Lab report 4:
System identification and Interaction Control

System identification

To identify the stiction torque, the motor current was being increased in small steps until a movement is being detected (Δx > sensor noise, 0.616°). This stiction motor current was being recorded 5 times for each spinning direction of the motor and the mean stiction torque was being calculated. The damping relative to the paddle axis was calculated by using the motor characteristics from the datasheet.

Equation:

$$\tau_{stiction} = \tau_{motor} = i_{m,stiction} * \overline{K}$$

$$\overline{K} = k_\tau * \frac{r_{p1}}{r_m} = 0.0538 \frac{Nm}{A} * \frac{75mm}{4.3mm} = 0.938 \frac{Nm}{A}$$

Current needed to start moving cw(paddle) [A]	Current needed to start move ccw(paddle) [A]
-0.017133	0.008577
-0.017133	0.012862
-0.017133	0.012862
-0.017133	0.017147
-0.021418	0.017147
Mean: -0.017990	**Mean: 0.013719**

Motor torque needed to start moving cw(paddle) [Nm]	Motor torque needed to start moving ccw(paddle) [Nm]
-0.016071	0.008045
-0.016071	0.012065
-0.016071	0.012065
-0.016071	0.016083
-0.020090	0.016083
Mean: -0.016875	**Mean: 0.012868**

Motor damping coefficient:

$$\frac{i_{m,noload} * k_\tau}{\omega_m} = B_m = \frac{0.0137A * 0.0538 \frac{Nm}{A}}{8450rpm * 2\pi/60 \frac{rad}{s}} = 0.000000833 \frac{Nm*s}{rad}$$

Damping coefficient relative to the paddle axis:

$$\overline{B} = B_p + B_m * (\frac{r_{p1}}{r_m})^2 = 0 + 0.000000833 \frac{Nm*s}{rad} * (\frac{75mm}{4.3mm})^2 = 0.000253 \frac{Nm*s}{rad}$$

Explanation for stiction, Coulomb friction, and viscous friction

Stiction**:** Stiction is the breakaway force that an object needs to overcome to enable motion. It counteracts external forces below a certain level and thus prevents an object from moving. It's proportional to the normal force and the stiction coefficient.

Coulomb friction: Coulomb friction is a constant friction whose direction depends on the direction of the velocity. The value depends on the normal force and friction coefficient between two surfaces, but not on velocity.

Viscous friction: The viscous friction is velocity dependent friction, depending on viscous friction coefficient and the velocity. Its direction depends on the velocity too.

Observations

Our paddles gravity compensation itself does work as it should. Adding the friction compensation does lead to an overcompensation to both directions. The paddle oscillates over its whole ROM. We then reduced the compensation by a factor of 1.15 to get the behavior we had tried to implement before. In that case we got a slightly asymmetric paddle behavior. There are several reasons for that behavior. One could be a calibration issue as our position measurement recorded by the hall sensor is a bit off. Moreover, the stiction on different direction is different. In our case, the paddle usually stops when the it moves to its extreme counterclockwise position. That’s because the stiction in the counterclockwise direction is bigger, and the gravity cannot overcome this stiction to move the paddle back to its zero position, so the paddle usually stops on the right.

Interaction Control

The VI developed in lab session 4a was completed by implementing two virtual walls ($\Phi_d \pm 15°$). Additional boolean controls for the low-pass filter of position, velocity and the virtual walls itself were implemented. Values for stiffness (K) and damping (B) were adjusted until the paddle was showing a unstable / oscillating behavior. The Z-width of the paddle for the compensation and non-compensation case was defined by plotting K and B.

a) As discussed in the lecture, it is crucial to low-pass filter your velocity but not your position signal to receive a stable virtual wall. Why is this the case?

When we want to achieve a stiffer wall, we should increase the sampling time. However, as the sampling rate increases, the velocity resolution will get very high and we will get a much noisier velocity signal. But a good velocity estimate is necessary to render the virtual damping. Thus, filtering the velocity signal is necessary to get a more desirable performance. On the other hand, position’s estimate is still reasonable and filtering a signal increases computational load. Increased computational load will result in a slower loop rate and maximal stiffness compromises. So, in our application only the velocity signal was low-pass filtered to ensure accurate velocity signal and reduce computational load at the same time.

b) Write down your hypotheses about what you expect to observe in the two different conditions. Is there a difference?

