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Sled acceleration control for low speed impact testing and transient response studies

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1. Introduction

Whiplash Associated Disorder is the most common soft-tissue injury arising from low-speed car crashes (Siskind et al. 2013). To better understand whiplash injury mechanisms in the head-neck system, a sled was acquired. The sled was previously controlled in open loop mode, without any feedback of the resulting motion. The aim of this project is to safely control the motion and acceleration of the sled in order to be able to generate reproducible acceleration profiles.

2. Methods

A 5-meter sled was attached to the floor and controlled by a three-phase servo-motor (Compumotor APEX640), through a driver (Compumotor APEX40). In order to increase the torque, a toothed belt reduction connects the motor to the main toothed belt, which is able to set a 850 mm-diameter wooden pad plate in motion (Figure 1).

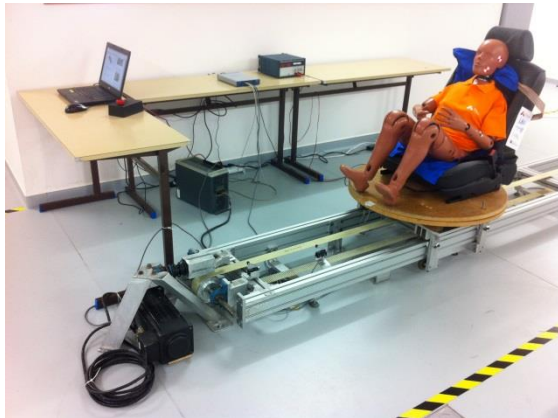


Figure 1 Global view of the sled.

Depending on the experimental conditions during a test, friction and mass may influence the response of the system. An open loop control system cannot evaluate this error. Consequently, a closed loop control has been developed.

The numerical regulation, input signal generation, filtering, error calculation and correction of the input signal were performed with LabView[®]. Control of the closed loop was achieved with a

Proportional-Integral-Derivative controller (PID-controller), a widely used system which is easy to implement. Each parameter of the PID-controller was experimentally identified in order to have a compromise between accuracy, stability and swiftness.

Feedback control was performed with two sensors: a tachometer gave the rotational speed of the motor itself, and a one-axis accelerometer was directly mounted into the wooden pad fixation with the main belt ($\pm 50g$, SM-B50 Sensel Measurement). First, the servo-control of the speed was tested using a Heaviside step function. However, the aim is to control the sled's acceleration, therefore the servo-control of acceleration was tested using both a Heaviside step function and a sinusoidal function (Equation 1). This sinusoidal function has the effect of minimizing jerk.

$$a(t) = \frac{A}{2} \left(1 - \cos\left(\frac{2\pi t}{T}\right) \right)$$

Equation 1

3. Results and Discussion

The first experiment regarding the servo-control of the speed using the tachometer led to no static error (the motor reached the prescribed conditions), and the response was close to that of a second order system.

The Heaviside step function applied to the acceleration led to no static error. However, it was essential to filter the accelerometer signal because the accelerometer was very sensitive to sled vibration. A non-negligible phase difference was then observed.

Finally, the sinusoidal acceleration input signal led to an error close to zero (Figure 2). The amplitude of the signal and the phase difference are linked to the gain level of the filter. A low gain value does not entirely remove the vibration but reduces the phase difference between the filtered and non-filtered signal.

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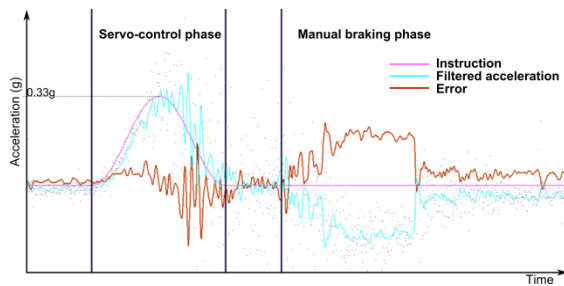


Figure 2 Response to the sinusoidal acceleration input signal.

Due to a limited length of the sled, all experiments were performed during very short time intervals. Moreover, the deceleration during the braking phase must also be safely controlled in order to be less than the starting acceleration.

It was observed that vibrations increased with velocity. One source of vibration is the toothed belts, another belt profile with better grip could possibly reduce this noise. However, even if vibrations have relatively high amplitudes compared to the input signal, they have a very small influence on motion, such that the rotational speed of the motor shows no jerk. This is due to the PID regulation which filters variations to the corrected input signal.

4. Conclusions

To conclude, we successfully controlled sled motion in closed loop mode for both speed and acceleration. Even though vibrations are substantial under some conditions, it was not necessary to filter

the sensor signal with a high gain value, avoiding introducing a significant phase difference.

Future work is planned to define several PID-controller parameters, according to the mass placed on the moving pad. Eventually, the aim is to have a robust tool to apply repeatable and safe accelerations for biomechanical tests.

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- Siskind V, Sheehan M, Rakotonirainy A, Cockshaw W. 2014. Road crash risk after Whiplash Associated Disorder. *Safety Science*. 63:151-156.