Product Design Specifications: Asymmetrical Force Sensor for Rowing Biomechanics

BME 400, Section 304

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Function:

Force sensors have been widely used in sports biomechanics to measure load distribution and center of pressure for the purpose of correcting form and mitigating injuries. However, getting real-time data during rowing is often difficult to obtain in non-clinical settings and may be very expensive to implement, especially due to environmental and equipment-related constraints. Rowing is a rigorous sport that can lead to injuries in the lumbar spine, the shoulders, the knees, and the hips when the right and left lower extremities generate asymmetrical forces [1]. Additionally, this asymmetry is difficult to quantify visually, and current methods include using stationary rowing simulation machines that disparately underestimate the mechanical power required against water currents [2]. Specifically, these current methods of evaluating rowing form focus mainly on upper body metrics such as stroke power and involve studies outside of the rowing environment. Our design aims to provide accurate real-time data of rowers' lower extremities by integrating a force sensor system on an ergometer base to transduce force measurements that can be viewed while rowing against current in a tank or on the stationary ergometer. The application of our design will allow athletes and coaches to assess and adapt athlete performance, identify risk factors for injury, and assess return to injury metrics.

Client Requirements:

- The device must be strong enough to withstand the force exerted by rowers during the drive phase of the stroke, which peaks at 900 N [3].
- The device must accurately measure the load transmitted through each leg and translate the data to an interface that provides real-time data viewing while rowing.
    - The device must display real-time data on the amount of force transmitted by the toe and heel (separately) of each foot onto the tank footplate.
    - The device must store relevant performance metrics from a trial, such as peak force per stroke and time to peak force.
- The frequency and duration of force data storage during rowing sessions must be adjustable.
- The client desires an easily integrated force measuring system that should operate without requiring change in rowing technique or excessive modification of current rowing equipment.
- The device must alert the rower when force exerted by the right and left foot are asymmetrical.

Design Requirements:

1. Physical and Operational Characteristics:

a. Performance Requirements:

- The product must track the degree to which rowers are exerting symmetric force through their entire lower extremity, to track any asymmetry present.
    - The device should quantify the degree of asymmetry using the magnitude of relative force between limbs in Newtons.
- The product should display real-time data during a rower's trial so they can monitor any fluctuations as they occur.
    - The real-time display must be easily interpretable by the user(s) using simple visual cues like colors, lights, figures, and text.
- The product should be able to store data so coaches and rowers can see the data in real time and analyze it later.

b. Safety:

- This product should not disrupt the motion of the rower or the ergometer as a stroke is completed.
- This product should not cause any electrical shocks to the rower's and have minimal large cords in close proximity to the rower. The device needs to be plugged into an outlet with standard voltage of 120 V [4].
- This product should be able to be cleaned between uses with alcohol-based solution or soap and water. Bleach and/or hydrogen peroxide should be avoided [5].
- This product should not have any sharp edges.

c. Accuracy and Reliability:

- The device should be made with easily available parts such that they are replaceable in the event of malfunction or failure.
- The product should display and store data with high accuracy with a margin of error at 5% [6].
- The product must have no more than a 0.5 second delay between a rower's stroke and the real-time display so as to provide feedback at least once per stroke [7].

d. Life in Service:

- The NCAA in-season hourly practice limitation is no more than 20 hours per week and roughly 8 months out of the year or about 34 weeks [8].
- The product should remain functionable for the duration of a full collegiate rowing career. The typical career of a collegiate rower is 4 years. This equates to roughly 6,800 - 8,160 hours.
- The Concept2 RowERG® requires all screws and connections to be thoroughly checked every 250 hours of use [7]. The product's connections and integrity should be checked concurrently.

e. Shelf Life:

- The average lifespan of a load cell is around 10 years with proper usage, maintenance, and protection [9].
- The appropriate range of ambient temperature for load cell storage is from -10°C - 40°C [10].

f. Operating Environment:

- The client would like this device to be compatible with the ergometer next to the tank, as well as ergometers in the training room, which exist in room temperature conditions. These conditions are around 20-22° C and low humidity.
- An outlet or extension cord should be provided in the room to power the device.

g. Ergonomics:

- Display
    - The display will be at eye level from the rower as they are rowing, roughly 1.1 m from the ground [11].
    - The feedback will be easy to interpret quickly, so that the rower can quickly adjust their form.
- Force Plate
    - The plates will not add any unnatural feeling for the rowers, and therefore they will not have to change their technique in order to use them.
    - The force plate will be mounted flat onto the existing ergometer footplate.
    - The force plate must be compatible with different foot sizes.

h. Size:

- Display
    - The visual display should be at least 12 cm wide and 6.75 cm tall so that the screen size allows alphanumeric text to be 10 mm tall (*see Standards and Specifications)*.

