ZEUS X1® Integrator Manual

Z-Excursion Universal Sampler – eXchange Series

HAMILTON®

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Hamilton Warranty

Please refer to the General Terms of Sale (GTS).

Important Notice

1 Introduction

1.1 Intended Use of ZEUS X1

Hamilton Z-Excursion Universal Sampler - eXchange Series (ZEUS X1) is a fully automated, self-contained, liquid handling module for integration in instruments requiring on-board pipetting. ZEUS X1 is based on Hamilton's revolutionary air-displacement pipetting technology and uses disposable tips to avoid carry-over. The module is equipped with Qualitative Pipette Monitoring (QPM) to ensure successful pipetting. ZEUS X1 can pipette volumes in the range of 1 µL to 1000 µL.

ZEUS X1 is a component for a liquid handling device and as a component cannot comply to in vitro diagnostic requirements or Title 21 Part 11. Only the complete liquid handling platform may be certified for in vitro diagnostic uses by the instrument manufacturer.

1.2 About this Manual

This Manual is designed to support the integration engineer during integration, operation and qualification of ZEUS X1. You should read through the entire Manual before beginning to install and operate the pipetting module. This manual describes the features of ZEUS X1 and its integration in liquid handling devices. Both the hardware and the communication between the pipetting module and the liquid handling platform are detailed in this manual. After reading this manual the integration engineer should be capable of operating ZEUS X1.

Throughout this manual, the following conventions are used to highlight various kinds of information:

> ⚠ **ATTENTION! Essential information for avoiding personal injury or damage to equipment.**

> NOTE: Important instructions or interesting information.

2 Safety Precautions and Hazards

> ⚠ **ATTENTION! Read the following safety notices carefully before installing and operating the OEM Pipetting Module.**

2.1 General Precautions

2.1.1 ZEUS X1 Pipetting Module

The operator of ZEUS X1 must be familiar with this manual. The procedures contained within this manual have been tested by the manufacturer and are deemed to be fully functional. Any deviation from the procedures given here may lead to malfunctions or even damage.

Use adequate enclosure of ZEUS X1 to ensure appropriate user protection.

For safe and correct use of ZEUS X1, it is essential that both operating and service personnel follow generally accepted safety procedures as well as the safety instructions given in this document, the ZEUS X1 Manual.

Any collisions of the pipetting module with other components have to be ruled out.

Cleaning, dismantling, and maintenance should only be performed by personnel trained in such work, and who are aware of the possible hazards involved. Only certified technicians are authorized to perform mechanical maintenance on ZEUS X1.

> ⚠ **ATTENTION! Teaching of ZEUS X1 and accurate definition of the Container Geometry and Deck Geometry parameters is required prior to operation.**

For repair or shipment, all mechanical parts must be put in their rest positions. Any ZEUS X1 returned to Hamilton for repair must always be decontaminated (see Chapter 9.4). The pipetting module must be sent back in the original reusable packaging box. There must not be any labware including tip on the pipetting module during transportation.

Only original ZEUS X1-approved parts, tools and accessories (e.g., pipetting tips) may be used with the pipetting module (see Chapter 11). The use of any other parts, any alterations or modifications to the system may be dangerous and will void the warranty.

2.1.2 Operating ZEUS X1

When using the ZEUS X1, Good Laboratory Practices (GLP) must be observed. Suitable protective clothing, safety glasses and protective gloves must be worn, particularly when dealing with a malfunction of the instrument where the risk of contamination from spilled liquids exists.

Adequate protection including clothing and ventilation must be provided if dangerous liquids are

SAFETY PRECAUTIONS AND HAZARDS

used in the analytical work. In case of incidental spillage, carefully wipe with a dry cloth, taking into account the nature of the spilled liquid and the necessary safety precautions.

During operations, stand clear of any moving parts or the working deck of the instrument. Do not attempt to disable any security measure.

The instrument developer is responsible for the use of the appropriate probe, materials (e.g., pipetting tips, containers), and parameters (e.g., liquid class, container geometry, tip type) consistent with the validated application. Ensure the use of tips of the appropriate size. Failure to do so may lead to pipetting errors, contamination or damages to ZEUS X1. Make sure that the pipetted samples are consistent with the samples used for performance validation. Generally, it is recommended to centrifuge the samples to avoid foam, bubbles or clot formation.

Pipetting accuracy and precision may not be ensured in case of process interruption. As a consequence it is recommended to discard the pipetted sample and repeat the required pipetting steps.

2.2 Environmental Influence

The accuracy and the precision of pipetting with ZEUS X1 are highly influenced by the laboratory environmental conditions. Temperature, humidity and air pressure of the laboratory should be controlled to achieve specified accuracy and precision. When working with samples, which will be used in particularly sensitive tests, take the evaporation and condensation that may occur into account.

During operation, ZEUS X1 should be shielded from direct sunlight and intense artificial light.

⚠ ATTENTION! Hamilton will not assume liability if damage arises from the improper handling of liquids.

2.3 Electrical Safety Precautions

Do not connect the pipetting module to a power source of any voltage beyond the range stated on the power rating Technical Specifications (see Chapter 10). Only use a cable which conforms to the given specifications (see Chapter 4.4). Make sure the cable is intact and properly connected to avoid any short circuit. Connect the power ground of the ZEUS X1 module to the ground of the instrument housing. Failure to do so will impair the functionality of the capacitive LLD.

Keep ZEUS X1 away from other equipment that emits electromagnetic radio frequency fields, and minimize static electricity in the immediate environment of the pipetting module.

⚠ ATTENTION! Switch off the main power and unplug the FFC cable before dismounting ZEUS X1.

2.4 Chemical, Radioactive or Biological Hazard Precautions

Selection of the appropriate safety level and implementation of the required safety measures for working with ZEUS X1 is the sole responsibility of the user.

If ZEUS X1 becomes contaminated with biohazardous, radioactive or chemical material, it should be cleaned in accordance with the maintenance procedures given in the Chapter 7. Always decontaminate your instrument and replace the samples on the instrument in case a tip detaches, to avoid cross-contamination and pipetting errors. Failure to observe and carry out the maintenance procedures may impair the reliability and correct functioning of the pipetting module.

If working with hazardous samples observe and carry out the maintenance procedures, paying particular attention to cleaning and decontamination. Use filter tips and do not reuse tips to avoid cross-contamination. Design your waste container to avoid spillage during tip discard. Wear gloves during the cleaning process. Any surfaces on which liquid is spilled must be decontaminated.

Do not use disinfecting materials which contain hypochlorite (Javelle water, Clorox) or bleaching fluids.

3 Product Description

3.1 General Description

ZEUS X1 is a self-contained pipetting module designed for integration into instruments requiring on-board liquid handling. It is based on Hamilton’s revolutionary air-displacement pipetting technology and uses disposable tips to avoid any sample carry-over. The z-motion is integrated in order to facilitate integration of the module. The pipetting module is also equipped with Qualitative Pipetting Monitoring (QPM) to ensure successful pipetting. Both capacitive and pressure liquid level detections are integrated and may even be combined for demanding applications.

3.2 Hardware Description

3.2.1 General Overview

ZEUS X1 is composed of two subunits: the pipette head and the channel body. The pipette head contains the pipetting drive which moves the plunger, the CO-RE II tip coupling mechanism which picks up the tips, a capacitance sensor and pressure sensor for liquid level detection, and a tip sensor. The channel body consists of the Z-drive and the main board which controls all functionality.

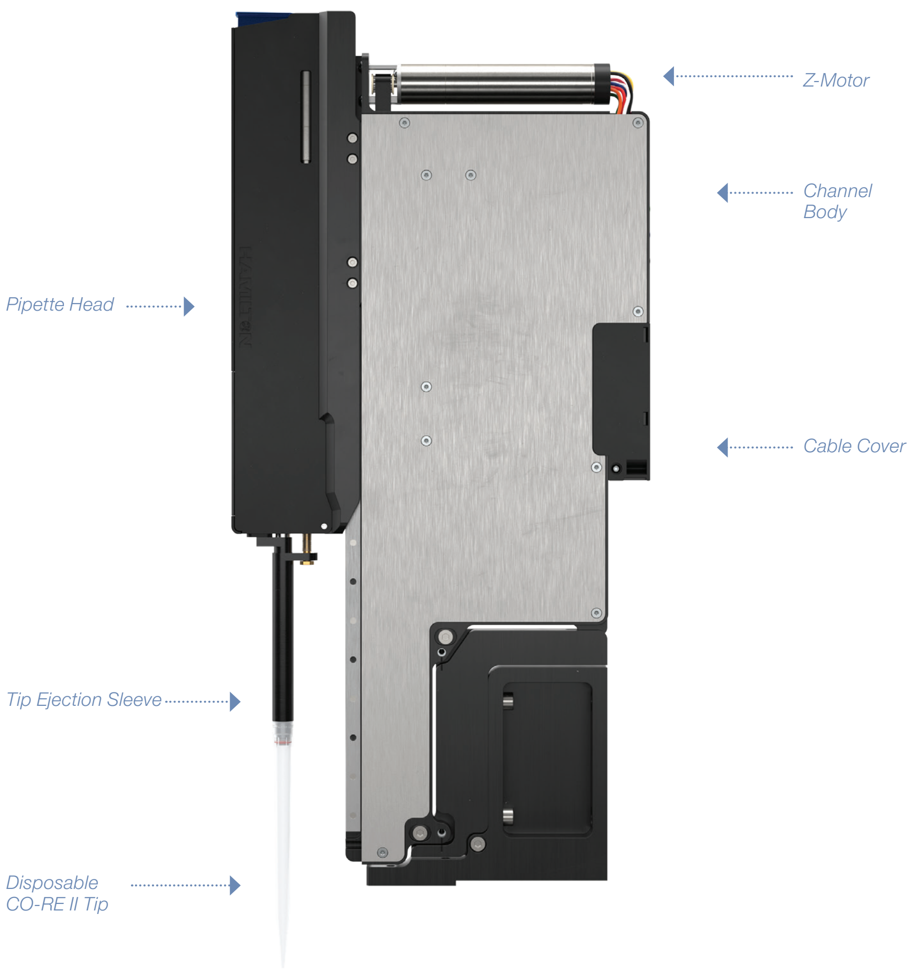


Figure 1: Hardware overview.

3.2.2 Pipetting Head Technology

ZEUS X1 is based on an innovative air-displacement technology. Air displacement means that the liquid is aspirated into and dispensed from a disposable tip by the movement of a plunger, similar to the functioning of hand pipettes. Air displacement enables the use of consumable pipetting tips which limits cross-contamination and sample carry-over.

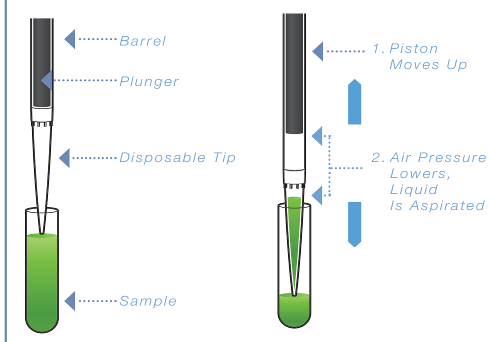


Figure 2:
Innovative pipetting head technology.

3.2.3 Unsurpassed Accuracy and Precision with CO-RE II Tips

Hamilton CO-RE II tips are the highest quality tips available for precise and accurate pipetting. They have been designed to solve the problems of sealing and alignment plagued by press-fit pickup techniques. Hamilton Compression O-Ring Expansion (CO-RE) technology creates a reliable seal between the tip and the barrel, and provides excellent tip retention.

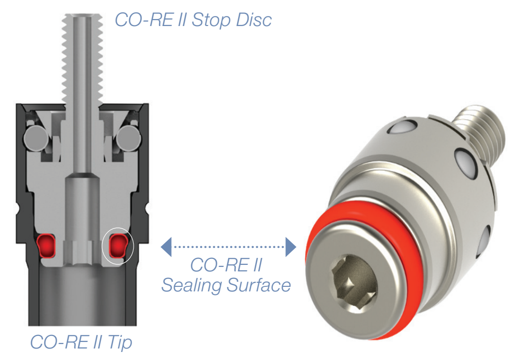


Figure 3:
Precise attachment of CO-RE II tips on ZEUS X1.

3.2.4 Status Lights

Hamilton's ZEUS X1 is equipped with three indicator lights located on the channel body, providing a convenient means of identifying the device's current status.

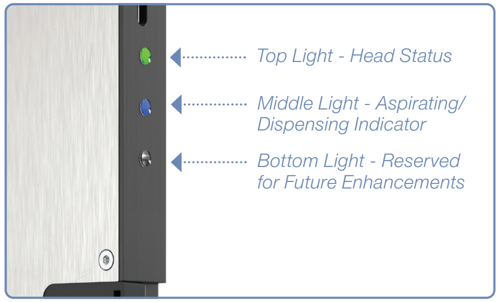


Figure 4: ZEUS X1 Status Lights

PRODUCT DESCRIPTION

3.3 Automated Pipetting Process

3.3.1 Pipetting Process

The automated pipetting with the ZEUS X1 follows five successive steps (Figure 5).

1. ZEUS X1 picks up a pipetting tip and automatically verifies its presence.
2. ZEUS X1 supports two modes of Liquid Level Detection (LLD), capacitance LLD for conductive liquids and pressure LLD for non-conductive liquids. The integrated z-motion is used to detect the liquid level and to follow the liquid during aspiration and dispense.
3. ZEUS X1 aspirates the volume of liquid defined by the user in the range of 1 µL - 1000 µL into the pipetting tip. The complete pipetting cycle is automatically verified with the Qualitative Pipette Monitoring (QPM). QPM detects the aspiration of foam, clots or air and follows predefined error handling procedures to ensure precise and accurate pipetting.
4. The liquid is dispensed in one or more aliquots and the process is monitored by QPM.
5. ZEUS X1 discharges the used pipetting tip.

Figure 5: ZEUS X1 automated pipetting process.

3.3.2 Liquid Level Detection

ZEUS X1 contains both capacitive and pressure liquid level detection (LLD). Capacitive LLD (cLLD) may only be used with conductive liquids and requires conductive tips. The pipetting channel modulates the tip with a high frequency AC signal. As soon as the tip touches the surface of the liquid, the capacitance of the system changes, which causes a change in the AC signal: the liquid level is detected.

The pressure LLD (pLLD) can be used with both conductive and non-conductive liquids. The z-drive moves down slowly while the plunger aspirates (i.e., moves up). When the tip hits the surface of the liquid the pressure sensor measures a change in pressure indicating that the surface has been found. This detection method cannot be used if liquid is inside the tip. Therefore, pressure LLD only works with new and empty tips during the aspiration phase. This process is slightly slower than capacitive LLD but is the only way to detect non-conductive liquids. The sensitivity of both cLLD and pLLD may be adjusted to the vessel size, tip type and the physical properties of the liquid to be detected.

3.3.3 Qualitative Pipetting Monitoring (QPM)

ZEUS X1 is equipped with a process monitoring system called Qualitative Pipette Monitoring (QPM), which ensures proper pipetting. If QPM is activated, the air pressure in the pipette tip is monitored during the entire aspiration and dispensing cycle and is instantly compared to predefined thresholds. When ZEUS X1 aspirates or dispenses foam, clots, or air due to insufficient reagent, the system immediately identifies the error. Adequate error-handling procedures may be associated to these errors and automatically performed to ensure proper pipetting. The foam detection is application dependent.

The working principle of QPM is illustrated in Figure 6 for the case of tip clogging during aspiration. The pressure is monitored during the whole pipetting cycle. Normal behavior is shown in red. If the tip clogs, e.g. during clot aspiration (blue), the pressure drops below a predefined threshold (dashed line). The system identifies an error. A more detailed description of all error cases is provided in Chapter 6.

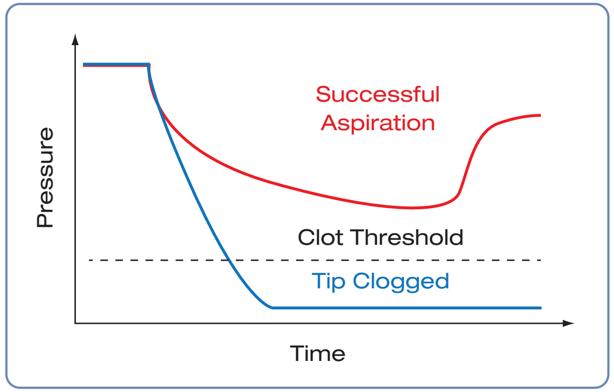


Figure 6: The working principle of QPM, illustrated for tip clogging during aspiration.

3.3.4 Anti-Droplet Control (ADC)

The ZEUS X1 process monitoring also includes Anti-Droplet Control (ADC). ADC works by continuously monitoring the pressure in the channel. ADC is used to pipette volatile liquids like acetone or methanol. Such liquids tend to evaporate inside the tip increasing the vapor pressure. Without ADC, the pressure is released by droplet formation which results in the loss of liquid and may lead to contamination of other samples (Figure 7, left). With ADC on, pressure differences are detected by the pressure sensor and compensated in real time by plunger movements: droplet formation is prevented (Figure 7, right).

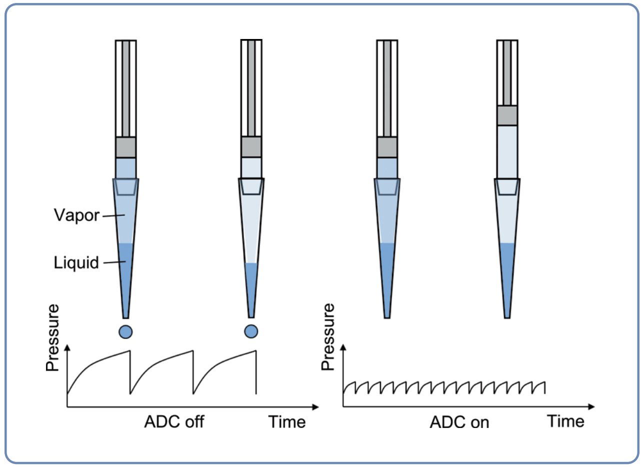


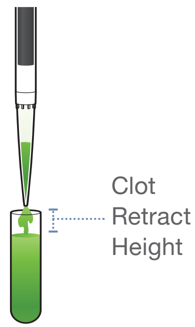
Figure 7: Working principle of the Anti-Droplet Control (ADC).

