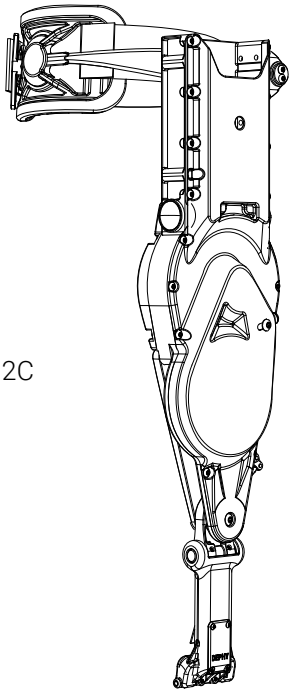
ExoBoot Walking Controller Guide



KEY FEATURES

- This proprietary user guide describes the use of the controller software that runs on the EB60 Dephy ExoBoot to provide augmentation during normal walking speeds
- Intended to be used by Dephy customers in conjunction with EB60 User Guide: C_0001_DS_0001_V01_EB60USERGUIDE
- Communication: Bluetooth Classic EDR (BLE coming soon), USB, RS-485, SPI, UART, and I2C
- Cross-platform GUI and full suite of C/C++, Python, and MATLAB demo scripts

COMPLIANCE

- Contains FCC ID: QOQBT121
- The EB60 uses an ActPack 4.1 Direct Drive module.
- Please refer to the **ActPack 4.1 Datasheet** for more compliance information.

SAFETY

- Before using your ExoBoot, make sure to read and understand the safety information in this guide and at **dephy.com/safety**

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Safety

For general product safety information please refer to: dephy.com/safety

- ExoBoot users must follow guidelines set forth in this user guide and accompanying manuals.
- The ExoBoot equipment changes your footprint and adds distal mass. Be aware of how the ExoBoot components may impact or interact with the environment.
- The ExoBoot may apply torque about the ankle joint in a manner that the user is not expecting. If the disturbance is great enough, it may cause the user to trip and fall. The control algorithm is designed to only apply power when it can accurately sense the gait pattern. When unsure of the gait, the device defaults to applying zero torque. Users are instructed to exercise caution during changes in terrain such as descending stairs.
- Users should select a boot size that fits comfortably to avoid discomfort or blisters.
- ExoBoot users are required to wear socks while operating the device.
- Due to the possibility of skin irritation after an extended use period, pants that extend past the calves of a user are recommended to minimize irritation.
- If the device is subjected to blunt impact (e.g., hit against an object while walking), be sure to inspect for damage before continued use.
- Inspect after each use for signs of wear, discontinue use if you see signs of wear or damage.
- Keep the mechanism free of obstructions and appendages as it poses a significant pinching hazard.
- Protect from water exposure.
- The ExoBoot housing may heat up during use. Use caution when handling after extended use.
- Read and follow battery charging and use instructions: C_0002_DS_0003_V02_SMARTDOCK. Charge only under supervision and contact Dephy if the battery exhibits a very fast red blinking pattern.
- Handle with care after extended exposure to sunlight as the device may heat up.
- User adaptation to device augmentation for extended periods may result in uneasy gait after doffing the device or turning off augmentation.
- Use Dephy approved cleaning methods and materials. See C_0001_PR_0004_V01_EXORETURN reference document for details.
- Device is to be stored between -10 and 60 degrees Celsius.
- Contact Dephy for proper handling during shipping and transportation.
- Read this guide carefully and contact engineering@dephy.com if you have any questions or concerns.

ExoBoot Operation

Power On

Follow the instructions in the EB60 User Guide to don the ExoBoot. To power on the ExoBoot, hold the button until the LED begins to flash green. Your ExoBoot system is now on.

Alignment

Immediately upon powering the system on, the ExoBoot will go through an alignment process. Stand upright and still on a flat, level surface. Wait for the system to apply slight pressure on your shins and then release. This should take no more than 15 seconds.

Training

Once the system has been aligned, the ExoBoot is ready for user training. To provide the best augmentation experience possible, we strongly recommend the following steps, otherwise training may need to be completed again. As of Release 6.0, training consists of taking 15 – 20 steps at a consistent pace, on a flat level surface. If available, we recommend training the system on a treadmill at 3 mph (1.34 m/s). If training overground, steps that deviate from each other (turning, dramatic changes in speed, stopping, etc.) will not count as successful steps towards the total required for training and may require extra steps to complete training. Additionally, greater variation in training steps may provide for a less optimized augmentation experience.

