material System and Structure, 1(2):207-234.
[2] Tanaka, K. 1986. "A Thermomechanical Sketch of Shape Memory Effect One-Dimensional Tensile Behavior", Res. Mech., 18:251-263.
[3] Brinson, L.C. 1990. "One-dimensional constitutive behavior of shape memory alloys: thermo mechanical derivation with non-constant material functions", Journal of Intelligent Materials and Structures, 1:207-234.
[4] Datla, N. V., Honarvar, M., Nguyen, T. M., Konh, B et al. 2012. "Towards a Nitinol Actuator for an Active Surgical Needle", ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems.