

Force Clamp and Electrical Stimulation on Decapod Appendages

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Abstract– The musculature of the decapods allows for a wide variety of motion given the limited degrees of freedom granted. This study focuses on a single degree of motion of a single leg segment of the crab (*Menippe mercenaria*) in response to electrical stimulation. A microprocessor was programmed to trigger an electrical stimulator and to provide force and length controls of the induced contraction. Digital feedback control algorithms were implemented on the microprocessor in conjunction with the Aurora Dual Mode Lever System to provide force clamp, length clamp, as well as other loading conditions. The resulting experiment setting provides a useful platform for studying the mechanics of muscle contractions.

I. INTRODUCTION

The locomotion of the common Florida Stone Crab (*Menippe mercenaria*) is governed by a combination of fast excitor neurons, slow excitor neurons, and inhibitor neurons, which are coupled only to the slow excitors [1]. Both electrical and mechanical stimulation of these neurons causes a response from the subject appendage up to an hour after separation from the animal's body [2]. Although the contractile response is greatly diminished within several minutes, it provides a sufficient time window to study the force-length relations of the muscular contraction.

Previously we developed an experimental setting for a force-clamp study using isolated clam hearts [3]. While the clam heart can maintain spontaneous contractions for several hours *in vitro*, its weak contraction force makes the instrumentation and feedback controls more difficult to implement. Thus, the purpose of this study is to develop an experimental setting with the crab leg that provides a stronger contraction force. Because the crab leg does not contract spontaneously, external electrical stimulation needs to be applied. The instrumentation is facilitated by use of a microprocessor to control the precise timing of the contractions.

II. MATERIALS AND METHODS

Figure 1 shows the block diagram of the instrumentation system. Control algorithms were developed in the C++ language on a microprocessor (PIC18F452, Microchip Technology, Chandler, AZ). After harvesting a walking leg of the crab, two small holes were drilled into the proximal and distal ends of the proximal segment. As shown in Fig. 2, the crab leg was clamped in a vertical position using two laboratory clamps in such a way as to restrain all but the most distal segment, allowing only for uni-axial motion. Copper wires from an electrical stimulator were inserted into the

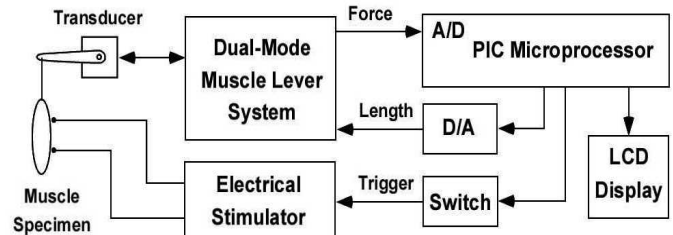


Fig. 1. Block diagram of the force clamp and electrical stimulation system for studying muscle mechanics.

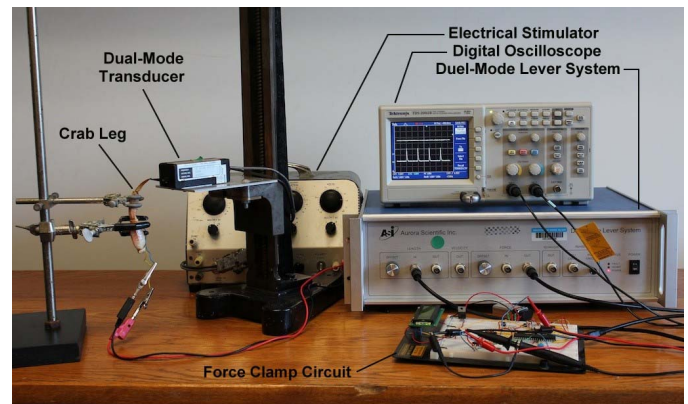


Fig. 2. Experimental setting for force-clamping the crab leg with a microprocessor controlled dual-mode muscle lever system.

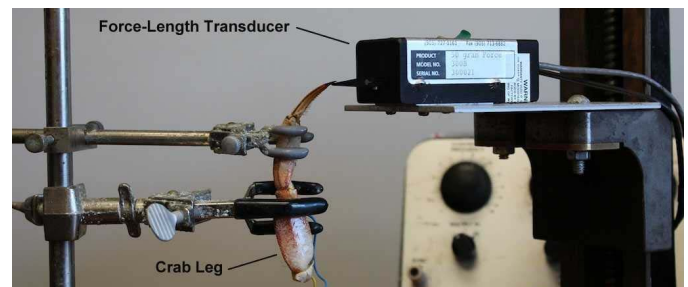


Fig. 3. The distal segment of a walking leg of the crab (*Menippe mercenaria*) positioned on the lever of the force-length transducer.

holes and the free moving segment was positioned on top of the lever arm of the Dual-Mode Lever System (300B, Aurora Scientific, Aurora, Ontario, Canada), as shown in Fig. 3. Pulses of varying magnitude were then sent into the appendage in order to induce a contractile response. The first test involved using a length clamp setup, which causes the lever arm to remain stationary while measuring the force (isometric contraction). The second test consisted of using the

force clamp setup, which causes the lever arm to move along with the force provided by the subject while measuring the displacement. A digital oscilloscope (TDS2002B, Tektronix, Beaverton, Oregon) with a USB drive interface was used to monitor and acquire the waveforms.