3.3.5 Capacitance-Based Clot Detection

In addition to pressure-based clot detection, the ZEUS X1 is equipped with capacitance-based clot detection. This detection approach works when the aspiration with capacitance Liquid Level Detection is switched on.

Functionality

The system measures the conductive signal when the tip leaves the liquid after aspiration. Due to the air gap between tip and liquid, the capacitance signal will vanish once a given height is reached (the “Clot retract height” (cg), which is specified within the aspirate command). If a clot is present, it bridges the distance and the signal will remain, resulting in an error message. A typical clot retract height is 2 - 5 mm, as illustrated below. This clot detection is independent from pressure-based monitoring. The capacitance-based clot detection is only valid if the liquid parameter “Clot retract height” (cg) is set (>0).



4 Getting Started

4.1 Unpacking

Open the cardboard box, remove the Certificate of Calibration, and pull the top foam out of the box. Carefully lift the pipetting module out of the box and remove it from the bag. Inspect the module for shipping damage or missing parts.

⚠ ATTENTION! Keep the original packing material in case the module has to be returned to Hamilton. Observe standard handling precautions to avoid electrostatic discharge.

⚠ ATTENTION! During module handling please do not manipulate the module from motors. The handling must be performed from chassis.

ZEUS X1 Packaging

ZEUS X1 Replaceable Head Packaging

Figure 7: Unpacking ZEUS X1. Please do not discard packaging. To avoid shipping damage, original packaging is required for return/repair shipment. ZEUS X1 packaging is designed to be used as standalone packaging (no additional packaging is required for shipment).

4.1.1 Handling Guide

The figure on the next page shows the recommended resting orientation for the ZEUS X1.

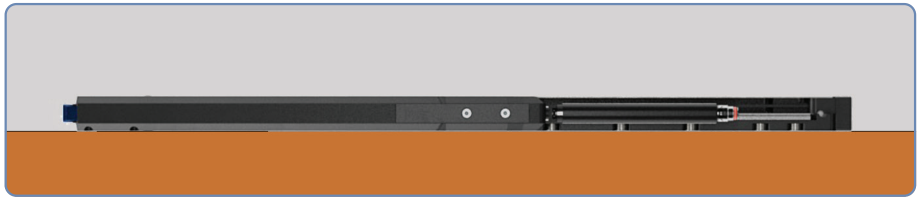


Figure 1: Recommended resting orientation for ZEUS X1.

The z-drive motor, indicated above in red, protrudes on both sides of the ZEUS X1 module. The ZEUS X1 module may be rested on its side with the motor in contact with the support surface as shown in Figure 1. To avoid damage, care must be taken to not press on the ZEUS X1 while in this orientation.

ZEUS X1 should be handled by the main body, as shaded green in Figure 2. To avoid damage, do not handle the unit by the head or the z-drive motor as shaded in red.

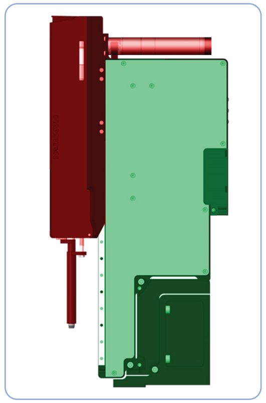


Figure 2: Recommended handling regions for ZEUS X1.

4.2 Hardware Installation

ZEUS X1 must be mounted on the holder of your instrument using M4 screws. Four M4 threads are provided for mounting, as pictured below. Please refer to the hardware specifications for exact mechanical requirements.

For proper tip pick-up, x-y positioning of ZEUS X1 must occur with an accuracy of 0.5 mm and z-positioning with an accuracy of 1 mm. Make sure that ZEUS X1 is built into your instrument to achieve these requirements.

⚠ ATTENTION! Make sure to secure all four external mounting points for proper fixation of ZEUS X1. Torque all four mounting screws to 20 in-lb. The tip pick-up process may generate forces up to 20 N. The consequent deformation of the x-y axis carrying ZEUS X1 may not exceed 2 mm.

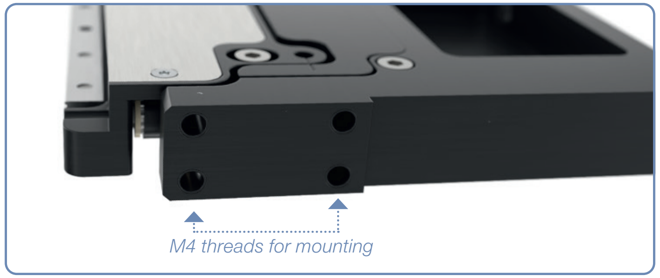


Figure 3: External Mounting Points

4.2.1 Alignment

All channels will be aligned before leaving the factory. Additional alignment may be performed by the user if desired.

4.2.2 Tilt and Offset Adjustment

Hamilton's ZEUS X1 is capable of fine tune adjustment of the channel. The channel can be adjusted with an offset of ±1 mm from nominal front to back (Figure 5). It can also be adjusted ±1° from nominal front to back (Figure 5) and left to right (Figure 4).

Figure 4: Left to right tilt.

Figure 5: Front to back tilt and offset.

To adjust the channel's left to right tilt shown in Figure 4, perform the following sequence:

- Use an M3 hex to loosen the two M4 screws shown in Figure 6.
- Using an M2.5 hex, tighten or loosen the tilt adjuster to adjust the left to right tilt of the channel. Tightening (clockwise) will angle the channel away from you. Loosening (counterclockwise) will angle the channel towards you. Once the channel is in the desired tilt position, torque the two M4 screws to 20 in-lb.

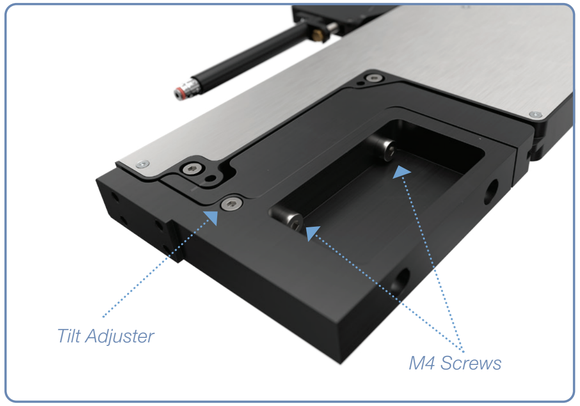


Figure 6: Left to right tilt adjustment.

To adjust the channel's front to back tilt or offset shown in Figure 5, perform the following sequence:

- Use an M2.5 hex to loosen the two M3 screws shown in Figure 7.
- Use an M2 hex to turn the tilt adjusters clockwise or counterclockwise to adjust the front and back tilt of the channel respectively. The etched precision lines may be used as a guide for alignment.
- Turn one adjuster to tilt the head forwards or backwards (±1°) or turn both adjusters to adjust the front to back offset (±1 mm).
- Once the channel is in the desired position, torque the two M3 screws to 8 in-lb.

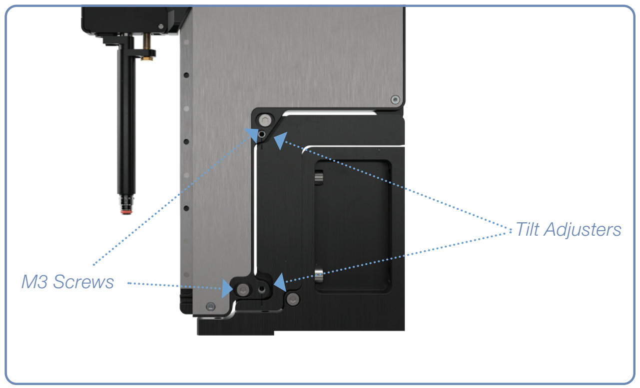


Figure 7: Front to back tilt and offset adjustment.

4.3 Hamilton CAN Communication

4.3.1 General

ZEUS X1 uses Controller Area Network (CAN) to communicate with a controlling unit (not CANopen). To successfully control ZEUS X1, your master control unit must support CAN communication.

Although CAN is designed as a bus the ZEUS X1 protocol employed considers each channel (CAN node) as a unique device on the CAN bus and therefore, each device is uniquely addressable.

Some things to note:

1. CAN 2.0 part A (CAN 2.0A)
2. Only CAN Data and Remote frames are supported/used
3. CAN Error and Overload frames are not supported/used
4. CAN Data frames always carry 8 bytes of data
5. Arbitration identifier (ID field) is standard 11 bits only
6. Arbitration identifier has bits defined as source and destination address of nodes as well as the type of frame
7. One node is generally the controller while remaining nodes are individual ZEUS X1 channels
8. It is possible to co-mingle the CAN bus with CAN node operating with 29 bit identifiers as long as the appropriate CAN filter is configured

Implementing the ZEUS X1 protocol is a non-trivial undertaking. This document describes the protocol and the general flow of communication between channel and controlling unit but not the implementation details.

To ease the process of communication with the ZEUS X1 channel Hamilton Company has created a set of source code that can be compiled into your application to handle all the protocol implementation details. A small number of stub functions are required by the user in order to integrate the user's hardware with the protocol implementation. The implementation is written using the C programming language. Refer to document number 6600284-01 for details.

The Protocol:

Although the ZEUS X1 channel uses only two types of CAN frames the protocol expands upon this slightly and employs three types of frames defined like so:

1. Data frame: a CAN data frame with the kick bit cleared
2. Kick frame: a CAN data frame with the kick bit set
3. Remote frame: a CAN remote frame

GETTING STARTED

All ZEUS X1 commands take the form of a string of varying length. CAN frames are capable of only carrying 8 bytes of data and one of these bytes is reserved as a control byte leaving only 7 bytes. Most ZEUS X1 commands and responses consist of more than 7 bytes of data and as such the exchange of data will necessitate the fragmentation of the string between the source and destination.

The general flow of communication between two nodes from the perspective of the sender and from the receiver is as follows:

Sender of Data

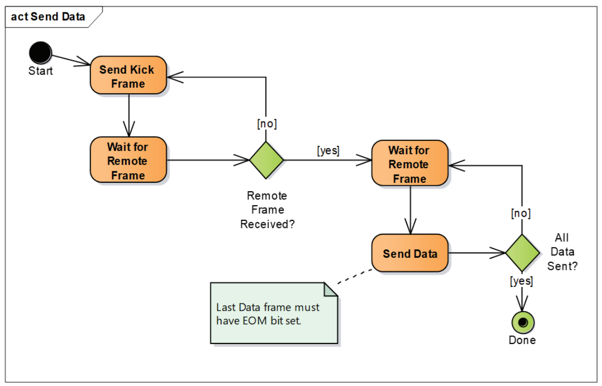
A node that wishes to send data must do so by querying the destination node to check if it is ready to receive data. This is accomplished via a Kick frame. The sender initiates a data transfer by sending a Kick frame. When the destination node is ready to receive data it will respond to the Kick frame with a Remote frame indicating how much data it can receive (DLC = 8). The protocol always sends 8 bytes of data so the DLC field must be 8. If the sender of the Kick frame does not receive a Remote frame after a period of time then it should repeat sending a Kick frame until either the Remote frame is received (destination node is ready to receive data) or sufficient time has expired to consider abandonment of the data transfer.

Once the Remote frame is received the sender then sends the first Data frame consisting of up to 7 bytes of data and a properly configured control byte as the 8th data byte. If fewer than 7 bytes of data are to be sent it is good practice to zero fill the remaining values (not required), but the 8th byte will always contain the control byte.

When the last Data frame is sent the receiving node will stop sending Remote frames.

Note that there is no provision in the protocol to abort a message transmission. Once started, a message must be sent in its entirety. Failure to do so will result in the destination node continuously sending Remote frames until power cycled.

The following diagram demonstrates the general flow of message transmission:



In summary:

1. Send Kick frame then wait for Remote frame. Remote frame should arrive within ~100 ms. If no Remote frame is received then send a Kick frame again. Repeat this process until the Remote frame is received or abandon the message transmission with an error.
2. Once the Remote frame is received send a Data frame. Since the Remote frame receive rate is ~100 ms it is best to send the Data frame immediately or additional Remote frames will be received. If more data is to be sent then wait for Remote frame.
3. Continue sending Data frames and waiting for Remote frames until the last Data frame is sent. Message transfer is complete. No additional Remote frame is expected.
4. As with sending the Kick frame if a Remote frame is expected but not received then send the Data frame again and repeat the process, but ensure that the Data frame is the same as the one already sent (repeated frame). If no Remote frame is received then abandon the message transmission with an error.
5. Kick frame has kick bit set in ID field
6. Data frame has kick bit cleared in ID field
7. ID field specifies the sender and receiver address for both Kick and Data frames
8. Data frame will always contain 8 bytes
9. Control byte will always be the 8th byte
10. Message must be fully sent
11. Control byte must be configured for each Data frame sent indicating data length, frame counter, and end of message bit

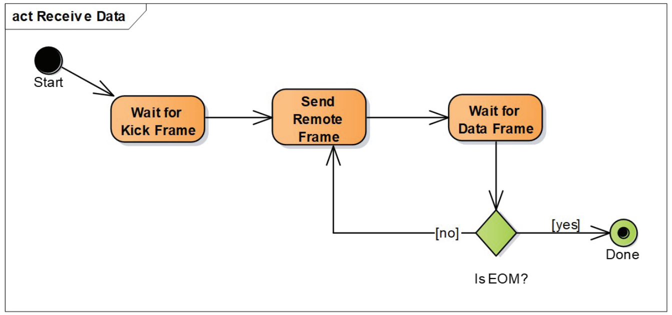
Receiver of Data

A node that is ready to receive data must wait for the reception of a Kick frame. Once a Kick frame is received the receiver will respond with a Remote frame with the DLC = 8 indicating that it is ready to receive 8 bytes of data. If the data is not received after a period of time the receiver should continue to periodically send Remote frames until a Data frame is received but not indefinitely, if no Data frame is received after a period of time reception of the message should be abandoned.

Upon receiving the Data frame the control byte should be checked to determine if the last message fragment has been received and if not send another Remote frame to receive the next Data frame. This process should continue until the last message fragment has been received in which case message reception is complete and no additional frames should be sent.

Note that while it is possible to receive messages from more than one node at a time it is not recommended to do so.

The following diagram demonstrates the general flow of message reception:



In summary:

1. Once a Kick frame is received send a Remote frame. Remote frame should be sent ideally within 100 ms.
2. Wait for a Data frame. If a Data frame is not received send a Remote frame again and continue to do so at a rate of ~100 ms for a period of time and abandon the reception of the message is no Data frame is received.
3. If received Data frame has EOM bit reset then send Remote frame and wait for the next Data frame. Adhere to the same timing constraints as above.
4. If received Data frame has EOM bit set then message reception is complete and no Remote frame should be sent.
5. Remote frame sent has same ID field as that received with kick bit cleared
6. Remote frame will always have DLC = 8
7. Control byte must be inspected for byte count
8. Control byte must be inspected for proper frame count order
9. Control byte with repeated consecutive frame counts should be considered a retransmitted frame from sender and can safely be discarded
10. Message must be fully received regardless of frame count order; a message received with an out of order frame count must be considered invalid

4.3.2 Example

The following shows an example of a transaction. The column labeled FID is the frame ID, it is not related to the protocol but is a means to discussing certain frames within a message transfer. The diagram shows a controlling unit requesting the version of firmware and the ZEUS X1 responding with the firmware version. Details in the following sections will refer to this diagram.

FID	Absolute	Delta	Elapsed	Type	Hex ID	Size	Summary	Data
00000				StdD	1 0000	0		
00001				StdR	0 0000	8	DF	
00002		00:00.013_000		StdD	0 0000	8	DF (EOM)	52-46-00-00-00-00-
00003				StdD	1 0001	0		
00004		00:00.001_000		StdR	0 0001	8	DF	
00005				StdD	0 0001	8	DF	52-46-69-64-30-30-
00006		00:00.001_000		StdR	0 0001	8	DF	
00007		00:00.013_000		StdD	0 0001	8	DF	30-72-66-32-2E-30-
00008		00:00.001_000		StdR	0 0001	8	DF	
00009		00:00.015_000		StdD	0 0001	8	DF	2E-30-30-30-28-42-
00010				StdR	0 0001	8	DF	
00011		00:00.013_000		StdD	0 0001	8	DF (EOM)	29-00-00-00-00-00-

4.3.3 Arbitration Identifier Field

The ZEUS X1 channel uses the CAN protocol CAN 2.0A and as such requires the use of an 11-bit arbitration identifier (ID field). In conjunction with the frame order, the ID field is used to identify the frame type, the sender, and the receiver of a frame. The bit assignment of the ID field is shown in the following picture:

Bit	10	9	8	7	6	5	4	3	2	1	0
Meaning	0-Data 1-Kick	CAN node of sender					CAN node of receiver				

In the example above and referring to FID 0 the ID represents a Kick frame as denoted by the kit bit set. The sender is from address 0 and the destination is to address 1. The value displayed is 1 00000 00001.

4.3.4 Data

Every Data Frame carries 8 bytes of data. The first 7 bytes are payload and the last byte is reserved as a control byte that describes the progress of the data being sent.

In the example above FID 2 is an instance of a Data frame. In this case it carries 2 bytes of data (as decoded by the control byte) and contains the value RF which is the request firmware command.

