Advanced Hill-type Muscle model as User Defined Material in LS-DYNA with Routing Capability for Application in Active Human Body Models.

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I. INTRODUCTION

Automated driving vehicles is an emerging topic for automotive industry and a significant challenge for virtual crash simulations within computer-aided engineering (CAE) software. Since an autonomous car will allow occupants to perform other activities, they will not necessarily be in the relatively permanent position anymore, as they are today. The same issue exist for other vulnerable road users, e.g., pedestrians, because they tend to move their extremities or head during a crash. To simulate such scenarios, finite element (FE) active human body models (AHBMs) capable of reflex, reactive and proactive behavior modelling should be utilized.

All in LS-DYNA® available AHBMs use a macroscopic Hill-type material model named *MAT_MUSCLE (*MAT_156), which consists of three simple mechanical elements in parallel: contractile element (CE), parallel elastic element (PEE) and a parallel damping element (PDE) (Fig. 1). Hill-type muscle models gained their popularity because of: a direct relation between muscle force and contraction velocity formulation, the absence of mass and inertia, ease of parameters finding and implementation into almost any simulation model. Nevertheless, the exact combination of the internal elements plays a great role for model application scenarios [1]. *MAT_156 implementation is based on a review in [2]. However, in following publications [3-5] it was shown, that such a three element formulation is not fully adequate to model real muscle's physiological behavior. Taking into account the explicit integration scheme used in LS-DYNA, it is not computationally efficient and robust enough. Furthermore, *MAT_156 is hardly applicable for physiological muscle path modelling (muscle routing) [6], which is crucial for correct muscle lever arms and thus resulting moments and forces generated in a model [7,8]. Therefore, the aim of this study is to implement a new user defined Hill-type muscle model as a user defined material in LS-DYNA. The proposed material is more physiological, computationally stable, robust and easier in routing comparing to the existing one *MAT_156 [6].

II. METHODS

A four element extended Hill-type muscle model (Fig. 2), composed of an active contractile element (CE), controlled by the activation level q, parallel (PEE) and serial (SEE) nonlinear spring elements and a serial damping element (SDE), proposed in [9] was chosen for the implementation. This model has an additional internal degree of freedom, representing a clear separation between muscle and tendon tissues, needs less parameter definition for the modelling process and is known from multibody simulations for robustness and speedup [10]. The realized user material has special material cards for first, the muscle activation dynamics in Zajac [11] and in Hatze [12] formulations, which transform nervous system stimulation input directly to muscle activity level. Second, for a muscle length offset, enabling easy application of the via-point muscle routing in AHBMs. The via-point method, particularly described in [11], could be easily applied by substituting the whole muscle tendon complex (MTC) length, usually modelled as a beam element with muscle material, by three different separate elements. The beam element with a user material, proposed in this contribution, in the middle, complemented by standard seatbelt elements, representing the tendons, on the both sides. Seatbelt elements than could be easily routed through required number of the predefined slipring nodes.

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III. INITIAL FINDINGS

The implemented Hill-type model was validated successfully with three sets of mammalian experimental data for piglet [5] (Fig. 3), cat [14] (Fig. 4) and rat [15] (Fig. 5) muscles, showing good agreement. A comparison with the *MAT_156 model parameterized in [16] indicates the improved accuracy in velocity decay and in the correct representation of the muscle damping properties, while the proposed model gives more realistic results.

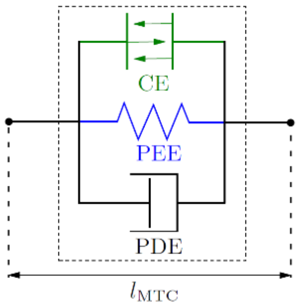

Fig. 1. Element structure of the *MAT 156 model.

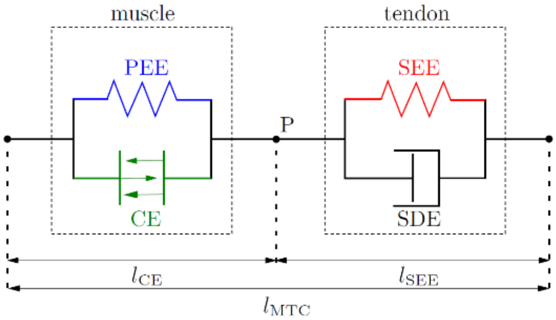

Fig. 2. Element structure of the implemented extended muscle model.

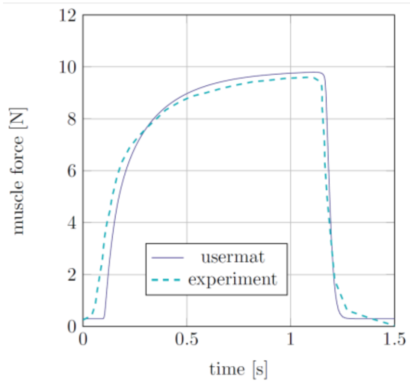

Fig 4. Cat Soleus Muscle.

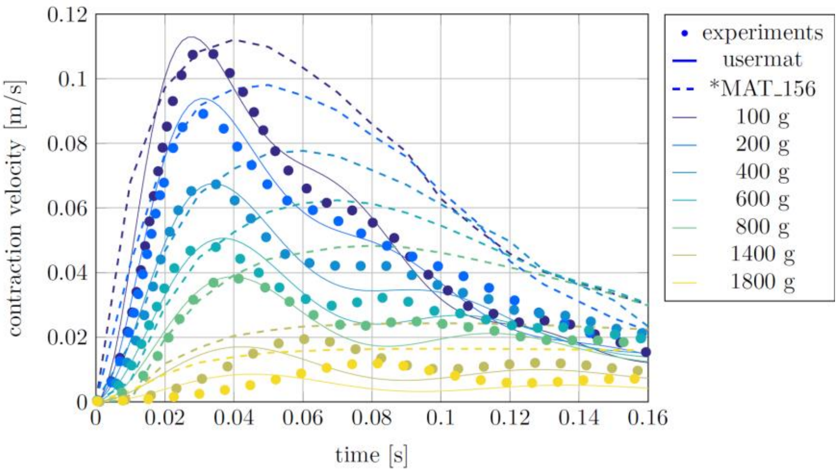

Fig. 3. Piglet Calf Muscle concentric contraction.

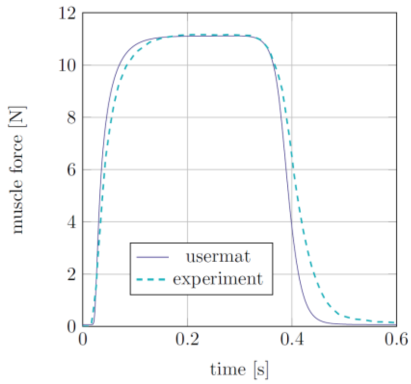

Fig. 5. Rat GM Muscle.

IV. DISCUSSION

The advanced Hill-type muscle model was successfully implemented as a user defined subroutine in LS-DYNA and validated with three different experimental data sets for in vitro mammalian muscle material. The next step would be a material application in HBMs, e.g. THUMS, taking into account physiological muscle routing. The resulting model could be used for crash simulations, mentioned above, with the addition of necessary controllers for the muscle element activation. The FORTRAN source code and all material cards will be available for download and use under an Open Source license after publishing of the whole research results online. In our opinion, the contributed model will contribute gratefully to muscle modelling in LS-DYNA in general and to AHBMs development in particular.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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