- Force Plate
    - The width of a singular footplate of the 2005 Concept2 Ergometer Model D in the rowing tank is 13.3 cm and the height is 30.7 cm. The force plate must be the same size or smaller than these dimensions to fit on top of the foot plate.
    - The average 200kg load cell thickness is between 10-35 mm [12][13]. Therefore the thickness of the product should not be thicker than 35mm in order to maintain a relatively level surface and not impede upon the toe or heel straps of the flexfoot.

i. Weight:

- Maximum user weight for the RowERG is 227 kg [1]. The weight range of a woman crew athlete is on average 50 - 84 kg [14]. To not exceed this scale, the product weight should not exceed 143 kg.

k. Materials:

- A strain gauge load cell will be used for measuring force in a force plate to provide a greater surface area for force distribution applied by the foot. The chosen strain gauge load cell will operate by measuring electrical resistance changes in response to applied strain or pressure on the load cell. This load cell should accurately assess and withstand weights of 200 kg applied while rowing based on surface strain. [15]
- Additionally, housing material for load cells should be safe to use in a sports testing environment and be in compliance with the Sports and Recreational Equipment General Safety Requirements (*see Standards and Specifications*)
- A load cell amplifier compatible with the chosen strain gauge load cells will be utilized and have an operation voltage of 5 Volts.
    - Will be used to amplify signals from the load cells for accurate weight measurements. It will also be compatible with microcontrollers for data acquisition. [16]
- A display screen such as a TV monitor, tablet, or laptop will be used to display rowers' data, as these screens are readily available in the UW Boathouse.

l. Aesthetics, Appearance, and Finish:

- Display
    - The visual display must have a frame rate of at least 24 Hz, which is the standard frame rate of motion pictures, so that changes on the display appear continuous to the human eye [17].

- Force Plate
    - The constructed force plate should have clean lines and match the neutral gray and black colors of the ergometer so that it blends in as an attachment.
- Any hardware or electronics used to connect the force plates to the display should be hidden in an electronics box, to maintain a neat appearance.

2. Product Characteristics:

a. Quantity:

- The team aims to fabricate one functioning prototype this semester, consisting of a right and left force plate connected to a display screen. In the future, the client would like a total of 8 prototypes for the 8 ergometers fit to the tank.

b. Target Product Cost:

- The budget for this design project is $500. The budget may be increased with approval from the UW Athletic Department.

3. Miscellaneous:

a. Standards and Specifications :

- The device must not interfere with the construction of the Concept2 RowErg® such that it fails to comply with the ASTM Standard Specifications for Fitness Equipment (ASTM F2276 − 23) [18].
    - Specifies that edges should be free of burrs and sharp edges, and corners should be chamfered
    - Specifies that the ergometer should withstand 1560 on/off cycles
    - Specifies that the footplate should be slippage-resistant
    - Specifies that the ergometer should be able to withstand 136 kg or the maximum user weight, whichever is greater
- The device must also comply with the ASTM Standard Specification for Universal Design of Fitness Equipment for Inclusive Use by Persons with Functional Limitations and Impairments (ASTM 3021-17), such that rowers with functional limitations and impairments can use the device [19].
    - Specifies that color contrast on any visual display must be greater than or equal to 70%

    - Specifies that font size should be at least 10 mm
    - Specifies that the display should continue to display visual feedback at least 5 seconds after exercise has stopped.
- The device must comply with the Sports and Recreational Equipment General Safety Requirements (ISO 20957) to enhance safety and reliability of athletic testing equipment [20].
    - It includes guidelines for mechanical strength and endurance testing to ensure material can withstand forces applied during athlete testing.

b. Customer:

- The primary target customer for the product is the Physical Therapist and Athletic Training Staff for the University of Wisconsin Rowing Team.
    - University of Wisconsin collegiate rowers will be the primary operators of the device during use.
    - The device will also be used by the coaching staff of the University of Wisconsin Rowing Team.
- The customer(s) will use the device for routine evaluation of rowers' form, diagnosis of injury, and assessing progress during rehabilitation and return from injury.
    - Quantitative markers of asymmetry are required for determining the degree of injury and stage of progress during rehabilitation.
    - Positional placement must be adjustable between the ergometer and port or starboard sides of the tank, as well as between different models of ergometers.

c. Patient-Related Concerns:.

- The device should not interfere with proper rowing technique or injure the athlete in any way.
- The device should not interfere with the ergometer or boat such that they begin to degrade or malfunction.
- The device should be accompanied by a data storage drive or other technology that allows for patient performance data to be stored confidentially, in compliance with HIPAA [19].
    - The storage drive must be able to store multiple runs of longer rowing sessions between 40-100 minutes.

d. Competition:

- Bertec® produces portable force plates for gait, balance, and performance analysis [21].
    - The load cells contained inside utilize strain gauges and transducers to measure forces and moments in the x, y, and z directions

    - The portable force plates have a sampling frequency of 1000 Hz.
    - The portable force plates have loading capacities of 4440, 8880, or 17760 N.
- Biorow produces a 2D force sensor that uses four load cells fixed to a plate, and the plate is screwed between the foot straps of the ergometer and the foot stretchers [22].
    - The load cells can measure from -800 to +3200 N.

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