Control Byte

The control byte is used to convey certain information about a Data frame and assigns certain bits as follows:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit2	Bit1	Bit0
EOM	Number of data bytes			Counter			

Counter Bits

Bits 0 through 3 are reserved for the count of the Data frames comprising a message. This field serves as a sequence number of the data as the message is sent. The counter starts at 1 and increments by one for each additional Data frame sent. Once the count reaches 15 the next count value will be reset to 1. It is this mechanism that allows the detection of a lost Data frame as well as a repeated Data frame. Care must be taken to examine the order of the received Data frames to ensure any repeats are ignored and to consider a message invalid if a Data frame is missing. No conditions permit out of order sequences.

In the example above FIDs 5, 7, 9, and 11 show the counter increasing from 1 to 4 as the message is sent.

Length bits

Bits 4 through 7 represent the number of bytes in the Data frame.

In the example above FIDs 5, 7, 9, and 11 show the number of bytes in the Data frame. The first three Data frames show a length of 7 bytes while the last (FID 11) has only one.

EOM bit

Bit 7 represents the End of Message field. When a Data frame is the last frame in a message this value will be 1.

In the example above FIDs 5, 7, and 9 have the EOM bit reset indicating to the receiver that more data is to follow. The frame at FID 11 has the EOM bit set indicating that the Data frame is the last one.

GETTING STARTED

4.4 Power and CAN Connection

Power connection and CAN communication are provided by a Flexible Flat Cable (FFC) with 16 pins and a 1.0 mm pitch (Figure 9 and 10). To connect the FFC, first remove the cover as shown in Figure 9.

Cable type	FFC cable
Number of pins	16
Pitch	1.0 mm
Cable connection	ZIF / Right angle
Contact	Top

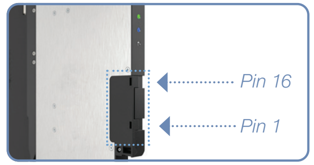


Figure 9: Connection location and specifications of the cable providing power and CAN communication with ZEUS X1.

The table below describes the pin assignment required for the cable appropriate configuration.

	Pin	
CAN	1	CAN_H
	2	CAN_L
	3	GND_CAN
Power Supply 1	4	+48V
	5	+48V
	6	GND_48V
	7	GND_48V
Power Supply 2 (only if the digital outputs are used)	8	+24V
	9	+24V
	10	GND_24V
	11	GND_24V
Digital Output	12	DIGITAL_OUTPUT_1
	13	DIGITAL_OUTPUT_2
Power Ground	14	POWER GROUND
	15	POWER GROUND
	16	POWER GROUND

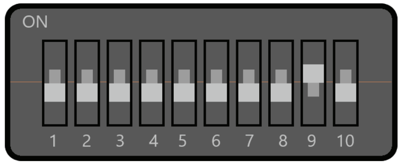
Figure 10: FFC cable pin assignment.

⚠ ATTENTION! Connect the power ground of the ZEUS X1 module to the ground of the instrument housing. Failure to do so will impair the functionality of the capacitive LLD. GND_48V and GND_24V must also be connected.

The CAN node, the Baud Rate, and the CAN Termination must be assigned using the DIP-switches on the Main Board (Figure 11). The address of ZEUS X1 is already preset (default: 1 ON). It must be adjusted if additional units are used.

DIP SWITCH										CAN node
1	2	3	4	5	6	7	8	9	10	
CAN Termination (0 = Off, 1 = On)	0	0	Baud Rate (0 = 500 kBaud, 1 = 125 kBaud)	0	0	0	0	1	0	1
				0	0	0	1	0		2
				...	...	...	...	...		...
				1	1	1	1	1		31

Figure 11: Assignment of CAN node and baud rate.



NOTE: the address 00 is reserved to the master and not recommended for the ZEUS X1 module.

NOTE: CAN termination is generally only needed at the end points of the CAN bus.

5 Programming Basic Functions

5.1 Data Transfer Format

Commands sent to ZEUS X1 begin with two capital letters followed by the relevant parameters. The parameters usually consist of two lower-case letters with the value following. Liquid class parameters described in Chapter 6 have a different format: a space followed by the parameter value. An identification parameter (id) may be defined to allocate the command sent and the response. This may be particularly useful when communicating with several ZEUS X1 modules.

Parameters are initialized with default values after power on and software reset. These values remain valid until new values are defined. All required parameters must be sent with a command. If a parameter is missing the value last sent or the default value will be used.

NOTE: Only one command can be sent per message. Parameters are not sent to a defined address as in standard open CAN protocols. Request commands may be sent anytime.

Parameter tables have been created in order to define and store the values of certain pre-defined parameters, such as the tip parameters, the geometry of the container, the geometry of the instrument or the liquid class of the solutions.

After execution of a command, or in the event of an error, the module returns a confirmation of the command (symbolized by ⇨ in the command tables below). This consists of the command itself, the returned id parameter and the error parameter (er) which contains the error number. If no id parameter is sent along with the command string, the id parameter last sent or the default value is used for the response. The possible errors are listed in the error table (Chapter 5.14.5). An example command string is shown in Figure 12.

Command string sent

GAai10000ge01go01lq01gq0lb0cf1000

-- Command
-- Associated parameters

Response

GAid0001er00

-- Command
-- Default id value
-- response

Figure 12: Example command string and the associated response.

5.2 Validating Connection and CAN Communication

A good way to validate proper connection and functional CAN communication with ZEUS X1 is to send a status request for the firmware version.

Command string sent

RF

-- Command

Example response

RFid0001rf1.00.000(xx)

-- Command
-- Default id value
-- Parameter name
-- response firmware version

Figure 13: Command string required to request a firmware version and example response.

PROGRAMMING BASIC FUNCTIONS

5.3 Precautions Prior to Operation

Proper teaching of ZEUS X1 and accurate definition of the Container Geometry and Deck Geometry parameters is required prior to operation.

5.4 Initialization Commands

Before sending commands that controls ZEUS X1 it is necessary to initialize both the z-drive and the pipetting drive. The z-drive should be initialized first to avoid crashes with objects on the deck. Afterwards, move ZEUS X1 to the waste prior to initializing the pipetting drive. If a pipetting tip is mounted, it will be emptied and discarded during initialization of the pipetting drive.

Command	Parameter	Parameter values	Default value	Name and Description
DI				Initialize Dosing Drive Following steps are performed: 1) The ZEUS X1 plunger drives down to empty any tip that may be present. 2) ZEUS X1 discards the tip. This is optional. 3) The plunger drives to the manufacturer preset dosing zero position.
	id####	0000..9999	0	Identification Number This parameter allocates the command sent and the response. It may be particularly useful when communicating with several ZEUS X1 modules.
	oo	0..1	0	Discard Tip Option. 0 = Discard tip, dosing drive will be initialized then the tip will be discarded. 1=Do not discard tip.
⇨	DIid####er##			See Error Messages
ZI				**Initialize z-Drive** This command moves ZEUS X1 to the manufacturer preset z-origin, which corresponds to the highest possible position.
	id####	0000..9999	0	Identification Number
⇨	ZIid####er##			See Error Messages
SI				Initialize Squeeze Drive This command is optionally called at the start of a method to confirm the squeeze drive is operational and ready for use. If a tip is held when the command is called, the tip will be dropped.
	id####	0000..9999	0	Identification Number
⇨	SIid####er##			See Error Messages

5.5 Z-Drive Commands

The position of the z-drive is defined either by the stop disc of ZEUS X1 if no tip is mounted or by the point of the pipetting tip if a tip has been picked up (Figure 14). It is relative to the preset z-origin, which is the highest possible z-position of the cone of ZEUS X1 (Figure 15). ZEUS X1 maximal z-excursion is 180 mm. If a tip has been picked up, the length of the tip need to be added to the z-excursion to define the current z-position of ZEUS X1.

State	Definition of the z-position	Minimal z-position	Maximal z-position
No tip mounted	Position of the cone of ZEUS X1	0	2000
Tip mounted	Position of the point of the pipetting tip	Length of the tip (in 0.1 mm)	2000 + length of the tip

Figure 14: Minimal and maximal z-position of ZEUS X1 with or without a tip mounted.

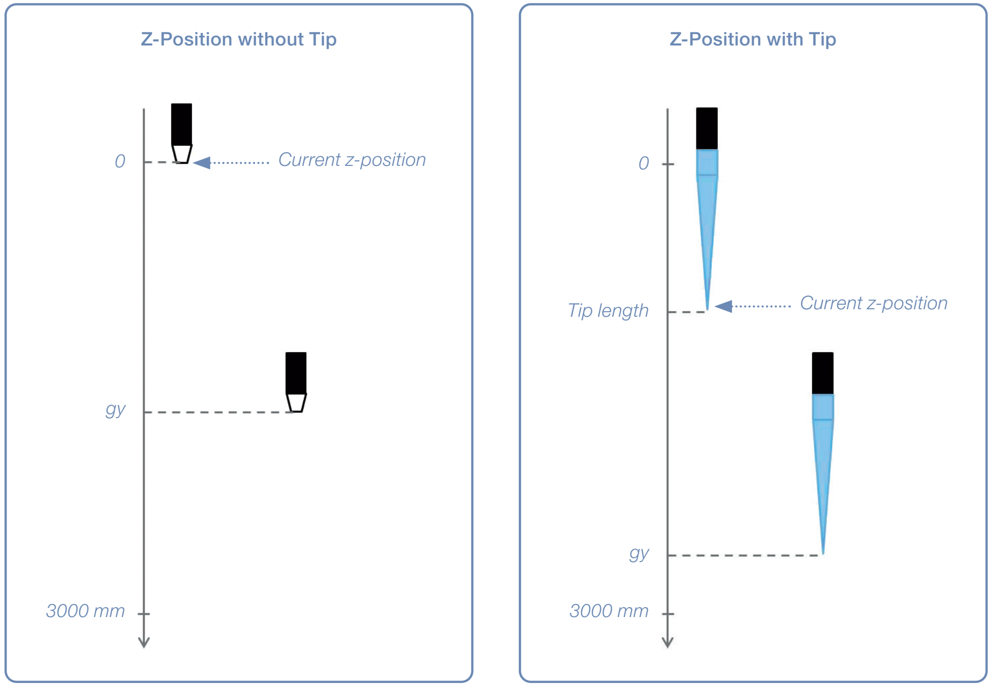


Figure 15: Definition of the z-position of ZEUS X1 with and without tip.

Effective Length (in 0.1 mm)	Tip Size
206	10 µL
206	10 µL with filter
411	50 µL
411	50 µL with filter
506	300 µL
506	300 µL with filter
858	1,000 µL
858	1,000 µL with filter
857	300 µL slim
857	300 µL slim filter

Figure 16: Tip length by volume.

Command	Parameter	Parameter values	Default value	Name and Description
GZ				**Move z-Drive** This command moves ZEUS X1 along the z-axis to a defined position relative to the preset z-origin and at the chosen speed.
	id####	0000..9999	0	Identification Number
	gy#	0000..3000	0	Position of the z-Drive The position of the z-drive is set in increments of 0.1 mm and is relative to the preset z-origin.
	gw	0..1	0	Speed of the z-Drive Two speeds can be set: 0=slow (37 mm/s), 1=normal (350 mm/s) Standard pipetting applications require the normal speed. The slow speed is essentially used when teaching the drive.
	zz	000..3500	0	Selectable Speed of the z-Drive If zz=0 speed from gw is used. If zz>0 this will be the speed of the z-drive set in 0.1 mm/s.
⇨	GZid####er##			See Error Messages

Command	Parameter	Parameter values	Default value	Name and Description
GY				**Move z-Drive to Traverse if Lower** This command moves to traverse height, if current position is lower. If it is already above the traverse height, it will not move.
	id####	0000..9999	0	Identification Number
	te#	0000..3000	0	Traverse Height
	gw	0..1	0	Speed of the z-Drive Two speeds can be set: 0=slow (37 mm/s), 1=normal (350 mm/s). Standard pipetting applications require the normal speed. The slow speed is essentially used when teaching the drive.
	zz	000..3500	0	Selectable Speed of the z-Drive If zz=0 speed from gw is used. If zz>0 this will be the speed of the z-drive set in 0.1 mm/s.
⇨	GYid####er##			See Error Message

Command	Parameter	Parameter values	Default value	Name and Description
ZO				Switch z-Drive Power to Off
	id####	0000..9999	0	Identification Number
⇨	ZOid####er##			See Error Messages

5.6 Tip Handling Commands

The tip handling commands control tip picking and tip discarding. Parameters describing the type of tip and the deck geometry are required to run these commands properly.

⚠ ATTENTION! Make sure to send the right Tip Type Table Index with the tip handling commands. Failure to do so may lead to pipetting errors or damage to ZEUS X1.

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
GT				**Pick-up Tip** Following steps are performed: 1) ZEUS X1 plunger drives down to the initial position if not already there. 2) ZEUS X1 drives to the Beginning of Tip Picking Position defined in the Deck Geometry Table (tm). 3) ZEUS X1 drives further down until a tip has been picked up, as recognized by the sensor detecting tip presence. 4) ZEUS X1 drives up to the End Traverse Height (te) defined in the Deck Geometry Table.
	id####	0000..9999	0	Identification Number
	tt##	0..30	0	Tip Type Table Index See Tip Type Table)Chapter 5.12.3)
	go##	00..99	0	Deck Geometry Table Index See deck geometry table index (Chapter 5.12.2)
⇨	GTid####er##			See Error Messages
GU				**Discard Tip** 1) ZEUS X1 drives down to the tip discard (tr) position defined in the Deck Geometry Table. 2) The plunger drives down to empty the tip. This is optional. 3) The tip is discarded. 4) ZEUS X1 drives up to the minimum traverse height at the end of the command (te) defined in the Deck

Command	Parameter	Parameter values	Default value	Name and Description
	id####	0000..9999	0	Identification Number
	go##	00..99	0	Deck Geometry Table Index See Deck Geometry Table (Chapter 5.12.2)
	dk	0..1	0	Empty Tip Options 0=Empty tip, 1=Plunger does not move.
⇨	GUid####er##			See Error Messages

PROGRAMMING BASIC FUNCTIONS

5.7 Liquid Handling Commands

The liquid handling commands control aspiration and dispensing with ZEUS X1.
The aspiration height may be either fixed when the LLD mode is off or automatically detected if the LLD is activated. The aspiration volume is also sent with this command.

NOTE: To pipette correctly, the Liquid Class parameters need to be accurately defined in the Liquid Class Table.

Command	Parameter	Parameter values	Default value	Name and Description
GA				**Aspiration** The aspiration position is either fixed if the LLD mode is off or automatically detected if the LLD mode is on. If the LLD mode is on (lb1): 1) ZEUS X1 drives to the LLD Search Position (zp). 2) ZEUS X1 drives further down until the liquid level is detected. 3) The set volume (ai) is aspirated. 4) ZEUS X1 drives out of the liquid and up to End Minimum Traverse Height (te) If the LLD mode us off (lb0): 1) ZEUS X1 drives down to the defined liquid surface (cf). 2) Aspirate set volume (ai). 3) ZEUS X1 drives out of the liquid and up to End Minimum Traverse Height (te)
	id####	0000..9999	0	Identification Number
	ai#####	00000..10000	0	Aspiration Volume The volume aspirated is set in increments of 0.1 µL
	ge##	00..99	0	Container Geometry Table Index
	go##	00..99	0	Deck Geometry Table Index
	lq##	00..99	0	Liquid Class Table Index
	gq#	0..1	0	QPM on/off 0=off;1=on
	lb#	0..1	0	LLD on/off 0=off;1=on

Command	Parameter	Parameter values	Default value	Name and Description
	zn#	0..1	0	Search Bottom Mode 0=off, 1=on
	zp####	0000..3000	0	LLD Search Position If the LLD mode is on, this is the z-position (in increments of 0.1 mm) from which the LLD detection will start looking for liquid. zp must always be higher than the real liquid level.
	cf####	0000..3000	0	Liquid Surface If the LLD mode is off, this is the z-position (in increments of 0.1 mm) at which the liquid will be aspirated. It should be defined with a tolerance of ± 0.5 mm.
	ma#####	00000..10000	0	Mix Volume This is the volume (set in increments of 0.1 µL) required to mix the probe.
	mb#####	00001..14280	0	Mix Flow Rate This is the flow rate (set in increments of 0.1 µL/s) at which the probe is mixed.
	dn##	00..99	0	Mix Cycles Number of mixing cycles.
	yi####	0000..2000	0	Mix Z Minimum Height Offset to “ce”, at which mixing cycle stops.
	ap####	0000..1000	0	Mix Delay This is the delay in 0.001 s after mixing is complete.
	yw##	00.15	12	Force during Z movement down to cf. Only used when LLD mode is off. Low force setting will require low speed movement.
	cg####	0000..2000	0	Check height of clot detection above current surface of the liquid in 0.1 mm.
	sf#	0..1	0	Surface Following 0=on, 1=off
	ie####	0000..2000	0	Immersion Depth (ie=0, value taken from stored container geometry).
	yr####	0000..2000	0	Fixed Height (yr=0, value taken from stored container geometry).
⇨	GAid####yl####yc####yd####er##			See Error Messages yl#### is the position of the liquid surface after the command in 0.1mm. yc#### is the LLD height in 0.1mm, 0000 will be returned if LLD mode is off.