If you need to restart training, or you are using Multi-User Training mode and want the ExoBoot trained to a new user, please follow the directions in the “Restart Training” section below.

Receiving Augmentation

Augmentation will begin to be applied upon completion of a successful training, or immediately after alignment if a system has been trained in Single-User Mode. Applied torque ramps up over the first 3 – 5 steps while walking. Applied torque is dependent upon user gait and speed.

Augmented Movements

The Dephy walking controller is optimized for level ground walking of speeds from 2.0 - 4.5 mph (0.89 – 2.01 m/s). Inclines and declines from -20 to +20 degrees are also augmented. Outside of these movements, the Dephy ExoBoot will perform in a “transparent” mode, where the system is still on but no longer provides augmentation. We recommend that users are careful around transitions to movements such as stair ambulation and jumping as these are possible to be detected as walking and the user may receive undesired augmentation.

Adjusting to Augmentation

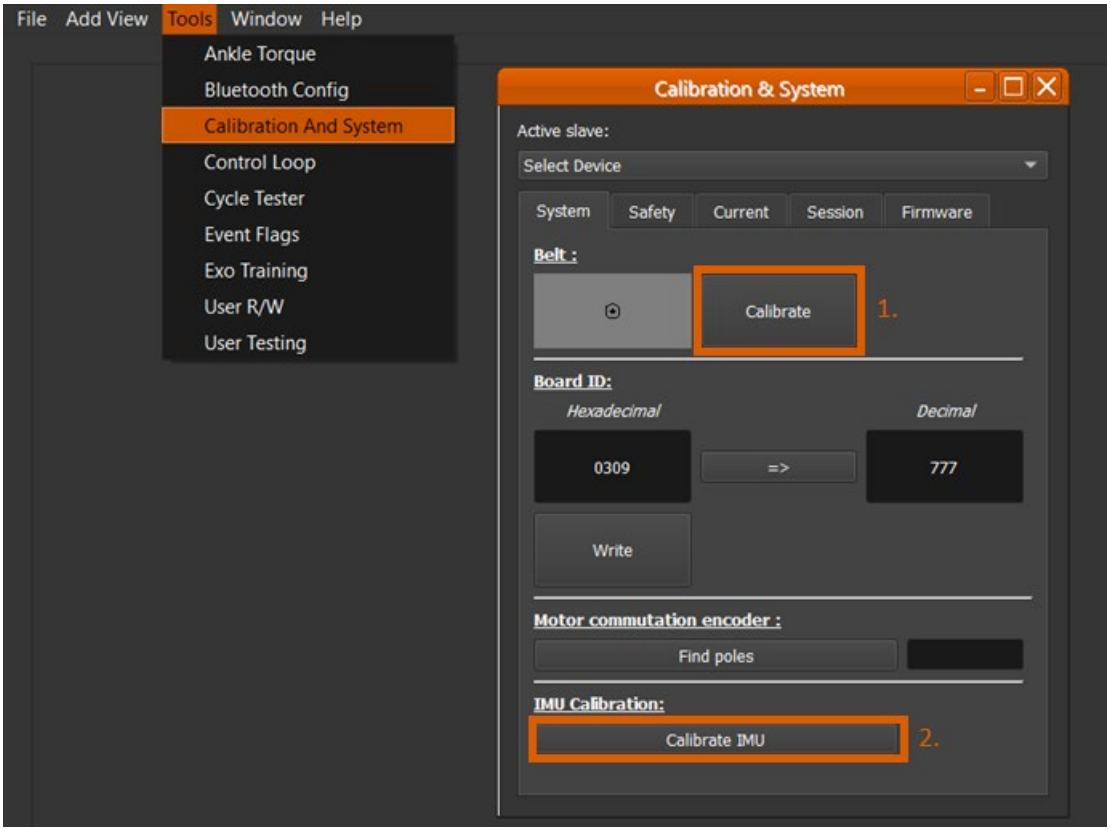
Users typically adapt to ExoBoot augmentation very quickly, usually within several minutes of beginning to receive augmentation. We recommend giving new users plenty of time to familiarize themselves with the system. If conducting a study, we recommend allowing each user time to experience and get comfortable with augmentation in all conditions they will be testing in (e.g., overground, treadmill, with and without a backpack).

