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## Comparison of Ogden Two-network and Ogden Three-network Model as a Replacement for Kelvin Model in the Posture Module

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This technical note discusses the changes made to the posture module in SPEAK project (NCVS Voice Simulator). The Kelvin model used in the previous posture module was replaced with Ogden two-network and Ogden three-network modules. Updates to this memo can be downloaded at <u>http://www.ncvs.org/research\_techbriefs.html</u>.

Keywords: Kelvin model, Ogden two-network model, Ogden three-network model, Posturing model, Laryngeal model, vocal folds.

## **1** Introduction

The passive axial properties of laryngeal tissues are key components to global shaping and displacement of the larynx (Hunter, Titze, & Alipour, 2004), as well as to pitch control (Titze, 1994). To better understand how these properties relate to shaping, displacement and pitch control, large-scale biomechanical models have been created (Hunter et al., 2004; Titze & Hunter, 2007) which rely on tissue models of the axial properties. The axial properties of laryngeal tissue are both highly nonlinear (Hunter, Alipour, & Titze, 2007; Hunter et al., 2007; Hunter & Titze, 2007) as well as viscous (rate dependent and hysteretic to cyclic loading) (Chan, Fu, Young, & Tirunagari, 2007). The nature of the material has two primary time constants of creep, with a shorter term creep captured both as a short effect (Alipour-Haghighi & Titze, 1985; Chan et al., 2007; Hunter & Titze, 2007; Hunter & Titze, 1999; Alipour-Haghighi & Titze, 1985; Chan, Siegmund, & Zhang, 2009).

This report focuses primarily on the implementation of an Ogden-type model with two networks (Chan et al., 2007, 2009; Zhang et al., 2009) (shorter term creep) and three networks (long-term creep) (Chan et al., 2009) into a larger posturing model (Hunter et al., 2004) found in the NCVS Speak Simulator. The posture module, used in the NCVS Speak Simulator, is used to compute the stresses and strains due to posturing of different larynx muscles and ligaments dynamically over time. Kelvin visco-elastic model was used in the computation of these stresses and strains. In order to obtain better output results, the Kelvin model was replaced with hyper-elastic models Ogden two-network and Ogden three-network. Future directions would allow for the addition of active contraction (Alipour, Titze, Hunter, & Tayama, 2005) to the simulator.



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## 2 Ogden two-network model

A number of changes were made to the original Titze modified Kelvin<sup>1</sup> model (hereafter referred to as Kelvin) to make the posture module implement Ogden two-network model<sup>2</sup>. Some of the major changes are detailed below:

### 2.1 Creation of Subroutines:

The whole posture module was divided into several subroutines to make the posture module more readable.

- The tissue strains, in the form of stretch ( $\lambda_A$ ), were computed in a single subroutine.
- All 5 muscle stresses were computed in one subroutine and ligament stresses were computed in another.
- The differential forces for translation and rotation of CA joint were computed in one subroutine and the differential forces for translation and rotation of CT joint were computed in another.

### 2.2 Input Parameters:

The Ogden two-network input parameters, which differ from the Kelvin input parameters, were introduced into the posture module. The input values for these parameters were obtained from optimization models.

#### 2.3 Other Changes:

Logic was introduced to have the initial values of Ogden model start at zero, like the Kelvin model. One of the important changes made in order to make the results from Ogden model similar to Kelvin model was changing the constant value, which was added to stretch ( $\lambda_A$ ). It was observed from the number of trails that the calculation of strain dynamically was dependent on so many variables that it created interdependency between those variables. The original constant value added to stretch ( $\lambda_A$ ), 0.0001, was varied to observe which value resulted in both models yielding similar outputs.

### 2.4 Comparison of results:

The results obtained from the changes made to the posture module are compared to the results obtained from Kelvin model. All the outputs compared were obtained by running the program with dynamic strain calculation. The comparison graphs for different constant values are shown below:



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**Figure 1**: Comparison of Kelvin and Ogden models output with constant 0.0001 and no active force.



**Figure 3**: Comparison of Kelvin and Ogden models output with constant 0.00003 and no active force.



**Figure 2**: Comparison of Kelvin and Ogden models output with constant 0.0000377 and no active force.



**Figure 4**: Comparison of Kelvin and Ogden models output with constant 0.0001 and active force.

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**Figure 6**: Comparison of Kelvin and Ogden models output with constant 0.00003 and active force.

It can be seen from all the comparisons that, for both active and no active force, Ogden model stress value decreased with decrease in the constant value. At constant value of 0.0001 the comparison of Kelvin and Ogden models shows that the results obtained for no active force are further apart than the results from active force. But, at the other two constant values the results were further apart with active force rather than no active force.

Also, with active force, a lot of fluctuations were observed in the Ogden model between  $2 \times 10^4$  and  $2.5 \times 10^4$ . Although the exact reason for these fluctuations was not determined yet, one of the reasons could be the direct addition of the active force to the muscle stresses. The future work would be to integrate the active stress into the muscle stress equation.

# **3** Ogden three-Network Model

The Ogden three-network model <sup>3</sup> is similar to the Ogden two-network model, but with an addition of a third network in parallel with the other two. The third network serves as a long-term visco-plastic network. All the input parameter values were obtained from optimization model. The third network component was added to the stress computation.

The output obtained from this model is shown below:



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**Figure 7**: Comparison of Ogden three-network model output for different constants and with no active force.

**Figure 8**: Comparison of Ogden three-network model output for different constants and with active force.

It can be observed that the Ogden three-network model has approximately the same output, even with different constant values, for both active and without active force, unlike the Ogden twonetwork model. Also, the fluctuations seen in the Ogden two-network model are more prevalent in Ogden three-network model.

The stress values are higher than that obtained for Ogden two-network or Kelvin as the input parameters obtained are different for Ogden three-network.

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# Revisions

- 1.0 Sree Harsha Jampala: Main document (April. 2012)
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