Command	Parameter	Parameter values	Default value	Name and Description
				yd#### is the bottom height in 0.1mm, 0000 will be returned if search bottom is off. The values will not be updated if an error occurred.
GD				**Dispensing**
	id####	0000..9999	0	Identification Number
	di#####	0000..10000	0	Dispensing Volume The volume dispensed is set in increments of 0.1 µL.
	ge##	00..99	0	Container Geometry Table Index
	go##	00..99	0	Deck Geometry Table Index
	gq#	0..1	0	QPM on/off, 0=off;1=on
	lq##	00..99	0	Liquid Class Table Index
	lb#	0..1	0	LLD on/off, 0=off;1=on Pressure LLD is not available during dispensing.
	zp####	0000..3000	0	LLD Search Position If the LLD mode is on, this is the z-position (in increments of 0.1 mm) from which the LLD detection will start looking for liquid. zp must always be higher than the real liquid level.
	cf####	0000..3000	0	Liquid Surface If both the LLD mode and the Search Bottom Mode are off, this is the z- position (in increments of 0.1 mm) at which the liquid will be dispensed. It should be defined with a tolerance of ± 0.5 mm.
	zm#	0..1	0	Search Bottom Mode This mode is not possible with 50 µL and 25 µL Axygen tips. 0=off, 1=on
	ma#####	00000..10000	0	Mix Volume This is the volume (set in increments of 0.1 µL) required to mix the probe.
	mb#####	00001..14280	0	Mix Flow Rate This is the flow rate (set in increments of 0.1 µL/s) at which the probe is mixed.
	dn##	00..99	0	Mix Cycles Number of mixing cycles.

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Command	Parameter	Parameter values	Default value	Name and Description
	yi####	0000..2000	0	Mix Z Minimum Height Offset to "ce", at which mixing cycle stops.
	ar####	0000..1000	0	Mix Delay This is the delay in 0.001 s after mixing is complete.
	sf#	0..1	0	Surface Following 0=off, 1=on
	yw##	00..15	12	Force for driving down to yr, yq, and ie for jet/surface and empty/part. Low force setting will require low speed movement.
	ie####	0000..2000	0	Immersion depth (ie=0, value taken from stored container geometry).
	yr####	0000..2000	0	Fixed Height (yr=0, value taken from stored container geometry).
⇨	GDid####yl####yc####yd####er##			See Error Messages yl#### is the position of the liquid surface after the command in 0.1 mm. If fixed height, the cf value will be returned as liquid height yc#### is the LCD height in 0.1 mm, 0000 will be returned if LLD mode is off. yd#### is the bottom height in 0.1 mm, 0000 will be returned if search bottom is off. The values will not be updated if an error occurred.

5.8 Shutdown Procedure

To shut down the unit, simply discard the tip. ZEUS X1 saves all lifetime and cycle counters in real time.

5.9 Volume Check Commands

The Volume Check commands are used to calculate the volume present in the container before or after pipetting. The calculation relies on the accurate definition of the container geometry and the use of the proper container geometry table.

Command	Parameter	Parameter values	Default value	Name and Description
GJ				**Calculate Container Volume** Calculate the volume present in the container based on the container geometry and the liquid level. The liquid level is detected by LLD if the LLD mode is on or defined.
	id####	0000..9999	0	Identification Number
	ge##	00..99	0	Container Geometry Table Index
	go##	00..99	0	Deck Geometry Table Index
	lq##	00..99	0	Liquid Class Table Index
	lb#	0..1	0	LLD on/off; 0=off; 1=on
	zp####	0000..3000	0	LLD Search Position If the LLD mode is on, this is the z-position (in increments of 0.1 mm) from which the LLD detection will start looking for liquid.
	cf####	0000..3000	0	Liquid Surface If the LLD mode if off, this is the z-position (in increments of 0.1 mm) at which the liquid will be aspirated. It should be defined with a tolerance of ± 0.5 mm.

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
⇨	GJid####yl####aw########er##			**See Error Messages** yl#### is the position of the liquid surface after the command in 0.1 mm (values between 0000-3000). The values will not be updated if an error occurred. aw######## is the calculated volume in the container in 0.1 µL.
GN				**Calculate Container Volume after Pipetting** Calculate the volume present in the container after pipetting and uses the parameters defined in GA or GD. It may be used after GA error 71 not enough liquid present.
	id####	0000..9999	0	Identification Number
⇨	GNid####yl####aw########er##			See Error Messages yl#### is the position of the liquid surface after the command in 0.1 mm (values between 0000-3000). The values will not be updated if an error occurred. aw######## is the calculated volume in the container in 0.1 µL.

5.10 Status Request Commands

The status request commands are used to request the current value of a specific parameter, and various other statuses.

Command	Parameter	Parameter values	Default value	Name and Description
RE				**Request error code** The last saved error messages can be retrieved. The error buffer is automatically voided when a new command is started.

Command	Parameter	Parameter values	Default value	Name and Description
	id####	0000..9999	0	Identification Number
⇨	REid####er##			See Error Messages
RF				**Request Firmware Version**
	id####	0000..9999	0	Identification Number
⇨	RFid####rf'..'			rf'..' is the returned firmware version, for example: RFid0000rfNGC Runtime V1.5.0.275 6606664 Rev X
RA				Request Parameter Value
	id####	0000..9999	0	Identification Number
	ra&&			Parameter Name The parameter name consists of two lower case letters. For example, the command string to request the value of the aspiration volume is RAraai.
⇨	RAid####&&'..'			&&'..' is the returned parameter value. For example, the response to the request for the value of the aspiration volume is RAid0001ai01000.
QW				**Request Instrument Initialization Status**
	id####	0000..9999	0	Identification Number
⇨	QWid####qw#			qw# is the returned initialization status 0 = the z-drive or / and the dosing drive is not initialized 1 = both the z-drive and the dosing drive are initialized
VP				**Request Name of Last Faulty Parameter**
	id####	0000..9999	0	Identification Number
⇨	VPid####vp'..'			vp'..' is the returned syntax error. This command is especially useful to identify a parameter that is out of range.

Command	Parameter	Parameter values	Default value	Name and Description
RT				**Request Tip Presence Status**
	id####	0000..9999	0	Identification Number
⇨	RTid####rt#			rt# is the tip presence status (0 = no tip, 1 = tip present).
QT				**Request Technical Status**
	id####	0000..9999	0	Identification Number
⇨	QTid####pn'..'rx'..'sn'..'ph'..'rs'..'sh'..'			pn'..' is the returned channel part number rx'..' is the returned channel revision sn'..' is the returned channel serial number ph'..' is the returned head part number rs'..' is the returned head revision sh'..' is the returned head serial number
RZ				**Request Absolute z Position**
	id####	0000..9999	0	Identification Number
⇨	RZid####gy####rz'..'			gy#### is the returned height of the stop disc or tip if installed in increments of 0.1 mm. rz'..' returns 2 values separated by a blank. 1st value is the returned commanded height of the stop disc in increments of 0.1mm. 2nd value is the returned actual height of the stop disc in increments of 0.1 mm.
RV				**Request Cycle Counter** na, nb, nc and nd counters are stored on the head and stay with the head if replaced. nz counter stays with the channel.
	id####	0000..9999	0	Identification Number
⇨	RVid####na'..'nb'..'nc'..'nd'..'nz'..'			na'..' indicates the number of tip pickup cycles (10 char) nb'..' indicates the number of tip discard cycles (10 char) nc'..' indicates the number of aspiration cycles (10 char) nd'..' indicates the number of dispense cycles (10 char) nz'..' indicates the lifetime of the z-axis. It is measured as the cumulated distance run in 0.01 mm. (11 char)

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
RY				**Request Lifetime Counter**
	id####	0000..9999	0	Identification Number
⇨	RYid####ry'..'			ry'..' indicates the lifetime of the plunger seal (11 char). It is measured as the cumulated distance run in 0.01 mm by the plunger seal during aspiration, dispensing and mixing.

Command	Parameter	Parameter values	Default value	Name and Description
RQ				Request Instrument status
	id####	0000..9999	0	Identification Number
⇨	RQid####rq&&&&			qq&&&& is the returned instrument status 1st character Bit 3 Bit 2 Bit 1 Bit 0 **1st character:** Bit 0 : stop Bit 1 : single step mode Bit 2 : Test mode Bit 3 : 2nd character Bit 3 Bit 2 Bit 1 Bit 0 **2nd character:** Bit 0 : control process 0 Bit 1: control process 1 Bit 2 : control process 2 Bit 3 : Download mode 3rd character Bit 3 Bit 2 Bit 1 Bit 0 **3rd character:** Bit 0 : error EEPROM comm. Fl. EEPROM Bit 1 : error wrong FW download Fl. EERROM Bit 2 : error pres. Sensor adjustment: error RAM Test Bit 3 : 4th character Bit 3 Bit 2 Bit 1 Bit 0 **4th character:** Bit 0 : error download Bit 1 : error program Bit 2 : Bit 3 : error EERPOM checksum

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Command	Parameter	Parameter values	Default value	Name and Description
XB				Request Liquid Class Revision
	id####	0000..9999	0	Identification Number
⇨	XBid####xa‘..‘			xa’..’ is the returned revision of the liquid class (#.##.##)

Command	Parameter	Parameter values	Default value	Name and Description
RM				**Request PLD Version**
	id####	0000..9999	0	Identification Number
⇨	RMid####rm'..'			rm'..' is the returned PLD version, for example: RMid0000rmNGC_CHANNEL_CTRL V0.0.0.29 6606110-01 REV X1<FS>
RG				**Request Head Presence**
	id####	0000..9999	0	Identification Number
⇨	RGid####rd#			rg# is the returned head 0=no head detected 1=1 mL ZEUS X1 head present 2=Reserved for future enhancements
RU				**Request Voltages on the Channel**
	id####	0000..9999	0	Identification Number
⇨	RUid####vm###vn###vo###			Response is in 0.1 volts vm### is the returned 48 volt bus vn### is the returned 5 volt bus vo### is the returned 3.3 volt bus
RD				**Request Absolute Dispense Position**
	id####	0000..9999	0	Identification Number
⇨	RDid####di#####			di##### is the returned positon of dispense drive in increments of 0.1 µL.
TB				**Request Head Temperature**
	id####	0000..9999	0	Identification Number
⇨	TBid####tb####			tb#### is the temperature of the pipette head in increments of 0.1° C.
RW				**Request Sensor Status**
	id####	0000..9999	0	Identification Number
⇨	RWid####rw####			rw#### is the returned status of each sensor 0=off, 1=on 1st value: Not used, 0 will be returned 2nd value: Z Drive home sensor 3rd value: Not used, 0 will be returned 4th value: Tip presence sensor
RO				**Request Firmware Download Date**
	id####	0000..9999	0	Identification Number
⇨	ROid####ao'..'			ao'..' indicates the date of download (YYYY-MM-DD) (10 char)

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
PQ				**Request PLD Download Date**
	id####	0000..9999	0	Identification Number
⇨	PQid####ao'..'			ao'..' indicates the date of download (YYYY-MM-DD) (10 char)

5.11 Special Commands

Command	Parameter	Parameter values	Default value	Name and Description
AB				**Emergency Stop ON** The Emergency stop is only software-based. It may be used to stop ZEUS X1 to avoid user injuries. For example if coupled to a cover closing.
	id####	0000..9999	0	Identification Number
⇨	ABid####er##			See Error Messages
AW				Emergency Stop OFF
	id####	0000..9999	0	Identification Number
⇨	AWid####er##			See Error Messages
OU				**Switch Digital Output (24V, 300mA)**
id####		0000..9999	0	Identification Number
	ou#	0..1	0	Digital Output 1 Status 0=off;1=on
	ov#	0..1	0	Digital Output 2 Status 0=off;1=on
⇨	OUid####er##			See Error Messages
SL				**Switch the Status LED Manually** Per default, the middle LED is blue during aspiration and dispensing and red in case of an error. This default setting cannot be overwritten but it is possible to define additional status.
	id####	0000..9999	0	Identification Number
	sl#	0..1	0	Status Blue LED 0=off;1=on

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
	sk#	0..1	0	Status Red LED 0=off;1=on
⇨	SLid####er##			See Error Messages
AT				**Test Mode Command**
	id####	0000..9999	0	Identification Number
	at#	0..1	0	Test Mode Status 0 = off, 1 = on If the test mode is switched on, commands are acknowledged but not carried out (except the status requests).
⇨	ATid####er##			See Error Messages
AO				**Set Firmware Download Date** This command should used after a firmware update.
	id####	0000..9999	0	Identification Number
⇨	AOid####ao'..'			ao'..' indicates the date of the download (YYYY-MM-DD) (10 char)
PO				**Set PLD Download Date** This command should used after a PLD update.
	id####	0000..9999	0	Identification Number
⇨	POid####ao'..'			ao'..' indicates the date of the download (YYYY-MM-DD) (10 char)

5.12 Parameter Tables

Parameter tables have been created in order to define and store the values of certain pre-defined parameters, such as the tip parameters, the geometry of the container, the geometry of the instrument, or the liquid class of the solutions. The parameter tables are saved on a non-volatile memory with a limited number of writing cycles. As a consequence, the parameter tables should not be sent to ZEUS X1 per default during initialization and parameter comparison should be performed by the controlling software.

5.12.1 Container Geometry Table

All parameters required to describe the geometry of a vessel (Figures 16 and 17) used are summarized in the Container Geometry Table. It includes the type of vessel bottom and the vessel dimensions. Each vessel is described in its respective table, which is identified by Container Geometry Table Index.

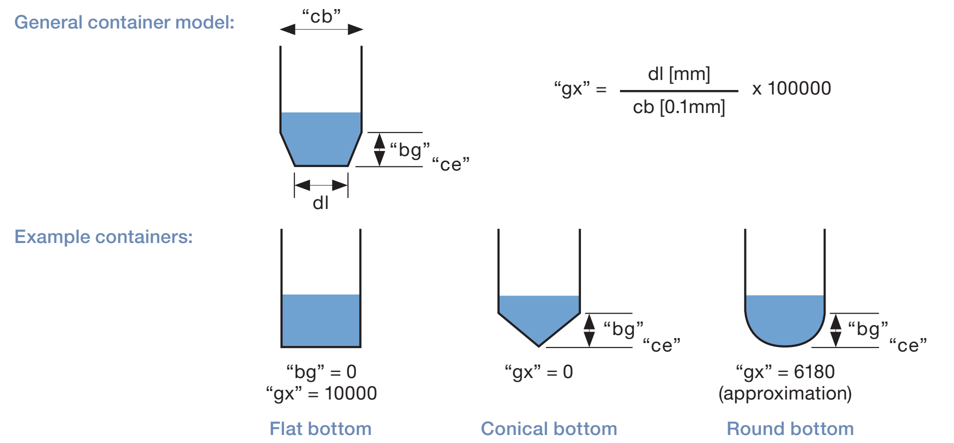

Figure 16: Container parameter required for aspirating.

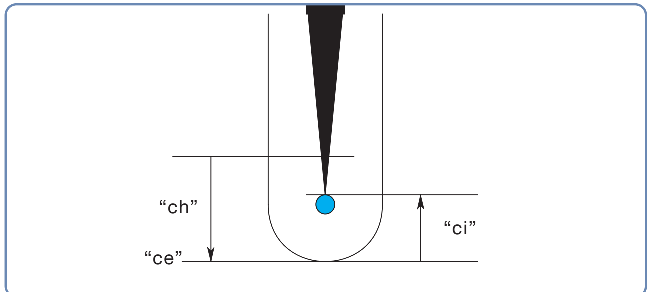

Figure 17: Container parameters required for dispensing if the Search Bottom mode is activated.

Command	Parameter	Parameter values	Default value	Name and Description
GC				**Set Container Geometry Parameters**
	id####	0000..9999	0	Identification Number
	ge##	00..99	0	Index of the Container Geometry Table
	cb###	000..999	0	Diameter for Round Container In increments of 0.1 mm.
	bg####	0000..2000	0	Height of the Container Bottom Measured from "ce" in 0.1mm.

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Command	Parameter	Parameter values	Default value	Name and Description
	gx#####	00000..10000	0	Section of the Container Bottom This parameter describes the geometry of the tube bottom (Figure 16). gx = 10'000 for a flat bottom gx = 0 for a conical bottom gx = 6'180 for a round bottom
	ce####	0000..3000	0	Position of the Container Bottom This parameter defines the z-position (in increments of 0.1 mm) of the container bottom. It corresponds to the maximal immersion position. If the LLD mode is active the liquid level will be search until this position.
	ie####	0000..2000	0	Immersion Depth Depth (in increments of 0.1 mm) of penetration of the tip below the liquid surface cf.
	yq####	0000..2000	0	Leaving Height Height (in increments of 0.1 mm) above the liquid surface cf during which ZEUS X1 drives slowly to penetrate in or exit from the liquid.
	yr####	0000..2000	0	Jet Height Height (in increments of 0.1 mm) above the liquid surface cf at which the liquid will be dispensed in the jet mode, ie. whithout liquid contact.
	ch####	0000..2000	0	Start of Height Bottom Search This is the distance (in increments of in 0.1 mm) above the container bottom ce from which the container bottom will be automatically detected if the search bottom mode is activated.
	ci####	0000..2000	0	Dispense Height after Bottom Search If the Search Bottom Mode is on, this is the height above the container bottom ce at which dispensing starts in increments of 0.1 mm.
⇨	GCid####er##			See Error Messages

Command	Parameter	Parameter values	Default value	Name and Description
GB				**Request Container Geometry Parameters**
	id####	0000..9999	0	Identification Number
	ge##	00..99	0	Index of the Container Geometry Table
⇨	GBid####ge##cb###bg####gx#####ce####ie####yq####yr####ch####ci####			

5.12.2 Deck Geometry Table

All parameters required to describe the geometry of the instrument deck (Figure 18) on which ZEUS X1 is integrated are summarized in the Deck Geometry Table. The deck geometry table includes the traverse height, the tip pick up, and the discard height. Several Deck Geometry Tables may be defined within one application, for example if different Traverse Heights are required with or without tips, if different tubes heights are used or several tip storage positions. Each deck is described in its respective table, which is identified by the Index of the Deck Geometry Table.