Calibration

If you have recently flashed new firmware on the Dephy ExoBoot, it is necessary to perform belt and IMU calibrations. To perform these, please lay the ExoBoot armature without the boot attached on a flat, level surface free from obstructions. Power the ExoBoot with a battery and pair the ExoBoot to Dephy Plan GUI. Calibrations can only be conducted on one side of the system at a time.

Belt Calibration

Place the ExoBoot on a flat surface, with the shin pad attachment facing upwards so that the ankle joint can move freely. Go to Tools > Calibration & System > System Tab to access the Belt calibration option and click “Calibrate” (labeled 1. in the picture below). After a few seconds, the motor should begin to tug on the belt until the belt is fully spooled. Once the motor has fully spooled the chain, you will hear/feel the motor disengage.



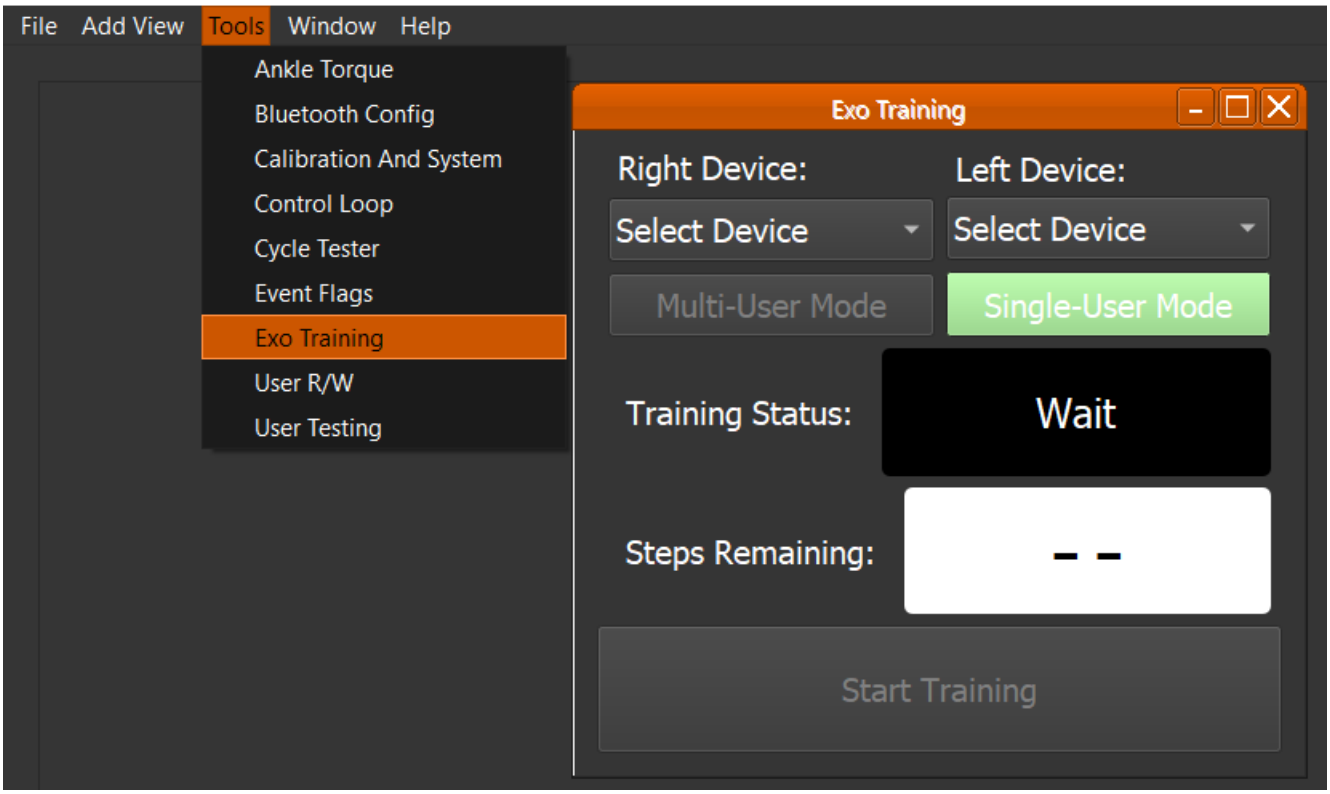
IMU Calibration

While your system is still flat on the surface after a Belt Calibration, further down in the Calibration and System > System Tab you can see a “Calibrate IMU” button (labeled 2. In the picture above). Press this button, you will hear the motor disengage and the system will calibrate the onboard IMU for approximately 30s. Be sure not to shake, move, or subject the ExoBoot to any vibrations during this time. IMU calibration can be conducted multiple times if you are not satisfied with the environment it was conducted in.

