BIODYNAMIC MODELING AND PHYSICAL CAPACITY ASSESSMENT OF HUMAN ARM RESPONSE IN EXPERIENCED TORQUE TOOL OPERATORS

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INTRODUCTION

The objective of this study was to develop and validate a new methodology for characterizing the human arm's response to impulsive pulling forces based on a single degree-of-freedom, second-order, linear model. Such forces are encountered while operating right-angle torque tools, and are thought to pose a risk of injury [1,2]. Previously published research involved human testing in which subjects, instructed to stabilize an underdamped mechanical system released from a non-equilibrium initial position, were subjected to an oscillating torque input [3]. This task differs from using a torque tool where the input is an impulsive torque with typical durations of 35 - 1000 *ms*, depending on stiffness of the fastened joint. Because human arm viscoelasticity is task-dependent [4], the new parameter assessment method was designed to more closely mimic right-angle torque tool operation. Testing was conducted with experienced torque tool operators. Effects of gender and working posture were examined.

METHODS

In order to validate the model and assess effective stiffness (k), mass (m) and damping (c) parameters, a novel apparatus (Fig. 1) and protocol were developed to test human subjects.

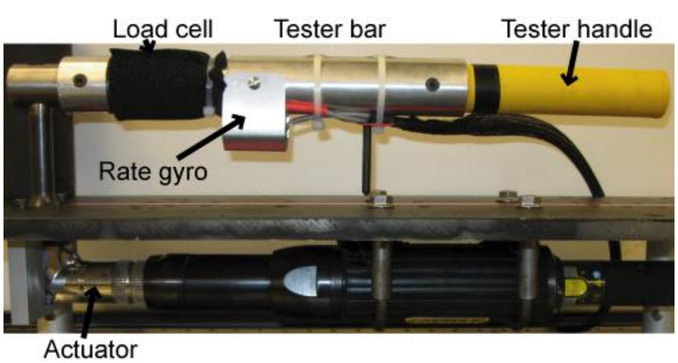

Figure 1: Physical appearance of the test apparatus.

A tester bar with textured handle on one end was connected to a fixed rotational actuator at the other end. The tester bar was instrumented with strain gages and a rate gyro in order to measure handle force and angular velocity, respectively.

Subjects were instructed to hold the handle stationary and prevent its horizontal rotation to the best of their ability, while a software-controlled sinusoidal torque pulse of 24 *Nm* amplitude and 233 *msec* duration was generated at the actuator and applied to the tester bar. Input torque, handle force and handle displacement data were sampled simultaneously. The angular displacement and acceleration of the handle were calculated using numerical integration and differentiation of the velocity signal, respectively.

Human arm response was modeled as a linear, single degree-of-freedom, second-order system with effective k, m, and c elements to be identified (Fig. 2).

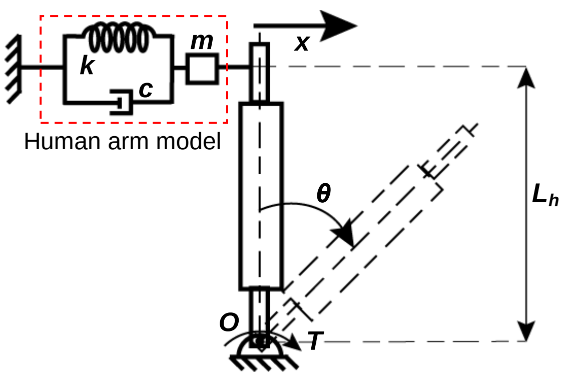

Figure 2: Description of the system model.

Equations (1) through (4) describe the system dynamics of the model:

$$T = K\theta + C\dot{\theta} + M\ddot{\theta} \qquad (1)$$

$$K = kL_h^{\,2}\ (2), \quad C = cL_h^{\,2}\ (3), \quad M = mL_h^{\,2} + I_O\ (4)$$

The system identification problem was set up with the torque applied by the actuator (T) as input and handle angular displacement (θ) as output. K, C, and M denote the stiffness, damping, and mass values of the combined system of human and the tester bar. These parameters are related to the human arm k, c, and m through the measured tester bar handle length (L_h) and mass-moment of inertia with respect to the fixed pivot point O (I_O). The least-squares method in the time domain was used to identify system parameters based an input-output relationship-type approach [5].

The identified model parameters were validated in two ways. (a) The identified model was simulated with the same torque input in order to reproduce handle displacement. The reproduced handle displacement was then compared to the experimentally measured handle displacement data. (b) The handle reaction force (F_r) profile was calculated using equation (5) and compared to the strain gage measurement.

$$F_r = L_h\left(k\theta + c\dot{\theta} + m\ddot{\theta}\right) \quad (5)$$

As a first test of the newly developed parameter assessment methodology, physical capacity assessment experiments were performed with experienced tool operators. Subjects were asked to apply maximum effort in order to minimize horizontal rotation of the tester bar while standing in five different working postures.

RESULTS AND DISCUSSION

The reproduced displacement and calculated force profiles compared well with the experimental data. The linear model was appropriate for 93% of the 897 test trials; average difference in displacement peak time was 2.8 ms (sd=2.6; max. difference limit set to +/-12 ms = 10% of displacement duration). Average relative peak force error was 6.1% (sd=4.6%); an additional 5 trials were excluded because the force error was 20-25%. Fig. 3 provides sample results comparing measured handle force and displacement profiles to those calculated based on the identified model. In this example, the difference between measured and reproduced peak handle displacement times was 2 *msec*. The measured and calculated peak handle forces were 63.09 *N* and 66.77 *N*, respectively.

As expected, (k, m, c) parameters were affected by gender and posture. Peak handle displacement was found to vary with respect to k, m, and c, whereas peak handle force was not.

Additionally, the newly developed parameter identification methodology is directly applicable to characterize arm response while using an actual DC-torque tool, if instrumented with a rate gyro.

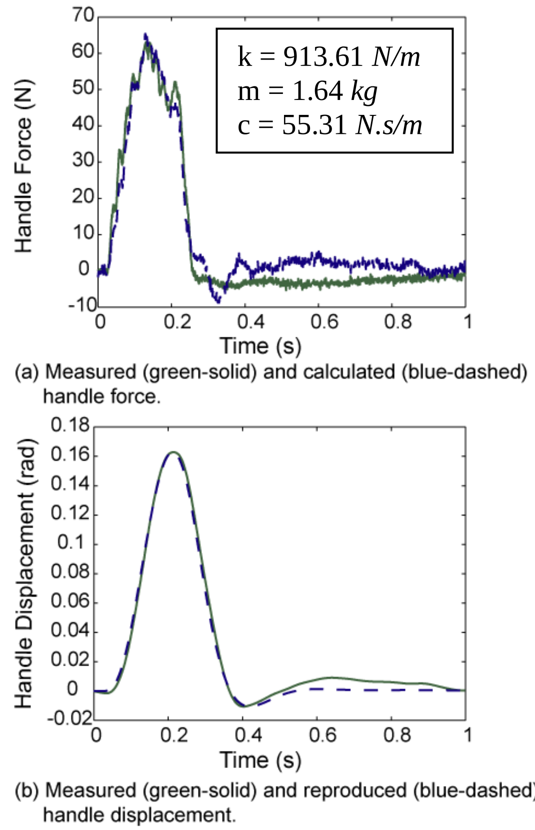

Figure 3: Sample results showing model validation.

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