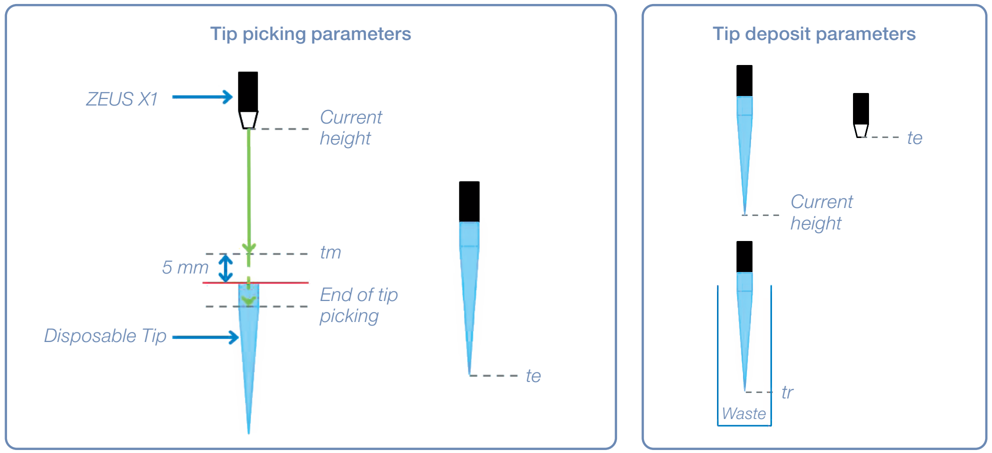

Figure 18: Description of the Deck Geometry parameters during tip picking and deposit.

PROGRAMMING BASIC FUNCTIONS

Command	Parameter	Parameter values	Default value	Name and Description
GO				**Set Deck Geometry Parameters**
	id####	0000..9999	0	Identification Number
	go##	00..99	0	Index of the Deck Geometry Table
	te####	0000..3000	0	End Traverse Position Traverse Position at the end of a command in increments of 0.1 mm. This is also the traverse height at which the x- and y-movements will be performed.
	tm####	0000..2000	0	Beginning of Tip Picking Position This is the z-position (in increments of 0.1 mm) at which the tip picking process starts. A control is implemented to detect whether a tip is already present or not. This position should be set at least 5 mm above the tip.
	tr####	0000..3000	0	Position of Tip Deposit Process This z-position (in increments of 0.1mm) should be set to limit splashes of remaining liquid and cross contamination on your instrument (Figure 19).
⇨	GOid####er##			See Error Messages
GR				**Request Deck Geometry Parameters**
	id####	0000..9999	0	Identification Number
	go##	00..99	0	Index of the Deck Geometry Table
⇨	GRid####go##te####tm####tr####			

The selected tip deposit heights should be large enough to account for height variations and tolerances on the targeted tip deposit location.

Tip Type	1000 µL	Slim	300 µL	50 µL	10 µL
Tip Part Number	98463-XX	98467-XX	98461-XX	98459-XX	98457-XX
Minimum Deposit Height	6.2 mm		4.2 mm		2.2 mm

Figure 19: Minimum tip deposit height by tip type. The deposit height is measured from the end of the stop disc to the surface the tip rests on.

5.12.3 Tip Type Table

The different types of pipetting tips are described in the Tip Type Table. It includes the volume and the type of pipetting tip used. Please contact Hamilton if you require any additional type of tips.

⚠ ATTENTION! ZEUS X1 does not include an automatic recognition of the tip type. Make sure to use the Tip Type Index of the tip which is actually picked up.

Tip Type Table for ZEUS X1 with CO-RE II tip attachment:

Index (tt)	Tip Description	Tip Part Number
00	10 µL CO-RE II tip, conductive, non-filtered	235900
01	10 µL CO-RE II tip, conductive, filtered	235901
02	50 µL CO-RE II tip, conductive, non-filtered	235966
03	50 µL CO-RE II tip, conductive, filtered	235948
04	300 µL CO-RE II tip, conductive, non-filtered	235902
05	300 µL CO-RE II tip, conductive, filtered	235903
06	1000 µL CO-RE II tip, conductive, non-filtered	235904
07	1000 µL CO-RE II tip, conductive, filtered	235905
08	300 µL CO-RE II slim tip, conductive, non-filtered	235806
09	300 µL CO-RE II slim tip, conductive, filtered	235647

The choice of tip should be adjusted to the type of container (Figure 20).

Container Diameter	Example of Container	Required x-y-Positioning Accuracy	Type of Tip
d ≥ 5.5 mm	96-well microtiter plate	0.5 mm	All
3.0 mm ≤ d ≤ 5.5 mm	384-well microtiter plate	0.5 mm	10, 50 and 300 µL tips
d ≤ 1.5 mm	1536-well microtiter plate	0.1 mm need to be taught	10 µL tips

Figure 20: Recommended tips for standard container diameter.

PROGRAMMING BASIC FUNCTIONS

5.12.4 Liquid Class Table

The different types of Liquid Classes are described in the Liquid Class Table. A liquid class contains all parameters required for accurate pipetting, including QPM parameters. These parameters are set based on gravimetric measurements obtained for dispensing of a specified liquid in defined conditions. Several predefined liquid classes are provided with your ZEUS X1 as shown in the table below. If your application is not covered by one of the predefined liquid classes, please contact Hamilton for a custom-made solution. Alternatively, you can create a new liquid class following the instructions described in Chapter 6.

Index (lq)	Medium	Dispensing Mode	Tip	LLD mode
00	Water (Hamilton Verification Solution)	Jet empty	50 µL	cLLD
01	Water (Hamilton Verification Solution)	Jet empty	300 µL	cLLD
02	Water (Hamilton Verification Solution)	Jet empty	1000 µL	cLLD
03	Water (Hamilton Verification Solution)	Jet part	50 µL	cLLD
04	Water (Hamilton Verification Solution)	Jet part	300 µL	cLLD
05	Water (Hamilton Verification Solution)	Jet part	1000 µL	cLLD
06	Serum	Jet empty	50 µL	cLLD
07	Serum	Jet empty	300 µL	cLLD
08	Serum	Jet empty	1000 µL	cLLD
09	Serum	Jet part	50 µL	cLLD
10	Serum	Jet part	300 µL	cLLD
11	Serum	Jet part	1000 µL	cLLD
12	Ethanol (100%)	Jet empty	50 µL	pLLD
13	Ethanol (100%)	Jet empty	300 µL	pLLD
14	Ethanol (100%)	Jet empty	1000 µL	pLLD
15	Glycerin (80%)	Jet empty	50 µL	cLLD
16	Glycerin (80%)	Jet empty	300 µL	cLLD
17	Glycerin (80%)	Jet empty	1000 µL	cLLD

5.13 Run Error Messages

Error	Error Message	Trigger/Description	Possible Cause
General			
00	No Error		
Transfer Check			
20	No Communication to EEPROM	I²C Bus Driver	I²C Bus or EEPROM not working
25	Search Bottom Start Out of Range	Unreachable Z Position	Bad input, wrong tip selected
26	Search Bottom End Out of Range	Unreachable Z Position	Bad input, wrong tip selected
27	Bottom Not Found	Bottom Search Failed	No solid surface in the search range
Syntax Check			
30	Undefined Command	Syntax Check	Unknown command
31	Undefined Parameter	Syntax Check	Unknown parameter
32	Parameter Out of Range	Syntax Check	Parameter outside of permitted range
33	Internal Range Error	Syntax Check	
34	Z Drive Range Error	Syntax Check	A combination of parameters are outside of permitted range. E.G. Container bottom and start search height are above accessible range of tip.
General Errors During Execution of Commands			
35	Voltages Outside of Permitted Range	Voltage Monitoring	Hardware not working properly
36	Emergency Stop During Movement		
37	No Communication with Head		
38	Empty Liquid Class Loaded		
39	Not Enough Memory		
Parallel Activity Errors			
40	No Parallel Processes Pemitted	Status Function	Two or more commands sent for the same protocol process
Dispensing Drive			
50	Initialization Failed	Init. Sensor	Hardware not working
51	Drive Not Initialized	Status Function	Command sent before drive initialized

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Error	Error Message	Trigger/Description	Possible Cause
52	Movement Error	Step Monitoring	Step Loss
53	Maximum Volume in Tip Reached	Step Monitoring	
54	Position Out of Permitted Area	Position Monitoring	
55	Volume Check Failed		"ai" > tip size "ai" < 1st base point of correction curve "ai" > 8th base point of correction curve Tip size < 8th base point of correction curve "ma" > tip size
56	Conductive Check Failed		Non-conductive tip used with cLLD-liquid class
57	Filter Check Failed		Filtered tip used with non-filtered liquid class. Non-filtered tip used with filtered liquid class
58	Unable to Reach Pressure	Leak test failed	Bad seal
59	Unable to Reach Vacuum	Leak test failed	Bad seal
Errors During Dowload			
41	Data in Intel Hex Line Sent are Wrong	Intel Check-Sum Wrong	Test of intel hex check sum yielded data error
42	Flash EPROM Cannot be Programmed	Programming Error	Flash EPROM or processor card not Working
Z-Drive			
60	Initialization Failed	Init. Sensor	Hardware not working
61	Drive Not Initialized	Status Function	Command sent before drive initialized
62	Movement Error	Step Monitoring	Step loss
63	Not Possible Z-Position		Not possible to travel to "cf-yr"
64	Not Possible Z-Position		Not possible to travel on "gy"
65	Not Possible Z-Position		Not possible to travel on "te"
66	Not Possible Z-Position		Not possible to travel on "ce"
67	Not Possible Z-Position		Not possible to travel on "cf"
68	Not Possible Z-Position		Not possible to travel on "zp"
69	Not Possible Z-Position		Not possible to travel on "tr"

Error	Error Message	Trigger/Description	Possible Cause
Liquid Level Detection			
70	No Liquid Level Found	LLD Sensor	No liquid present, wrong sensitivity used.
71	Not Enough Liquid Present	Monitoring of Maximal Access Range	Immersion depth or surface following position below minimal access range
74	Liquid at a Not Allowed Position Detected	LLD Sensor	
Error On Tip Handling			
75	No Tip Picked Up		No tip present at position (tip pick-up) No tip picked up (module commands)
76	Tip Present when it Should Not Be		A fresh tip cannot be picked up, because one is already present. Tip stuck, eject sleeve stuck.
79	Solenoid Failed to Latch		
Error During Liquid Handling			
80	Clot Detected During		
81	Empty Tube During		
82	Foam Detected During		
83	Capacitive Clot Detected		
85	ADC Error		
86	Leak Detected	Leak test failed	Dirty stop disc or teaching needle, bad CORE II o-ring, bad seal.

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5.14 Firmware Download

5.14.1 Typical Firmware Update Process

It is possible to upload new firmware update on ZEUS X1 according to the typical process described below.

Command	Answer	Description
AP		Switch over to download mode, if the module is not yet in that mode. No command response follows.
RQ	RQrq****	Check that the module is in download mode. The download mode bit must be set in instrument status.
DE	DEer'...'	Delete Flash EPROM
DPdp'........'	DPer'...'	Import new firmware line after line. Each line is described by the parameter dp.
DPdp'.......'	DPer'...'	This step is repeated until the entire program has been loaded
DC	DCer'...'	Calculate check sums to verify that the program has been correctly loaded.
AP		Switch to loaded program. No command response follows.
RQ	RQrq****	Check whether the module has switched to the actual firmware. The download mode bit must be reset.
AOaoYYYY-MM-DD	AOer00	Specify the date reprograming took place. This is an optional step.
RF	RFrf'...'	Request the version of the PLD. This is an optional step.

After updating firmware, call AO to update the firmware download date.

5.14.2 Download Commands

Command	Parameter	Parameter values	Default value	Name and Description
DE				Clear Flash EPROM
DP				Import FW file fragment
	dp'...'	512 Chars Maximum		File Fragment
DC				**Control Download** Calculate the check sums and verify that the program has been correctly loaded.

Command	Parameter	Parameter values	Default value	Name and Description
PE				Clear PLD Flash
	pp	0	0	Target PLD
PP				Import PLD File Fragment
	pp	0	0	Target PLD
	dp'...'	512 Chars Maximum		File Fragment
PC				Program PLD and Calculate Checksums
	pp	0	0	Target PLD

For intel HEX files the dp parameter consists of a single line of text from the HEX file not including the carriage return/line feed. Alternatively, a number of lines from the file can be sent as long as entire lines are sent and delimited by a carriage return/line feed.

The following is an example of Intel HEX file content:

```
:020000040048B2
:1000000000840201955510051FD4D00A5FC4D0040
:10001000D1FC4D0055FC4D0079FC4D000000000066
:100020000000000000000000000000051FD4D0035
:1000300051FD4D000000000051FD4D0051FD4D00EF
:1000400051FD4D0051FD4D0051FD4D0051FD4D0044
:1000500051FD4D0051FD4D0051FD4D0051FD4D0034
:10024000666004F1080008F035FEDFF86C0723262D
:1002500000F1080200F12001226000F1AC034030FF
:100260006160A06004F1A400236300210160142 2F6
:10027000152325214260322283603323016134211A
```

The first three lines of the HEX file can be sent using the DP command either line by line like so:

```
DPdp:020000040048B2
DPdp:100000000008402019555100 51FD4D00A5FC4D0040
DPdp:10001000D1FC4D0055FC4D0079FC4D000000000066
```

The same three lines can be concatenated like so:

```
DPdp:020000040048B2<CR><LF>:10000000000840201955510051FD4D00A5FC4D0040
<CR><LF>:10001000D1FC4D0055FC4D0079FC4D000000000066
```

Whichever method is used the limitation of 512 characters is imposed.

5.14.3 Status Requests

Refer to RQ command for status request.

5.14.4 Typical PLD Update Process

Command	Answer	Description
AP		Switch over to download mode, if the module is not yet in that mode. No command response follows.
RQ must	RQrq****	Check that the module is in download mode. The download mode bit be set in instrument status.
PE	PEer00	Delete PLD flash
PPdp'...'	PPer00	Import new PLD code fragment. This step should be repeated until entire PLD program has been loaded.
PC		Perform PLD programming. This step will take approximately 40 seconds.
AP		Switch to loaded program. No command response follows.
RQ	RQrq****	Check whether the module has switched to the actual firmware. The download mode bit must be reset.
POpoYYYY-MM-DD	POer00	Specify the date reprograming took place. This is an optional step.
RM	RMrm'...'	Request the version of the PLD. This is an optional step.

Note: There are two instance of AP that have slightly different descriptions.

For the yellow line in 5.14.4, here is an additional note:

PLD code files are not text. This means that they must be converted to a text representation prior to reprogramming. The following C code can perform the conversion:

```
char* PldFile = "...\6606112-01_I2C.iex";
FILE* File = fopen(PldFile, "rb");
fseek(File, 0, SEEK_END);
long FileSize = ftell(File);
fseek(File, 0, SEEK_SET);

unsigned char* FileContents = new unsigned char[FileSize];
fread(FileContents, 1, FileSize, File);
fclose(File);

const int MaximumFileLength = 32;
char FileFragment[MaximumFileLength + 1]; //+1 for null term
for (int BytesProcessed = 0; BytesProcessed < FileSize;)
{
   for (int j = 0; (BytesProcessed < FileSize) && (j < MaximumFileLength); j += 2)
      sprintf(&FileFragment[j], "%02X", FileContents[BytesProcessed++]);

   //FileFragment contains the 'dp' parameter value to be sent in the PP command.
}

delete []FileContents;
```

5.14.5 Special Commands

Command	Parameter	Parameter values	Default value	Name and Description
AP				**Switch to loaded Program** After successful download, this command switches to the new program. This command is not acknowledged.

6 Creating a Liquid Class

6.1 Concept of Liquid Classes

A liquid class (LC) is a set of parameters determining the aspiration and dispensing behavior of the pipetting module for a specific liquid. The LC depends on the physical properties of the liquid (e.g., viscosity or vapor pressure), the tip type and the selected pipetting mode. It is also influenced by environmental effects such as temperature, pressure, and humidity. An individual liquid class is required for each type of liquid, tip type and pipetting mode. Liquid classes ensure accurate and precise pipetting.

Several predefined liquid classes are provided with your ZEUS X1 (see Chapter 5.12.4). If your application is not covered by one of the predefined liquid classes, please contact Hamilton for a custom-made solution. Alternatively, you can create a new liquid class following three steps described below:

1) Set the LC parameters for your specific application (either based on a predefined LC or by creating a new set of parameters). The right choice of parameters ensures high precision.

2) Perform gravimetric calibration for the new LC. This step ensures high accuracy.

3) Specify the associated settings for Qualitative Pipetting Monitoring (QPM).

NOTE: If LC parameters have been changed (step 1), then the gravimetric calibration and QPM parameters must be adjusted as well to ensure proper pipetting (steps 2 and 3).

6.2 Setting the Liquid Class Parameters

As a first step, the pipetting mode should be selected. The choice of the pipetting mode strongly influences the instrument’s behavior. Three different modes are available for aspiration (as illustrated in Figure 21) and four modes for dispensing (Figure 22).

“Simple” aspiration is used for most of the standard cases. Activate “Empty Cup” mode to aspirate all the volume in the container (specify a volume larger than what is expected to be in the container). In this case, the tip will follow the falling liquid level to the bottom of the container, staying there for the rest of the aspiration. Use “Consecutive” mode if the tip has already aspirated liquid before (e.g., 3 different aspirations before the dispensing step).