Restart Training

The Dephy ExoBoot learns an individual's gait based on 15 – 20 steps taken while the system is in training mode. If you are not satisfied with the augmentation you are receiving or a new user plans on using the ExoBoot, we recommend retraining the system. A training window can be accessed in Plan GUI by going to Tools > Exo Training. Here, you can select paired devices you would like to retrain, see training status of the system, and how many steps are remaining before a system is trained. You can also select your desired training mode:

- Multi-User Mode – Every time the ExoBoot is rebooted, training data is erased and the system must be retrained. The training process will start automatically at boot up.
- Single-User Mode – Power cycling the ExoBoot retains saved training data. Augmentation begins immediately upon first steps after alignment.

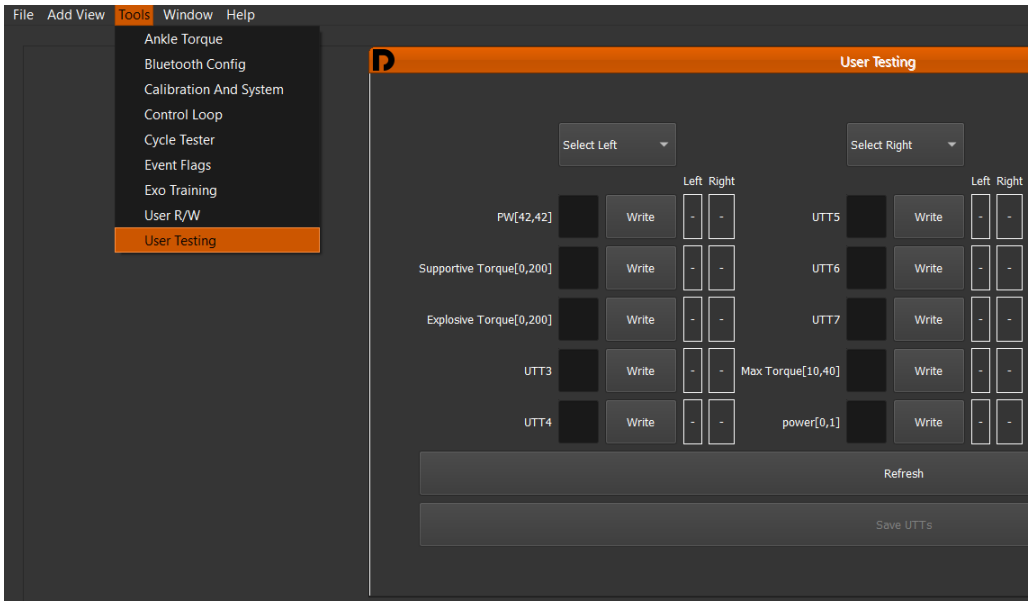


Tuning

Once augmentation has been turned on after the training process has been completed, the applied augmentation should feel comfortable for most users after a few steps. However, the ExoBoot can be further tuned to optimize the controller's behavior for a specific user using the User Testing window of the GUI. Each variable that you can change we refer to as a User Testing Tweak (UTT).

After opening the “User Testing” window, you must first click refresh to receive the current ExoBoot state. You should see both the left and right UTT values update. If this step is skipped or values for both sides are not received, writing may not be successful.

To change UTT values, type a new value or use the +/- button on the right side of the User Testing window to change the values. Then press write to send the command to the ExoBoots. The new value will appear under the Left and Right columns if the write was successful.



Only the following UTT variables should be adjusted during ExoBoot tuning:

- **Supportive Torque**: The percent of torque used to support your foot and act as a spring during dorsiflexion. The default value is 100 and the limits are 0 to 200.
- **Explosive Torque**: The percent of torque used to push your foot through powered plantarflexion. The default value is 100 and the limits are 0 to 200.
- **Max Torque**: The absolute maximum ankle torque the ExoBoot is allowed to apply during augmentation. The default value is 35 Nm, which is appropriate for most users. If a user is below 120 lbs or appears to be apprehensive while wearing the unpowered device, then 20 Nm may be an appropriate initial value. As subjects become more comfortable, this value can be increased based on user feedback and preference.
- **Power:** The Boolean variable that turns augmentation on or off. Set to 1 for augmentation and set to 0 to turn off augmentation.