When the friction and gravity compensation are ON, the motor will produce a compensation torque. The compensation torque and the torque generating the virtual wall have opposite directions. So, we assume the virtual wall will be weaker with the stiffness and damping coefficients. As a result, the adding of friction and gravity compensation will lead to a more stable behavior of the virtual wall. This leads to a larger range of stiffness K and damping B.

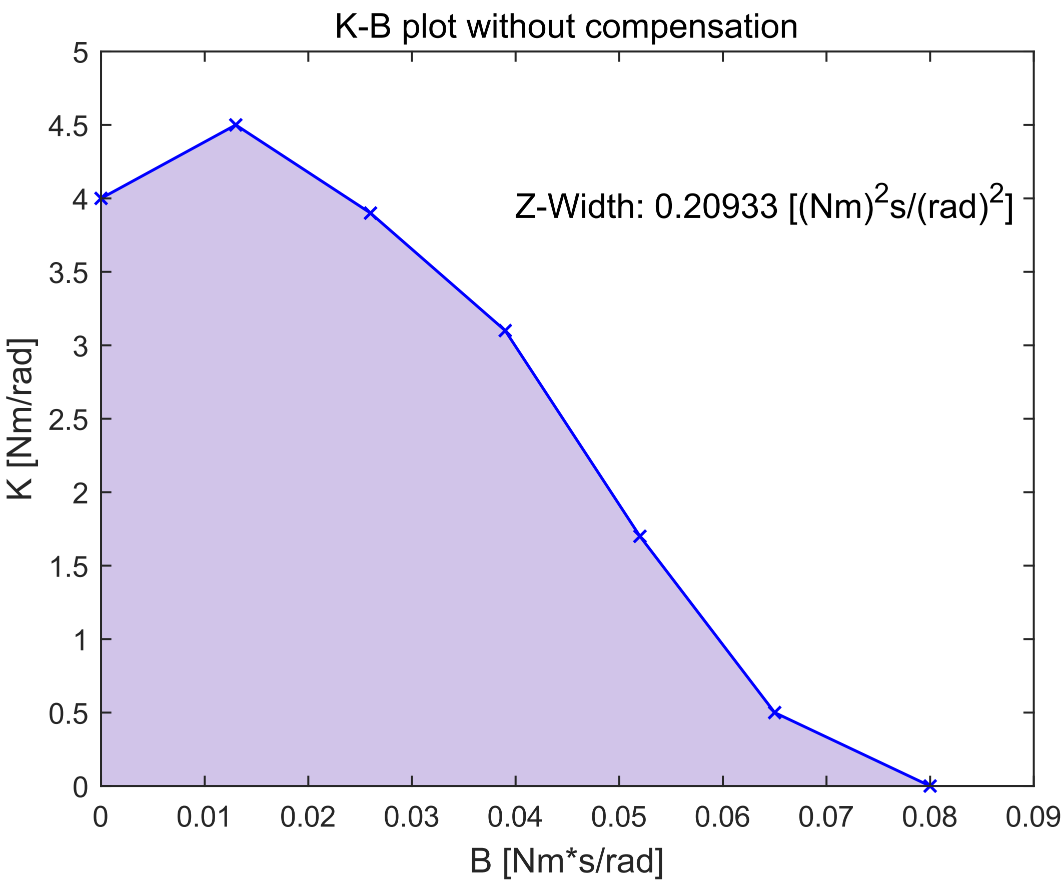
d) Discussion

When the compensations are ON, the same K and B values did result in a weaker virtual wall. The virtual wall was behaving little more stable and the area of the new K-B plots (the Z-width) is bigger if compensation is switched on. Although differences are quite small and we observe that the term *unstable* is depending on the operator very much. The paddle is more stable when we are holding it harder.