For force calibration a 5 gram mass was suspended from the lever arm. The resulting voltage was measured using an oscilloscope, resulting in an output of 1 volt or a scaling factor of 0.049 Newtons/V. For length calibration a ruler was placed alongside the tip of the lever arm, which was then lowered 1 mm, producing a response of 1 volt or a scaling factor 1 mm/V.

III. RESULTS

Lower magnitude pulses from the stimulator caused a weaker force response, which increases with the magnitude of the stimulation. The stimulation voltage did not seem to have any significant impact on the distance moved by the subject, which stayed at around 2 mm. The polarity of the stimulation often affects the contraction force. We observed that appendages from different sides of the crab usually require opposite polarity for optimal performance. The contraction force also depended on the locations where the wires were inserted.

Figure 4 shows the results for a length clamp (top) and two cases of force clamp (middle and bottom). In force clamp case 1, a constant force was only partially achieved. While the control algorithm was able to cancel out the main component of the contraction force by adjusting the length, a certain degree of oscillation was observed on the force waveform during the contraction. In force clamp case 2, the performance was significantly improved on a different crab leg with a slower contraction and a higher feedback throughput (32 KHz).

IV. DISCUSSION

This study has demonstrated an experimental setting that utilizes electrical stimulation and force clamp to study muscle contractions of the crab leg (*Menippe mercenaria*). Compared to our previous study using the clam heart [3], the setup using the crab leg has the advantages of much stronger contraction forces and the ease of preparation. The isolated crab leg maintains its contractility for about an hour in the air.

However, the strong and fast contraction makes the feedback control more challenging in the force clamp experiments. While the same digital control worked well in the clam heart experiment with a 1 KHz feedback throughput [3], it was unable to clamp the force to a completely constant value for the crab leg. By pushing the feedback throughput to 32 KHz, the limit of the PC processor running at the 4 MHz clock, an acceptable force clamp performance was achieved. For future work, improved digital control algorithms and the upgrade to a fast microprocessor will be investigated.

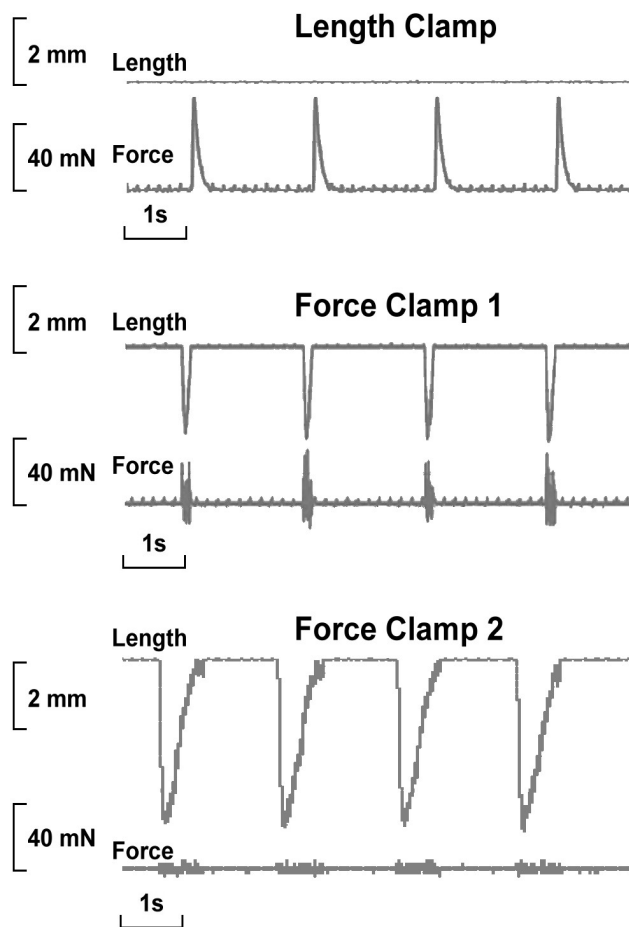


Fig. 4. Results of length clamp (top), force clamp case 1 (middle) and force clamp case 2 (bottom). Notice that in force clamp case 1, the force waveform showed oscillations during the contractions, which was improved in case 2.

ACKNOWLEDGEMENT

This study was supported in part by a grant from the National Institutes of Health (2R44NS048682-02A1, PI: Sun).

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