NOTE: For Fluid Handling Best Practices, visit: www.hamiltoncompany.com/LiquidHandlingBestPractices

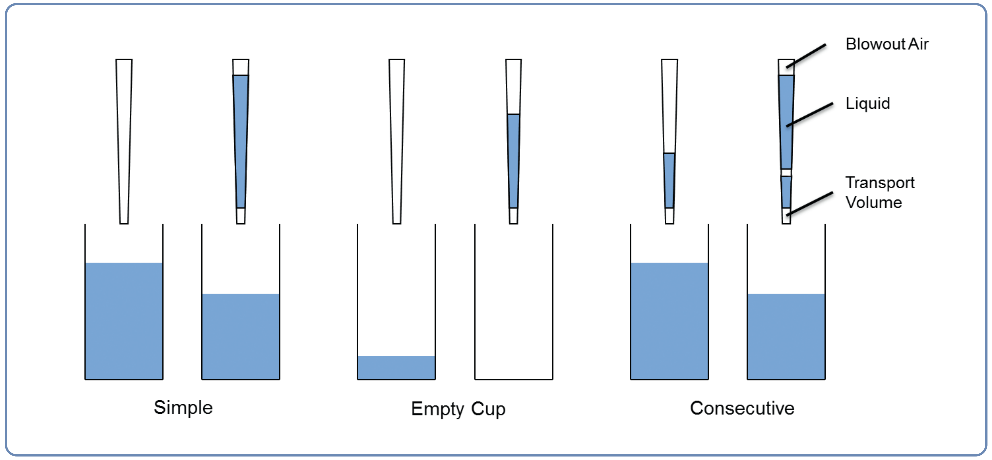

Figure 21: Schematics of possible aspiration modes. Each mode activates a different set of parameters.

“Jet empty” dispense mode is used for dispensing all the liquid in a jet without touching the surface to avoid cross-contamination. “Jet part” mode dispenses only a part of the liquid in a jet. If “Surface empty” mode is active, the tip touches the surface and dispenses all the liquid. “Surface part” mode leaves a residual volume in the tip. Surface modes are recommended for dispensing small volumes (<20µL).

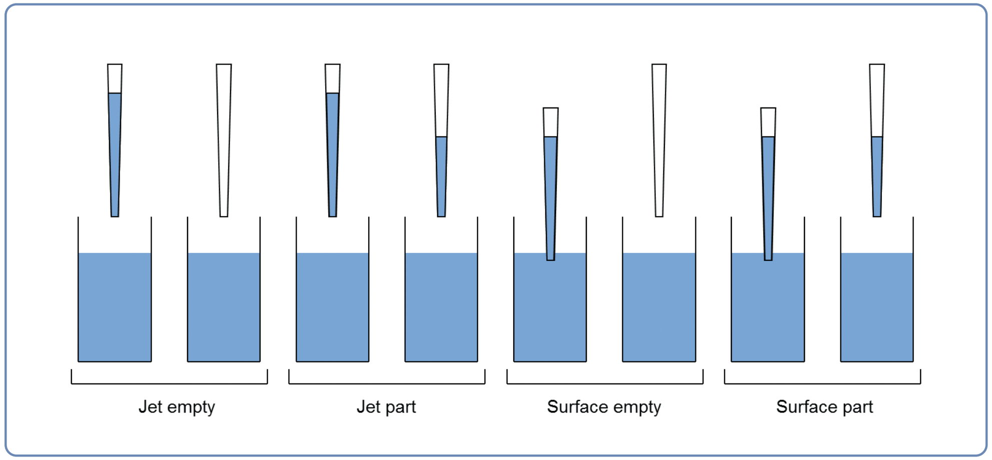

Figure 22: Schematics of possible dispensing modes. Each mode activates a different set of parameters.

Next, the relevant background parameters for a pipetting cycle have to be set. All liquid class parameters are described in the table below. To start with, choose a predefined liquid class which is similar to the liquid you would like to handle. After that, run a test and visually inspect the quality of the pipetting process (e.g. using a high-speed camera). If the pipetting behavior is fine, volume calibration can be done as described in the next section. Otherwise you might adjust some of the liquid class parameters to optimize the pipetting properties. Several examples of situations and possible solutions are listed below.

Situation	Possible solution
Unwanted air inside the tip after aspiration	Reduce flow rate; increase settling time
Drop formation at the tip orifice	Pre-wet tip by adding over-aspirate volume; add transport volume; add stop back volume; activate ADC
Liquid sticks to the outside of the tip	Reduce swap speed
Residual liquid volume inside the tip after dispensing	Reduce flow rate; add blowout volume; reduce stop flow rate
Liquid splashes during dispensing	Reduce flow rate, lower dispense height.

Command	Parameter	Parameter range	Default value	Name and Description
GL				**Set Liquid Class Parameter**
	id####	0000..9999	0	Identification Number
	lq##	00..99	0	Liquid Class Table Index
	uu#	0..1	0	Liquid Class for Filter Tips? (0 = no, 1 = yes)
				Aspiration
	#	0..2	0	Aspiration mode (0 = simple; 1 = empty cup; 2 = consecutive)
	#####	00001..14280	0	Flow Rate in 0.1 µL/s This parameter corresponds to the plunger speed during aspiration or dispense. The flow rate is the most critical parameter, influenced by tip geometry, liquid viscosity, density and vapor pressure: small tip opening -> slow flow rate, high viscosity -> slow flow rate, high density -> slow flow rate, high vapor pressure -> fast flow rate

Command	Parameter	Parameter range	Default value	Name and Description
	####	0000..9999	0	Over-Aspirated Volume in 0.1 µL After aspirating the required volume, this additional volume is aspirated and dispensed again immediately to pre-wet the tip (in simple mode). The effect is that the meniscus is balanced. It is used for accurate pipetting of small volumes (<10 µL).
	#####	00000..10000	0	Transport Volume in 0.1 µL Air is aspirated at the end of the aspiration or dispensing and is automatically dispensed again as an extra volume during the following dispense step. It is influenced by tip geometry and liquid vapor pressure. Prevents droplet formation during transport. This parameter is helpful when pipetting volatile substances.
	#####	00000..10000	0	Blowout Air Volume in 0.1 µL This air volume is taken up first during aspiration. It is blown out at the end of dispensing (empty mode only). It is influenced by liquid viscosity and vapor pressure. The blowout volume helps to completely empty the tip.
	####	0000..3000	0	Swap Speed in 0.1 mm/s Determines how fast the tip is withdrawn from the liquid after aspiration or dispense. This parameter is chosen based on the liquid viscosity and vapor pressure. Using a slow speed prevents a viscous liquid from sticking to the outside of the tip.

CREATING A LIQUID CLASS

Command	Parameter	Parameter range	Default value	Name and Description
	###	000..999	0	Settling Time in 0.1 s This parameter sets how long the tip remains in liquid after aspiration or dispense before moving out of the liquid. The tip geometry and liquid viscosity are considered when setting this parameter. If settling time is too short the liquid has not enough time to fill the tip and unwanted air is aspirated as soon as the tip is lifted out of the liquid.
	#	0..1	0	Liquid Level Detection (LLD) mode (0 = cLLD, 1 = pLLD) Use pressure LLD (pLLD) with non-conductive liquids and tips. pLLD only works with new and empty tips during aspiration. For conductive liquids, choose capacitive LLD (cLLD) in combination with conductive tips.
	#	1..4	1	cLLD Sensitivity (1 = very high, 2 = high, 3 = medium, 4 = low) The sensitivity may be adjusted to the vessel size and the liquid volume to be detected (small volume -> high sensitivity).
	#	1..4	1	pLLD Sensitivity (1 = very high, 2 = high, 3 = medium, 4 = low) Mainly determined by tip geometry. Use high sensitivity with large tip orifices.
	#	0..1	0	Anti-Droplet Control (ADC; 0 = off, 1 = on) Use ADC when pipetting liquids having low viscosity and high vapor pressure, such as ethanol. If the pressure reaches a critical value where dripping is likely to occur, the plunger is withdrawn as much as needed to reduce the pressure and to prevent droplet formation.
				Dispensing
	#	0..3	0	Dispensing mode (0 = jet empty, 1 = jet part, 2 = surface empty, 3 = surface part)

CREATING A LIQUID CLASS

Command	Parameter	Parameter range	Default value	Name and Description
	#####	00001..14280	0	Flow Rate in 0.1 µL/s Dispensing speed of the plunger. See description of aspiration Flow Rate.
	#####	00001..14280	0	Stop Flow Rate in 0.1 µL/s Dispensing speed of the plunger at which the dispense stops. If equal to “Flow Rate”, then the plunger stops abruptly without slowing down. If set to minimum, the plunger movement slows down gradually until it stops. When pipetting a viscous liquid such as glycerin, it is recommended to have a gradual stop (slow Stop Flow Rate) for complete dispensing.
	###	000..325	0	Stop Back Volume in 0.1 µL This air volume is aspirated again immediately after dispensing to have an abrupt cut-off of the liquid flow (jet part mode only). Prevents droplet formation when pipetting volatile liquids such as ethanol.
	#####	00000..10000	0	Transport Volume in 0.1 µL. See description of aspiration Transport Volume.
	####	0000..3000	0	Swap Speed in 0.1 mm/s. Surface dispensing modes only. See description of aspiration Swap Speed.
	###	000..999	0	Settling Time in 0.1 s. Surface dispensing modes only. See description of aspiration Settling Time.

Command	Parameter	Parameter range	Default value	Name and Description
⇨	GLid####er##			See Error Messages
GM				Request Liquid Class Parameter Aspiration
	id####	0000..9999	0	Identification Number
	lq##	00..99	0	Liquid Class Table Index (Aspiration)
⇨	GMid####lq##uu# # ##### #### ##### ##### #### ### # # # # # ##### ##### ### ##### #### ###			

6.3 Gravimetric Calibration

The second step in configuring a liquid class is gravimetric calibration which ensures the best possible pipetting accuracy. The calibration of a liquid class is performed by weighing eight reference points within that liquid class. The test procedure is as follows:

1) Define a meaningful measurement range for each tip size. Eight calibration points have to be taken covering the entire volume range of a tip. The density of points should be higher for smaller target volumes. Examples of four different tips are listed below (recommended values in 0.1 µL):

Calibration point	10 µL tip	50 µL tip	300 µL tip	1000 µL tip
1	5	5	50	100
2	10	10	100	200
3	20	20	250	500
4	30	50	500	1000
5	40	100	750	2000
6	60	200	1250	5000
7	80	300	2000	7500
8	100	500	3000	10000

2) For each calibration point, dispense a total of n samples (n=10 is recommended) into a weighing vessel, and weigh each sample after delivery. The balance should meet or exceed the following requirements:

Target volume range	Balance precision
1-10 µL	0.001 mg
10-100 µL	0.01 mg
100-1000 µL	0.1 mg

3) Record the measured mass and calculate the volume of each dispense (V_i, where i =1 to n) by dividing each mass value by the density of the liquid.

NOTE: The density depends on the temperature of the liquid. Please measure the temperature of the dispensed liquid and take the density value at the measured temperature.

4) Calculate the average dispensed volume $\overline{V}$ from the individual dispensed volumes: $\overline{V} = \frac{1}{n}\sum_{i=1}^{n}(V_i)$

5) Calculate the accuracy: $A = \frac{|\overline{V}-V_0|}{V_0}100\%$. V_0 is the target volume (entered in the settings).

6) Calculate the standard deviation s of the calculated volumes: $s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(V_i-\overline{V})^2}$.

7) Determine the coefficient of variation: $CV = \frac{s}{\overline{V}}100\%$. The CV value is a measure for precision.

8) Create a calibration curve using the average values V_i ("dispensed volume"). The commands and parameters for the volume calibration curves are shown in the tables below. Typically, the dispensed volume is a linear function of the target volume (see Figure 23). If a value between two calibration points is to be pipetted (e.g. 300 µL for the 1000 µL tip), the required volume is interpolated using two nearest calibration points (i.e. 200 and 500 µL). When aliquoting, the corrected volume begins with the volume of fluid currently held within the tip. For example, if there is 1000 µL in the tip and 200 µL are to be dispensed, the corrected volume will be the volume from 1000 µL to 800 µL, instead of the corrected volume at 200 µL.

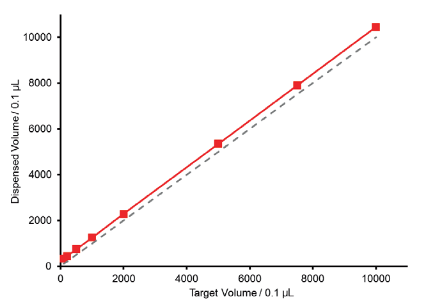

Figure 23: Average dispensed volume (V_i) vs. target volume (V_0) for a 1000 µL tip ("calibration curve"). "Target volume" is the volume to be pipetted (entered in the settings). Each measurement point (square) is an average over 10 dispensing cycles ("dispensed volume"). The dashed line shows the situation when target volume equals the dispensed volume.

Command	Parameter	Parameter range	Default value	Name and Description
GG				**Set Calibration Curve for Aspiration**
	id####	0000..9999	0	Identification Number
	gg##	00..99	0	Calibration Curve Table Index
	ck#####	00000..11000	0	1. Target Volume (in units of 0.1 µL)
	#####	00000..12500	0	1. Correction Volume* (in units of 0.1 µL)
	#####	00000..11000	0	2. Target Volume
	#####	00000..12500	0	2. Correction Volume
	#####	00000..11000	0	3. Target Volume
	#####	00000..12500	0	3. Correction Volume
	#####	00000..11000	0	4. Target Volume
	#####	00000..12500	0	4. Correction Volume
	#####	00000..11000	0	5. Target Volume
	#####	00000..12500	0	5. Correction Volume
	#####	00000..11000	0	6. Target Volume
	#####	00000..12500	0	6. Correction Volume
	#####	00000..11000	0	7. Target Volume
	#####	00000..12500	0	7. Correction Volume
	#####	00000..11000	0	8. Target Volume
	#####	00000..12500	0	8. Correction Volume
⇨	GGid####er##			See error messages
GE				**Request Calibration Curve for Aspiration**
	id####	0000..9999	0	Identification Number
	gg##	00..99	0	Calibration Curve Table Index
⇨	GEid####gg##ck##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####			

**Example: If the target volume is 100 µL and the actual volume aspirated is 95 µL, enter 105 µL as the Correction Volume to result in an aspiration of 100 µL.*

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Command	Parameter	Parameter range	Default value	Name and Description
GH				Set Calibration Curve for Dispensing
	id####	0000..9999	0	Identification Number
	gh##	00..99	0	Calibration Curve Table Index
	cl#####	00000..11000	0	1. Target Volume (in units of 0.1 µL)
	#####	00000..12500	0	1. Average Dispensed Volume (in units of 0.1 µL)
	#####	00000..11000	0	2. Target Volume
	#####	00000..12500	0	2. Average Dispensed Volume
	#####	00000..11000	0	3. Target Volume
	#####	00000..12500	0	3. Average Dispensed Volume
	#####	00000..11000	0	4. Target Volume
	#####	00000..12500	0	4. Average Dispensed Volume
	#####	00000..11000	0	5. Target Volume
	#####	00000..12500	0	5. Average Dispensed Volume
	#####	00000..11000	0	6. Target Volume
	#####	00000..12500	0	6. Average Dispensed Volume
	#####	00000..11000	0	7. Target Volume
	#####	00000..12500	0	7. Average Dispensed Volume
	#####	00000..11000	0	8. Target Volume
	#####	00000..12500	0	8. Average Dispensed Volume
⇨	GHid####er##			See error messages
GI				Request Calibration Curve for Dispensing
	id####	0000..9999	0	Identification Number
	gh##	00..99	0	Calibration Curve Table Index
⇨	Glid####gh##cl##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####			

6.4 Settings for Qualitative Pipetting Monitoring (QPM)

The last step in setting up a new liquid class is to define the threshold parameters for the Qualitative Pipetting Monitoring (QPM) – the on-board process monitoring system. Hamilton has identified three types of undesired events that can occasionally occur during pipetting: aspiration of clots, air and foam. The Qualitative Pipetting Monitoring has been developed to separate these events by continuously monitoring the pressure. If the measured pressure exceeds predefined threshold values, the system identifies an error. This section explains how to set these thresholds. The commands and parameters for QPM are listed in the tables at the end of this section (aspiration and dispense). Specific thresholds have to be defined for each of the 8 calibration points (see previous section).

NOTE: As there is very little pressure change during low-volume aspiration and dispense, QPM may not function as expected.

6.4.1 Successful Aspiration and Dispensing

A successful pipetting cycle is sketched in Figure 24. The pressure in the tip has a certain value at the beginning, and decreases below atmospheric when the plunger starts to move up. The liquid enters the tip to compensate for the pressure difference. The pressure increases again when the plunger movement stops. However, the pressure at the end of the aspiration cycle is lower than the initial value, because gravity acts on the liquid inside the tip. During dispense the pressure increases above atmospheric while the plunger moves down. If such pressure curve shape is measured, no error message is generated indicating a successful aspiration and dispense. Deviations from this curve shape are recognized by the QPM and discussed in the following for the aspiration cycle.

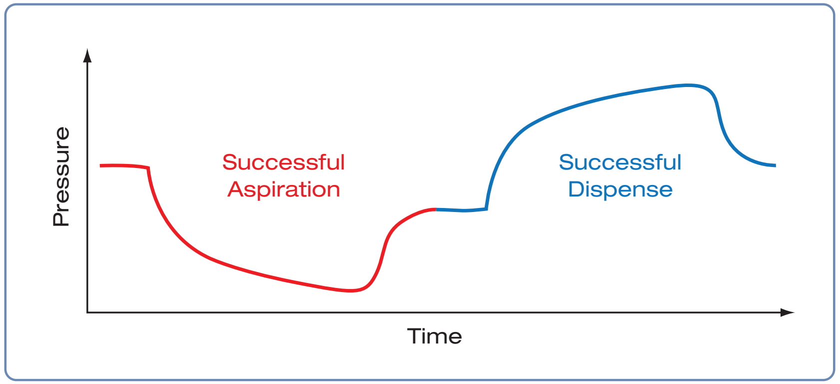


Figure 24: A successful pipetting cycle.