If a user is not comfortable with the default walking controller, or the operator wishes to tune the controller manually, follow the below procedure to efficiently tune the ExoBoot to a user:

1. Don, power, and align the ExoBoot following above instructions.
2. If the user is under approximately 120 lbs or appears apprehensive/unsure while wearing the unpowered ExoBoot, set **Max Torque** to 20 Nm.
3. Allow the user to take a few steps with augmentation to adjust to the ExoBoot.
4. If the ExoBoot appears to be ‘jerky,’ or ‘double actuates’ during stance, then a misalignment may have occurred. Power cycle both ExoBoots, re-align, and retrain. If the behavior continues, a full belt calibration (see “Belt Calibration” section) may be necessary.

5. Ask the user, 'Does it feel like the ExoBoot is applying augmentation too suddenly or like the ExoBoot is trying to plantarflex your foot more/longer than you'd like?'
    a. If the answer is 'yes' to either one, decrease the **Explosive Torque** to 80. After a few more steps, ask the same questions.
        I. If the answer is still 'yes,' continue to gradually decrease the **Explosive Torque**. You may also increase the **Supportive Torque** by increments of 5 or 10 until the user no longer reports the sudden augmentation or extensive plantarflexion. If you reach a value of 60 in **Explosive Torque**, then the user may need more time to adjust to wearing the device or the controller is not appropriate for this user.
        II. If the answer is 'no' then 80 should be used for this user during future tests.
6. Ask the user, 'Does it feel like the ExoBoot is resisting your movement?'
    a. If the answer is yes, decrease the **Supportive Torque** to 80. After a few more steps, ask the same questions.
        I. If the answer is still 'yes,' continue to gradually decrease the **Supportive Torque** until the user no longer reports the resistive augmentation. If you reach a value of 60 in **Supportive Torque**, then the user may need more time to adjust to wearing the device or the controller is not appropriate for this user.
        II. If the answer is 'no' then 80 should be used for this user during future tests.
7. The **Max Torque** default value of 35 is appropriate for most users. If a user is under 120 lbs or seems apprehensive using the ExoBoot, then the experimenter may gradually decrease **Max Torque** to the user's preference.
8. The variable *step_energy* (mJ) can be used to approximate how well a user is adapting to the ExoBoot. We typically aim for users to receive approximately 15 joules during each step, which is equivalent to a *step_energy* of 15000.
9. Plotting the variable *genvar_9* (in this case *genvar_9* is the desired ankle torque in mNm) in the 2D plot is also very useful for tuning.
    a. If *genvar_9* is not reaching at least 20000 then **Explosive Torque** may need to be increased.
    b. If *genvar_9* is plateauing at (**Max Torque** x 1000) then **Explosive Torque** may need to be decreased.
10. The general goal is to reach a *step_energy* value of at least 15000 (15 J) with the user feeling comfortable and completely natural.
11. After tuning the UTT values for a specific user, these values should be documented by the experimenter and re-written in the User Testing window any time the ExoBoots are powered on that specific user.

Data Collection

Data from the ExoBoot can be collected by pairing the Dephy ExoBoot with the Dephy Plan GUI. For instructions on how to pair your ExoBoot and collect data, please refer to Section 4 - Reading & Writing to/from a Device at **dephy.com/start.**

Reference Documents

- Safety Guide: **dephy.com/safety**
- Software Guide: **dephy.com/start**
- EB60 Data Sheet: C_0001_DS_0001_V02_EB60DATA
- EB60 User Guide: C_0001_DS_0001_V01_EB60USERGUIDE
- BA30 Data Sheet: **C_0002_DS_0001_V03_BA30DATA**
- SmartDock Data Sheet: C_0002_DS_0003_V01_SMARTDOCK
- Cleaning: C_0001_PR_0004_V01_EXORETURN

Date	July 9, 2021
Revision	C_0001_UG_0002_V01_WLKCTRL
Created by	Jonathan Kaplan
Reviewed by	Rachel Harris
Approved by	Luke Mooney 
Purpose	User guide for the walking controller that has been reviewed and approved for release

C_0001_UG_0002_V01_WLKCTRL

Final Audit Report 2021-07-13

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