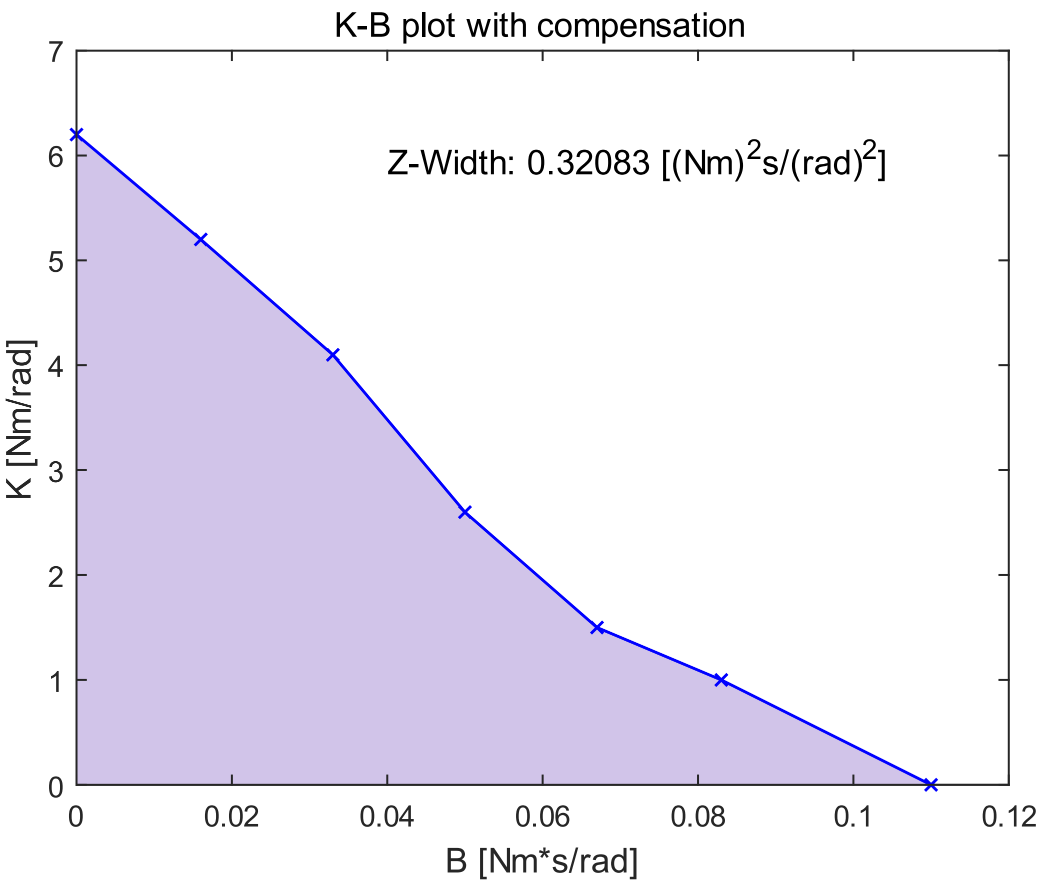
We think our system is not sufficient for a pHRI application cause of the lack of stiffness and stability. The use of such a devise in a rehabilitation environment does have very high requirements. In terms of stiffness, in our system we can still move across the virtual wall if we push the paddles harder and the voltage hits its limit, which might not be sufficient to simulate a real stiff object like a wall. As for stableness, patients with tremor or spasm need a much more stable system because of the movement patterns their impairment brings with it.

The system can become stiffer at one end. If we take larger actuators, we get more force and a higher upper end. This leads to more inertia and friction and performance reduction on the lower end. We can also add a force feedback loop to our system to compensate the device dynamics. The feedback error will get smaller and a larger force control gain with stable performance is possible. Moreover, we can increase computational power to ensure high loop rates and maximal stiffness. However, a high sampling rate will result in low accuracy for velocity estimation, which may lead to poor performance and instability. We need more filtering, higher resolution sensors, or analog sensors to deal with this situation. In conclusion, it's a compromise between performance in high impedance, performance in low impedance and stability.

K-B Plots with Z-width value



$$Z\_Width_{without\ compensation} = 0.20933 \frac{(Nm)^2 s}{(rad)^2}$$



$$Z\_Width_{with\ compensation} = 0.32083\frac{(Nm)^2 s}{(rad)^2}$$