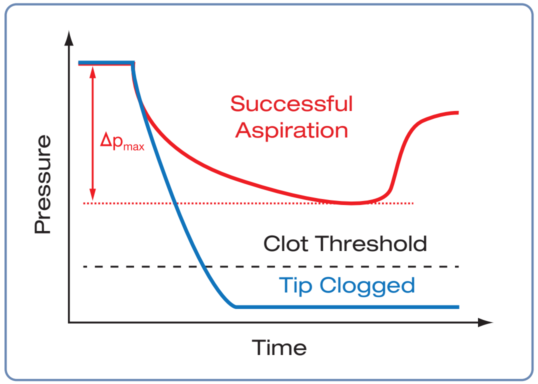


Figure 25: Schematics of a typical pressure curve for successful aspiration (red) and a clogged tip (blue). The threshold for clot detection is set to a value larger than $\triangle p_{max}$ (e.g. $2\triangle p_{max}$).

6.4.2 Tip Clogging

Some samples can contain solid objects such as blood clots. If these are aspirated they might (partially) clog the tip resulting in an inaccurate pipetting volume. In Figure 25, a successful aspiration cycle (red) is compared to a clogged tip (blue). The pressure drops rapidly if a blood clot is aspirated clogging the tip. The clot threshold (black dashed line) is set, for example, to twice the maximum pressure difference of a successful cycle $2\triangle p_{max}$.

NOTE: Clot detection will not work if the flow rate is set too high. For fluids with higher viscosity, the flow rate must be slowed down for clot detection to function properly.

6.4.3 Aspiration of Air

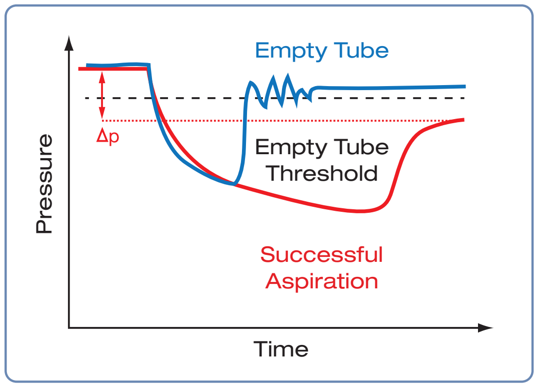


Figure 26: Undesired aspiration of air (blue). The empty tube threshold is set to $\triangle p/2$ (black dashed line).

Air can be aspirated if not enough liquid is present in the container, as illustrated in Figure 26 (empty tube, blue). If air enters the tip, the pressure increases and saturates at a certain level close to the initial value. The empty tube threshold is set to half of the pressure difference between start and end value of a successful cycle $\triangle p/2$. In the case of dispensing, the empty tube threshold is not defined, because this situation is already recognized and handled during aspiration.

NOTE: Due to the rapid change in pressure of an empty tube while aspirating, there are certain circumstances where foam may be reported instead of an empty tube.

6.4.4 Aspiration of Foam

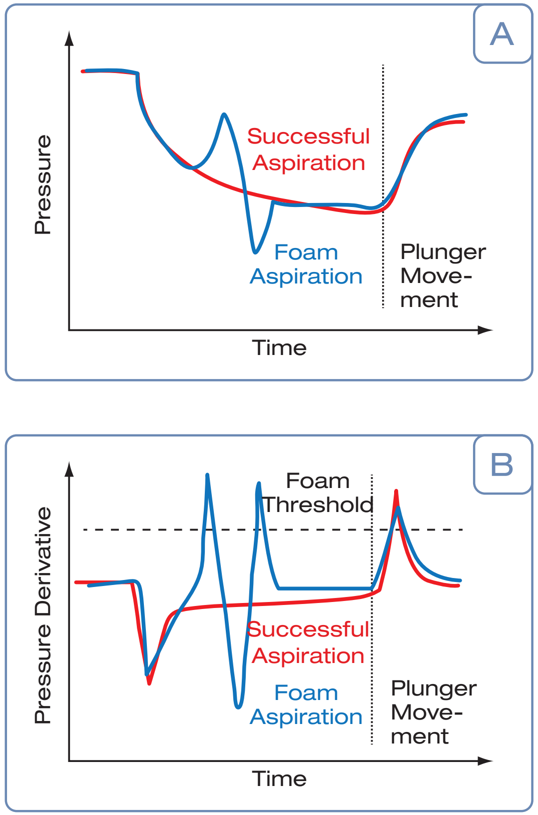


Figure 27: (A) If foam is aspirated (blue), strong pressure fluctuations occur. These are even more pronounced in the pressure derivative (sharp blue peaks in (B)). The foam detection threshold is defined for the pressure derivative and not for the pressure.

CREATING A LIQUID CLASS

Some samples have foam on their surface. If the liquid level detection mistakenly sees the foam as the surface of the liquid, then the channel starts to pipette with the tip still above the surface. Mostly foam will be aspirated. This case is depicted in Figure 27. Aspiration of foam causes strong pressure fluctuations during the cycle (blue curve in part a). These pressure variations are even more pronounced if the pressure derivative is plotted vs. time (b). Steep slopes of the pressure curve in (a) are converted to sharp peaks of the pressure derivative in (b). The foam threshold is set for the derivative (black dashed line). Note that the pressure is only monitored during the plunger movement. The peak beyond the vertical line (plunger movement stops) will not generate an error message. Hamilton recommends setting the foam threshold value to 50 (normal sensitivity). Lower values might be used if very high sensitivity is required (should be >10).

NOTE: During some aspirations of foam, a clot may be reported. This is due to the channel continuously looking for clots prior to foam. On some foam aspirations, there may be pressure spikes low enough to trip the clot threshold.

Command	Parameter	Parameter range	Default value	Name and Description
GQ				Set QPM Parameter for Aspiration
	id####	0000..9999	0	Identification Number
	gv##	00..99	0	QPM Parameter Table Index
	vv####	-6000..0000 for all aspirate clot	0000	1. Clot detection threshold (for 1st calibrated volume). Absolute value; 0 = Off.
	####	-6000..0000 for all aspirate empty tube	0000	1. Empty tube detection threshold. Value is set relative to the initial pressure. 0 = Off
	####	0000..6000 for all aspirate foam detection	0000	1. Foam detection threshold. Note that this threshold is set for the time derivative of the pressure curve. 0 = Off
	####	-6000..0000	0000	2. Clot detection threshold (for 2nd calibrated volume)
	####	-6000..0000	0000	2. Empty tube detection threshold
	####	0000..6000	0000	2. Foam detection threshold
	####	-6000..0000	0000	3. Clot detection threshold (for 3rd calibrated volume)

Command	Parameter	Parameter range	Default value	Name and Description
	####	-6000..0000	0000	3. Empty tube detection threshold
	####	0000..6000	0000	3. Foam detection threshold
	####	-6000..0000	0000	4. Clot detection threshold
	####	-6000..0000	0000	4. Empty tube detection threshold
	####	0000..6000	0000	4. Foam detection threshold
	####	-6000..0000	0000	5. Clot detection threshold
	####	-6000..0000	0000	5. Empty tube detection threshold
	####	0000..6000	0000	5. Foam detection threshold
	####	-6000..0000	0000	6. Clot detection threshold
	####	-6000..0000	0000	6. Empty tube detection threshold
	####	0000..6000	0000	6. Foam detection threshold
	####	-6000..0000	0000	7. Clot detection threshold
	####	-6000..0000	0000	7. Empty tube detection threshold
	####	0000..6000	0000	7. Foam detection threshold
	####	-6000..0000	0000	8. Clot detection threshold
	####	-6000..0000	0000	8. Empty tube detection threshold
	####	0000..6000	0000	8. Foam detection threshold
⇨	GQid####er##			See error messages
GS				Request QPM Parameter for Aspiration
	id####	0000..9999	0	
	gv##	00..99	0	
⇨	GSid####gv##vv#### ####			
GV				Set QPM Parameter for Dispensing
	id####	0..9999	0	Identification Number
	gp##	00..99	0	QPM Parameter Table Index
	ww####	0000..6000 for all dispense clot	0000	1. Clot detection threshold
	####	-6000..0000 for all dispense foam detection	0000	1. Foam detection threshold

Command	Parameter	Parameter range	Default value	Name and Description
	####	0000..6000	0000	2. Clot detection threshold
	####	-6000..0000	0000	2. Foam detection threshold
	####	0000..6000	0000	3. Clot detection threshold
	####	-6000..0000	0000	3. Foam detection threshold
	####	0000..6000	0000	4. Clot detection threshold
	####	-6000..0000	0000	4. Foam detection threshold
	####	0000..6000	0000	5. Clot detection threshold
	####	-6000..0000	0000	5. Foam detection threshold
	####	0000..6000	0000	6. Clot detection threshold
	####	-6000..0000	0000	6. Foam detection threshold
	####	0000..6000	0000	7. Clot detection threshold
	####	-6000..0000	0000	7. Foam detection threshold
	####	0000..6000	0000	8. Clot detection threshold
	####	-6000..0000	0000	8. Foam detection threshold
⇨	GVid####er##			See error messages
GW				**Request QPM Parameter for Dispensing**
	id####	0..9999	0	
	gp##	00..99	0	
⇨	GWid####gp##ww#### #### #### #### #### #### #### #### #### #### #### #### #### #### #### ####			

Command	Parameter	Parameter range	Default value	Name and Description
GP				**Piercing**
	id####	0000..9999	0	Identification Number
	gw##	0..1	0	Speed code z-Drive
	zz	0000..3500	0	Selectable Speed of the z-Drive If zz=0 speed from gw is used. If zz>0 this will be the speed of the z-Drive set in 0.1mm/s.
	yw##	00..15	12	Force, low force setting will require low speed movement
	gy####	0000..3000	0	Target position in 0.1 mm.
⇨	GPid####er##			See Error Messages
SB				**Search Bottom** This command searches in Z between the defined start and end position.
	id####	0000..9999	0	Identification Number
	sa####	0000..3000	0	Start position in increments of 0.1 mm
	sb####	0000..3000	0	End position in increments of 0.1 mm
⇨	SBid####yd####er##			See Error Messages yd#### is the position of the bottom in 0.1 mm.
AL				**cLLD without Z Movement**
	id####	0000..9999	0	Identification Number
	al#	0..1	0	0=cLLD off, 1=cLLD on
	lr####	1..5	1	Sensitivity 1=Very high, Use with 384-well plates 2=High, Use with 96-well round bottom plates 3=Med, Use with 96-well flat bottom plates 4=Low, Use with tubes, troughs or reservoirs 5=Tool, Used for solid objects
⇨	ALid####er##			See Error Messages
RN				**Request cLLD status**
	id####	0000..9999	0	Identification Number
⇨	RNid####rn#			rn# is the returned cLLD status 0=no cLLD detected 1=cLLD detected 2=no valid status, cLLD inactive

Command	Parameter	Parameter range	Default value	Name and Description
SA				**Simple Aspirate**
	id####	0000..9999	0	Identification Number
	ai#####	00000..10000	0	Aspirate Volume 0.1 µL
	aj#####	00001..14280	0	Aspirate Flow Rate in 0.1 µL/s
⇨	SAid####er##			See Error Messages
SD				**Simple Dispense**
	id####	0000..9999	0	Identification Number
	di#####	00000..10000	0	Dispense Volume in 0.1 µL
	ae#####	00001..14280	0	Dispense flow rate in 0.1 µL/s
⇨	SDid####er##			See Error Messages

7 Maintenance

Periodic maintenance routines need to be run to ensure safe and reliable operation of the ZEUS X1 pipetting module.

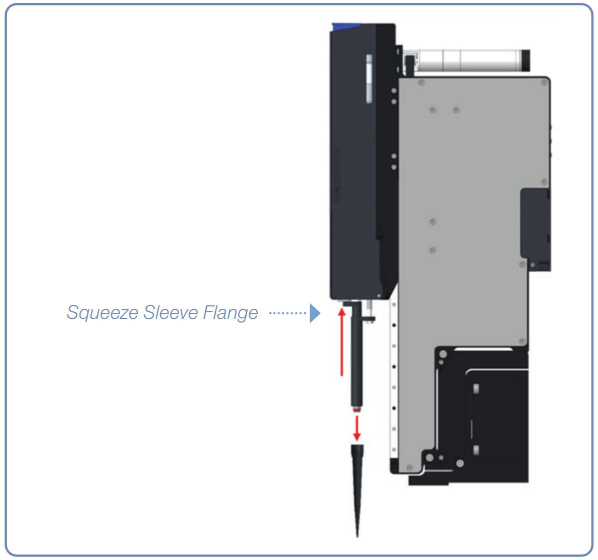
⚠ ATTENTION! Always wear suitable protective clothing, safety glasses and disposable gloves during maintenance.

Do not clean the instrument in the vicinity of naked flames or devices which could create sparks. Do not use hot air blowers to dry the instrument. The liquids used for cleaning are flammable.

Use cleaning, disinfecting, and decontaminating fluids in accordance with Hamilton's instructions. Do not use disinfecting materials which contain hypochlorite or bleaching fluids.

7.1 ZEUS X1 Manual Tip Ejection

To manually eject a tip from the ZEUS X1, first ensure any liquid within the tip has been dispensed. Place your finger on the flange of the squeeze sleeve shown below. Press upwards on the squeeze sleeve flange until it bottoms out on the bottom of the head. The tip will eject off the end of the nozzle.



MAINTENANCE

7.2 ZEUS X1 Pipette Head Replacement

Hamilton's ZEUS X1 is capable of simple and easy pipette head removal and replacement. Perform the following procedure to replace the pipette head on ZEUS X1.

To remove the pipette head:

1. Power off the instrument.
2. Place your index finger over the pipette head latch (blue) at the top of the head. Grip each side of the head using your thumb on one side and your remaining fingers on the other.
3. Press down on the pipette head latch (blue) with your index finger. This will release the head and allow the user to tilt the head away from the body.
4. With the head tilted away from the body, lift the head up so the corner pin on the head disengages the hook on the body. Set the head aside.

To replace the head:

5. Grab the replacement head.
6. Tilt the head back at an angle and place the pin on the bottom corner of the head into the hook on the body.
7. Gently tilt the head towards the body until the blue latch clicks into place. And you are done!

7.3 Cleaning ZEUS X1

Perform the cleaning procedure if the ZEUS X1 pipetting module is soaked accidentally in any liquid, if any spillage is noticed, or if contamination occurred.

1. Verify that no pipetting tip is mounted on the module. If a tip is present, follow the manual tip ejection procedure within Chapter 7.1.
2. Power off the ZEUS X1 pipetting module.
3. Remove the tip ejection sleeve. To do so loosen the fixation clip carefully, and strip down the tip ejection sleeve (Figure 28).

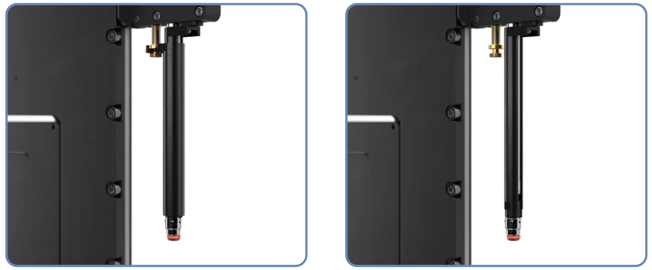


Figure 28: Removing the tip ejection sleeve.

4. Verify that the tip ejection sleeve is clean. Change the tip ejection sleeve if this is not the case.
5. Clean the exposed barrel of the ZEUS X1 pipetting module using a lint-free cloth soaked with Microcide SQ, Hamilton's recommended broad spectrum disinfectant (Figure 28).

⚠ **ATTENTION! Take care that no liquid gets inside the pipetting barrel.**

6. After cleaning, remount the ejector sleeve. You will need to initialize ZEUS X1 before using.

7.4 Leak Testing ZEUS X1

Perform the leak test on the ZEUS X1 as part of the daily maintenance or as desired. The leak test will pick up a teaching needle (182176) and perform a pressure and vacuum test to confirm a good seal. Make sure the teaching needle is clean and the ZEUS X1 is directly above the teaching needle before starting the test. Tip type table 04 (tt04) should be used with the teaching needle.

Command	Parameter	Parameter range	Default value	Name and Description
LX				**Leak Check** Following steps are performed 1) ZEUS X1 picks up a teaching needle. 2) ZEUS X1 performs a pressure test. 3) ZEUS X1 discards the teaching needle then picks it up again. 4) ZEUS X1 performs a vacuum test. 5) ZEUS X1 discards the teaching needle.
	id####	0000..9999	0	Identification Number
	tt##	00..30	0	Tip Type Table Index See Tip Type Table (Chapter 5.12.3)
	go##	00..99	0	Deck Geometry Table Index See deck geometry table index (Chapter 5.12.2)
⇨	LXid####er##			See Error Messages

MAINTENANCE

7.5 Recommended Maintenance

We recommend that you maintain the ZEUS X1 pipetting module at the following intervals:

Daily The Daily maintenance is recommended before using the instrument.

Yearly The yearly maintenance is recommended every year after one year of usage.

7.5.1 Daily Maintenance

⚠ ATTENTION! Use cleaning, disinfecting and decontaminating fluids in accordance with Hamilton’s instructions. Do not use disinfecting materials which contain hypochlorite (Javelle water, Clorox) or bleaching fluids.

Perform the daily maintenance at the beginning of each working day. The following tasks belong to the daily maintenance:

1) Perform visual check of the pipetting module to identify spillage and damages.

2) If the pipetting head needs to be cleaned, perform the cleaning procedure (see Chapter 7.4)

3) Perform the leak test procedure (see Chapter 7.4)

7.5.2 Yearly Maintenance

Perform the yearly maintenance after one year of usage. The following tasks are carried out during the yearly maintenance.

