Isometric Contraction of Parallel Skeletal Muscle Fiber

Aim:

To investigates muscle behavior under isometric conditions.

1. Introduction:

Muscle (from Latin musculus "little mouse") is the contractile tissue of the body. It is derived from the mesoderm layer of embryonic germ cells. It is classified as skeletal, cardiac, or smooth muscle. The most basic property of a muscle is its ability to contract and produce power. Muscles exert force and produce movement so can be considered as the basic element of movement mechanics in humans and animals. Much of muscle contraction occurs without conscious thought and is necessary for survival, like the contraction of the heart. Voluntary muscle contraction is used to move the body and can be finely controlled, like movements of the eye. There are two broad types of voluntary muscle fibers, slow twitch and fast twitch. Slow twitch fibers contract for long periods of time but with little force while fast twitch fibers contract quickly and powerfully but fatigue very rapidly.

2. Contraction of Skeletal Muscles

A muscle contraction (also known as a muscle twitch or simply twitch), a complex interaction of several cellular and chemical constituents, occurs when a muscle fiber shortens. The contracting part of a muscle is called contractile element. Contraction is controlled by the central nervous system comprised of brain and spinal cord. The brain controls voluntary muscle contractions, while the spine controls involuntary reflexes.

An isometric contraction of a muscle generates force without changing length. An example can be found in the muscles of the hand. When the forearm holds an object; the joints of the hand do not move but muscles generate sufficient force to prevent the object from being dropped.

3. Muscular Responses

One way to observe muscle contraction is connect the muscle to a device (EMG) that senses and records changes in the fiber's length. An electrical stimulator is usually used to promote muscle contraction.

4. Summation

The force that a muscle fiber can generate is not limited to the maximum force of a single twitch. A muscle fiber exposed to a series of stimuli of increasing frequency reaches a point when it is unable to completely relax before the next stimulus in the series arrives. When this happens, the individual twitches begin to combine, and the muscle contraction becomes sustained. In such a sustained contraction, the force of individual twitches combines by the process of summation. When the resulting forceful, sustained contraction lacks even partial relaxation, it is called a tetanic contraction (tetanus).

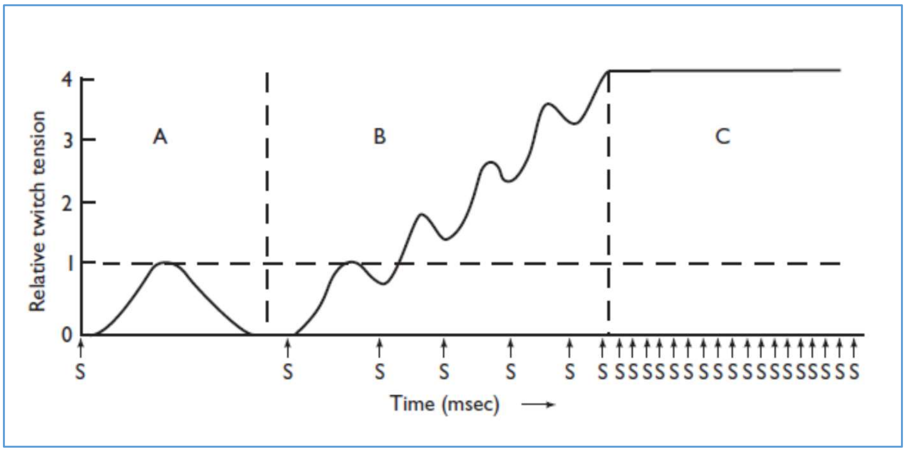

Figure 1. Tension developed in a muscle fiber (**A**) in response to a single stimulus, (**B**) in response to repetitive stimulation, and (**C**) in response to high-frequency stimulation (tetanus).

5. Hill Muscle Model

One of the most widely used mechanical models of muscle that takes into account both the active and passive components of muscle tension is the three-component model developed by A. V. Hill in 1938.

This **model** has two elements in series and one element in parallel (Figure 2). The contractile component (CC) represents the active tension of skeletal muscle, while the parallel elastic component (PEC) and series elastic component (SEC) represent two key sources of passive tension in muscle. The Hill muscle model has been the dominant theoretical model for understanding muscle mechanics and is usually used in biomechanical computer models employed to simulate human movement.

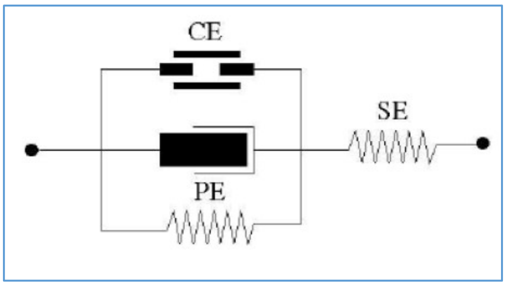

Figure 2. Hill muscle model

6. Procedure:

1. Build the Hill type muscle model shown in Figure 3 using MATLAB Simulink / SimMechanics, using the following parameters:

Ground 1 block Location: [0 0 0] mm Body spring & damper block: Kpe = 196 N/m [33] b = 49 N.s/m [33] Spring natural length = 0,040 m Ground 2 block Location:

[50 0 0] mm Body1 block: Mass = 10 g Inertia = [0,00002 0 0;0 0,00001 0;0 0 0,00001] g.cm^2 CS1 = [5 0 0] mm Body2 block: Mass = 10 g Inertia = [0,00002 0 0;0 0,00001 0;0 0 0,00001] g.cm^2 CS1 = [45 0 0] mm Joint spring & damper blocks: Kse = 1500 N/m

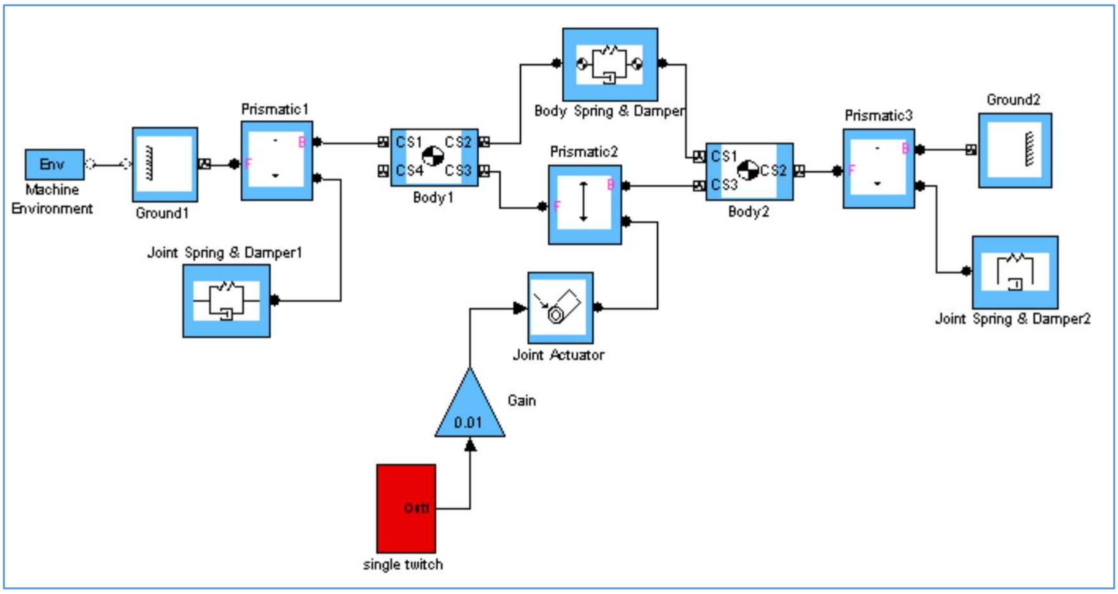

Figure. 3: Muscle model

Physiologically, the force production occurs as an external force or an electrical twitch acts on the muscle. The active force function implemented in the model is as follows:

$$h(t) = 48144\exp(-t / 0.0326) - 45845\exp(-t / 0.034)$$

where t is the time in seconds, h(t) is the time dependent active force function in grams. This function can be seen in Figure 4.

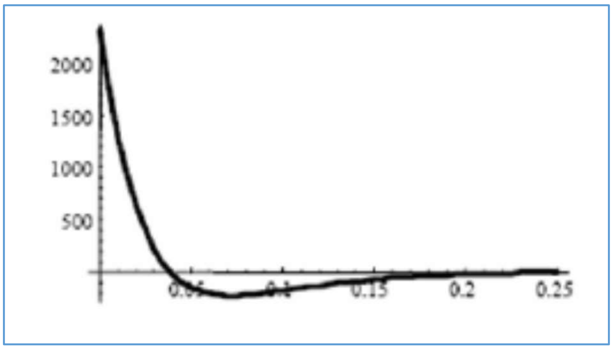

Figure. 4: Single twitch output. Y axis-Force in grams (g), X axis-Time in seconds(s).

2. For observing the isometric contraction, the model's both ends need to be fixed which has been done already in step 2.
3. Define the single twitch force production in a series of impulses using the trigger model shown in Figure.6.

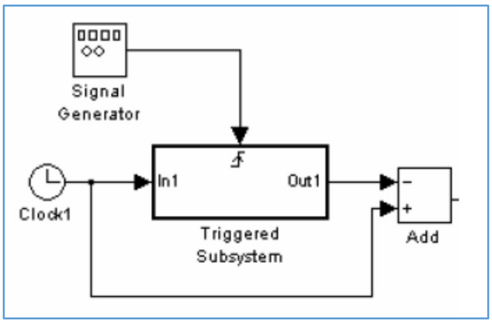

Figure.5: Triggered subsystem

4. Apply the following triggering frequencies: 20,40,60,80,100 Hz.
5. Record the build up force(N), and the CE length(mm) for all frequencies.

7. Discussion:

1. Discuss the saturation point "when contractile element does not change length at the ending point for each frequency".
2. Why the SE stiffness is about 10 times more than that for PE?

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