1. Perform visual check of the pipetting channel to identify spillage and damages.
2. Perform the cleaning procedure (see Chapter 7.4).
3. Perform the leak test procedure (see Chapter 7.4)
4. Clean and lubricate the Z-rail annually with Topaz AK50.
   - With a lint-free towel, wipe the Z-rail clean of any particulates or residue and apply a minimal amount of lubricant.
5. Replace the CO-RE II stop disc O-ring after 40,000 tip picking cycles.

ZEUS X1 MODULE QUALIFICATION

8 ZEUS X1 Module Qualification

This Chapter contains general recommendations to ensure that the ZEUS X1 module integrated in your instrument is installed and functioning correctly.

8.1 Module Qualification at Hamilton Factory

Each individual ZEUS X1 module undergoes final testing in our production. CAN communication, movements of the z-drive and of the pipetting drive, sensors functionality, and pipetting performance are verified during final testing at Hamilton factory. This enables you to integrate high quality validated modules in your instrument and simplifies your manufacturing process.

8.2 Recommended Qualification Procedures

Qualification of the ZEUS X1 module in your instrument may be required for:

- Factory testing after instrument production
- Installation and operation qualification at the customer site
- Instrument verification during yearly maintenance
- Functional validation after service
- The table below describes the recommended qualification procedures.

	Installation Qualification	Operation Qualification	Performance Qualification
Incoming goods inspection	n.a.	n.a.	n.a.
Factory testing	Recommended (see Chapter 8.3)	Recommended (see Chapter 8.4)	The instrument manufacturer carries the responsibility for the particular process. This exact procedure will strongly depend on the specific applications that ZEUS X1 as a component is used for. Hamilton can offer support related to the liquid handling.
Installation at customer site	Recommended (see Chapter 8.3)	Recommended (see Chapter 8.4)	The instrument manufacturer carries the responsibility for the particular process. This exact procedure will strongly depend on the specific applications that ZEUS X1 as a component is used for. Hamilton can offer support related to the liquid handling.
Yearly Maintenance	Recommended (see Chapter 8.3)	Recommended (see Chapter 8.4)	The instrument manufacturer carries the responsibility for the particular process. This exact procedure will strongly depend on the specific applications that ZEUS X1 as a component is used for. Hamilton can offer support related to the liquid handling.
Service	Recommended (see Chapter 8.3)	Recommended (see Chapter 8.4)	The instrument manufacturer carries the responsibility for the particular process. This exact procedure will strongly depend on the specific applications that ZEUS X1 as a component is used for. Hamilton can offer support related to liquid handling.

8.3 Installation Qualification

The purpose of the installation validation is to verify that the ZEUS X1 module has been properly mounted and connected.

1) Verify that the ZEUS X1 module has been properly mounted according to the instructions in Chapter 4.
2) Validate proper connection and CAN communication (Chapter 5.2).
3) Initialize pipetting drive and z-drive (Chapter 5.4).

8.4 Operation Qualification

The operation qualification aims to provide a general qualification of the pipetting performance of the ZEUS X1 module. It differs from the performance qualification which is specific to your application (Chapter 8.5). The recommended operation qualification for the ZEUS X1 module consists of a two-point volume verification.

Verify that the environmental conditions are within the specifications. The operation qualification has to be performed with a well-defined solution such as Hamilton Verification Solution (Chapter 11).

1) Install and calibrate the balance according to the manufacturer's instructions.
2) Pick up the disposable tip (Chapter 5.6).
3) Aspirate the test volume (Chapter 5.7).
4) Read weight.
5) Dispense in jet mode the test volume into a weighing vessel (Chapter 5.7).
6) Measure the dispensed weight (stable balance value).
7) Eject tip to waste (Chapter 5.6).
8) Repeat steps 1) – 6) ten times per volume and channel. Use new tip for each pipetting.
9) Calculate the average volumes using the corresponding liquid density (Chapter 6.3).
10) Calculate the accuracy R and precision CV (Chapter 6.3) and compare with field verification specifications (Figure 29). The verification is passed if the obtained values are lower than the specified. The field verification specifications are broader than the design specifications. They allow the use of a transportable balance and measurements under broader environmental conditions, typically found in laboratories.

Tip volume(µL)	Tested volume(µL)	Accuracy R (%)	Precision CV (%)
1000	1000	≤ 2.0	≤ 1.5
1000	50	≤ 5	≤ 2.5

Figure 29: Field verification specifications.

8.5 Performance Qualification

The performance qualification aims to verify the instrument performance in a specific application. It relates to a specific application and lies under the responsibility of the instrument manufacturer. Hamilton can offer support related to liquid handling.

9 Troubleshooting

9.1 Getting Technical Support

If a problem persists even after you have attempted to correct it, contact Hamilton's Customer Support: Please refer to the contact information at the back of this Manual.

9.2 Controlling the Functionality of pLLD and cLLD

It is possible to download the AD values of the last liquid level detection in order to troubleshoot proper functioning of pLLD and cLLD. The LLD values are recorded every 2 ms.

Command	Parameter	Parameter values	Default value	Name and Description
RB				**Request Number of LLD Data Recorded**
	id####	0000..9999	0	Identification Number
	lc#	0..1	0	Liquid level detection channel 0 = capacitive LLD 1 = pressure LLD
⇨	RBlc#rb'...'			rb contains seven 4 digits values: 7th value : number of data recorded
RL				**Request LLD Data**
	id####	0000..9999	0	Identification Number
	li####	0000..4999	0	Starting index for data request
	ln##	00..50	0	Number of values requested
	lc#	0..1	0	Liquid level detection channel 0 = capacitive LLD 1 = pressure LLD
⇨	RLid####rl'...'			rl contains 4 digits LLD values (AD values) separated by blanks.

Example:

Command	Answer	Description
RBIc0	RBid0000rb4920 0200 0200 0768 0000 0000 0292	Request the index where data record started and the number of data recorded. In the example the starting index is 4708 (4999-292+1) and 292 data points have been recorded.
RLIi4708In50Ic0	RLid0000rl0768 0767 0768 0768 0767 0769 0770 0769 0769 0770 0767 0768 0768 0768 0767 0769 …	Download 50 data points starting from index 4708 and ending at index 4757.
RLIi4758In50Ic0	RLid0000rl0768 0767 0768 0768 0767 0770 0770 0769 0769 0771 0768 0767 0768 0768 0767 0769 …	Download 50 data points starting from index 4758 (4708+50) and ending at index 4807.
		Repeat until the last recorded data points may be downloaded.
RLIi4958In42Ic0	RLid0000rl0768 0767 0768 0768 0767 0770 0770 0769 0769 0771 0768 0767 0768 0768 0767 0769 …	Download the last 42 data points starting from index 4958 and ending at index 4999.

9.3 Controlling Aspiration and Dispensing

It is possible to download the pressure curves measured during the last pipetting.

Command	Parameter	Parameter values	Default value	Name and Description
QH				**Request Parameters of Pressure Monitoring**
⇨	qh'...'			Six decimal values with 4 digits, separated by blanks: 1st value: Clot threshold value 2nd value: Number of data recorded 3rd value: Pressure value before operation 4th value: Pressure value after operation 5th value: Threshold of minimal Δ pressure before/after operation 6th value: Threshold max value of difference signal 7th value: Detect index

Example and Notes:

1. QH ⇨ QHqh+0000 +0000 +0000 +0000 +0000 +0000 +0000

Command	Parameter	Parameter values	Default value	Name and Description
QI				**Request Pressure Data**
	id####	0000..9999	0	Identification Number
	li####	0000..4999	0	Starting index for data request
	ln##	00..50	0	Number of values requested
⇨	Qlid####qi'...'			qi contains 5 digit pressure values (-6000mBar to 6000mBar in increments of 0.01) separated by blanks.

Example:

Command	Answer	Description
QH	QHid0000qh0600 0689 0901 0879 0010 0015	Request the number of data recorded. In the example 689 data points have been recorded. As a consequence data record start at index 4999-689+1=4311
Qlid0000li4311ln50	Qlid0000qi0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 0901 …	Download 50 data points starting from index 4311 and ending at index 4361.
Qlid0000li4361ln50	Qlid0000qi0881 0879 0878 0876 0875 0872 0871 0869 0867 0866 0863 0861 0859 0857 0855 …	Download 50 data points starting from index 4361 and ending at index 4411.
		Repeat until the last recorded data points may be downloaded.
Qlid0000li4961ln39	Qlid0000qi0879 0879 0880 0880 0880 0880 0880 0880 0880 0880 0880 0880 0880 0880 0880 …	Download the last 39 data points starting from index 4961 and ending at index 4999.

9.4 Returning ZEUS X1 for Repair

Before returning a ZEUS X1 to Hamilton for repair, contact our Customer Service (see Chapter 9.1) and request a Returned Materials Authorization (RMA) number.

Do not return a ZEUS X1 pipetting module to Hamilton without an RMA number. This number ensures proper tracking of your components. Pipetting modules that are returned without an RMA number will be sent back to the customer without being repaired.

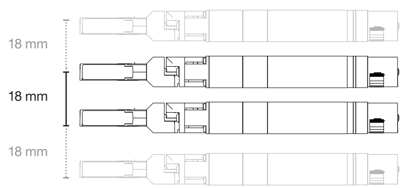
Decontaminate the ZEUS X1 pipetting module and remove health hazards, such as radiation, infectious diseases, corrosive agents etc. Provide a complete description of any hazardous materials the unit may have been exposed to.

⚠ ATTENTION! Hamilton reserves the right to refuse a return shipment of any Hamilton product that could be hazardous to Hamilton employees.

10 Technical Specifications

Dimensions*
Width x Depth x Height

16 x 161 x 335 mm
Straight configurations
(Single or parallel arrangement)



For detailed dimensions please request the Technical Specifications Drawings.

Weight	1075 g	
z-Drive	Maximum z-Excursion	200 mm
	Resolution z-Axis	0.1 mm
	Maximum Speed	350 mm/s
Pipetting Drive	Volume Range	1 µL – 1,000 µL
	Resolution	0.1 µL
	Maximum Speed*	1,428 µL/s*
Pipetting Mode	Single and aliquot dispensing	
Process Security	Tip presence sensor	
	Pressure-based and capacitive Liquid Level Detection (cLLD and pLLD)	
	On board Qualitative Pipeting Monitoring (QPM)	
	Anti-Droplet Control (ADC)	
Operating Data	Power requirement	36.9-50 VDC, 2 A
	Temperature range	18°C – 32°C
	Relative humidity	40% – 80% (non-condensing)
	Noise level	< 60 dBA
	Indoor use only	
Storage and Transportation	Temperature range	-25°C – +70°C
	Relative humidity	40% – 80% (non-condensing, indoors)
Communication	CAN (Hamilton protocol)	
	FFC connector	
	Selectable baud rates	125, 500 kBaud (others on request)
	Device addressing	up to 31 modules on a single CAN bus
RoHS Compliant	Yes	

*Maximum speed of the plunger. Maximum aspirate and dispense speed will vary based on the tip used and the viscosity of the fluid. Complete cycle times are dependent on the commands given and the length of the movement.

Pipetting Performance*	Disposable Tip Size	Pipetting Volume	Accuracy	Precision
	10 µL	1 µL	5.0%	4.0%
	10 µL	5 µL	2.5%	1.5%
	10 µL	10 µL	1.5%	1.0%
	50 µL	1 µL	5.0%	4.0%
	50 µL	5 µL	2.5%	1.5%
	50 µL	50 µL	2.0%	0.75%
	300 µL	10 µL	5.0%	2.0%
	300 µL	50 µL	2.0%	0.75%
	300 µL	300 µL	1.0%	0.75%
	1000 µL	10 µL	7.5%	3.5%
	1000 µL	100 µL	2.0%	0.75%
	1000 µL	1000 µL	1.0%	0.75%

* Pipetting specifications were determined gravimetrically using a high precision balance and strictly controlled environmental conditions: test temperature: 20 ± 2°C, relative humidity: 50% ± 5%, test liquid temperature range: ≤± 0.5°C of room temperature, balance used: Mettler Toledo XP6. The measurements were done with Hamilton Verification Solution (deionized water with 0.1% NaCl and 0.01% Tween detergent) using standard CORE conductive tips. A new tip was used for each pipetting cycle (aspiration and dispense). At least 10 points were taken for each volume and pipetting module. Volumes > 20 µL were dispensed in jet mode. Volumes ≤ 20 µL were dispensed in surface mode. Results may vary using other liquid or environmental conditions.

11 Ordering Information

11.1 ZEUS X1 Pipetting Module

Part Number	Description
6606801-01	ZEUS X1 Module
202977-0020	Test platform containing ZEUS X1 holder, communication box and demo software
202977-0021	Holder for mounting a ZEUS X1 test module
202977-0022	Communication box containing power supply and Hamilton CAN-USB converter

11.2 Disposable CO-RE II Tips*

Part Number	Description			
235904	1000 µL tip	non-filtered	conductive	40 racks of 96
235905	1000 µL tip	filtered	conductive	40 racks of 96
235902	300 µL tip	non-filtered	conductive	60 racks of 96
235903	300 µL tip	filtered	conductive	60 racks of 96
235806	300 µL slim tip	non-filtered	conductive	40 racks of 96
235647	300 µL slim tip	filtered	conductive	40 racks of 96
235966	50 µL tip	non-filtered	conductive	60 racks of 96
235948	50 µL tip	filtered	conductive	60 racks of 96
235900	10 µL tip	non-filtered	conductive	60 racks of 96
235901	10 µL tip	filtered	conductive	60 racks of 96

**other tips available on demand*

11.3 Accessories and Spare Parts

Part Number	Description
6606804-11	Replacement Pipetting Head
196263	CO-RE II Tip Ejection Sleeve (1/pk)
98551-01	CO-RE II Stop Disc O-ring(1/pk)
6607080-02	CO-RE II Stop Disc O-ring (10/pk), with Removal Tool
173229	Hamilton Verification Solution
3995-01	Microcide SQ Ship Kit
800336	Holder for CO-RE II Tip Rack
182176	Teaching Needle

12 Appendices

12.1 Appendix A: ASCII Chart

Binary	Decimal	Hex	ASCII
00000000	0	00	<NUL>
00000001	1	01	<SOH>
00000010	2	02	<STX>
00000011	3	03	<ETX>
00000100	4	04	<EOT>
00000101	5	05	<ENQ>
00000110	6	06	<ACK>
00000111	7	07	<BEL>
00001000	8	08	<BS>
00001001	9	09	<HT>
00001010	10	0A	<LF>
00001011	11	0B	<VT>
00001100	12	0C	<FF>
00001101	13	0D	<CR>
00001110	14	0E	<SO>
00001111	15	0F	<SI>
00010000	16	10	<DLE>
00010001	17	11	<DC1>
00010010	18	12	<DC2>
00010011	19	13	<DC3>
00010100	20	14	<DC4>
00010101	21	15	<NAK>
00010110	22	16	<SYN>
00010111	23	17	<ETB>
00011000	24	18	<CAN>
00011001	25	19	<EM>
00011010	26	1A	<SUB>
00011011	27	1B	<ESC>
00011100	28	1C	<FS>
00011101	29	1D	<GS>
00011110	30	1E	<RS>
00011111	31	1F	<US>
00100000	32	20	
00100001	33	21	!
00100010	34	22	“
00100011	35	23	#
00100100	36	24	$
00100101	37	25	%
00100110	38	26	&
00100111	39	27	‘
00101000	40	28	(
00101001	41	29	)
00101010	42	2A	*
00101011	43	2B	+
00101100	44	2C	,
00101101	45	2D	-

Binary	Decimal	Hex	ASCII
00101110	46	2E	.
00101111	47	2F	/
00110000	48	30	0
00110001	49	31	1
00110010	50	32	2
00110011	51	33	3
00110100	52	34	4
00110101	53	35	5
00110110	54	36	6
00110111	55	37	7
00111000	56	38	8
00111001	57	39	9
00111010	58	3A	:
00111011	59	3B	;
00111100	60	3C	<
00111101	61	3D	=
00111110	62	3E	>
00111111	63	3F	?
01000000	64	40	@
01000001	65	41	A
01000010	66	42	B
01000011	67	43	C
01000100	68	44	D
01000101	69	45	E
01000110	70	46	F
01000111	71	47	G
01001000	72	48	H
01001001	73	49	I
01001010	74	4A	J
01001011	75	4B	K
01001100	76	4C	L

Binary	Decimal	Hex	ASCII
01001101	77	4D	M
01001110	78	4E	N
01001111	79	4F	O
01010000	80	50	P
01010001	81	51	Q
01010010	82	52	R
01010011	83	53	S
01010100	84	54	T
01010101	85	55	U
01010110	86	56	V
01010111	87	57	W
01011000	88	58	X
01011001	89	59	Y
01011010	90	5A	Z
01011011	91	5B	[
01011100	92	5C	\
01011101	93	5D	]
01011110	94	5E	^
01011111	95	5F	_
01100000	96	60	`
01100001	97	61	A
01100010	98	62	b
01100011	99	63	c
01100100	100	64	d
01100101	101	65	e
01100110	102	66	f
01100111	103	67	g
01101000	104	68	h
01101001	105	69	i
01101010	106	6A	j
01101011	107	6B	k

Binary	Decimal	Hex	ASCII
01101100	108	6C	l
01101101	109	6D	m
01101110	110	6E	n
01101111	111	6F	o
01110000	112	70	p
01110001	113	71	q
01110010	114	72	r
01110011	115	73	s
01110100	116	74	t
01110101	117	75	u
01110110	118	76	v
01110111	119	77	w
01111000	120	78	x
01111001	121	79	y
01111010	122	7A	z
01111011	123	7B	{
01111100	124	7C	|
01111101	125	7D	}
01111110	126	7E	~
01111111	127	7F	

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