Operating Manual

Cavro® XCalibur Modular Digital Pump

October 2005

733085-B

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Cavro® XCalibur Modular Digital Pump

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October 2005
733085-B

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Part Number 733085-B

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Title:	Cavro® XCalibur Modular Digital Pump Operating Manual		
ID:	733085-B, en		
Version	Revision	Issue	Major changes
1	B		New edition

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1 Getting Started

Congratulations on your purchase of the Cavro® XCalibur Modular Digital Pump from Tecan Systems.

The XCalibur is a compact OEM pump module designed to handle precision liquid handling applications in the 5 µL to 5 mL range. It is controlled by an external computer or microprocessor and automates pipetting, diluting, and dispensing functions.

This chapter includes these topics:

- Regulatory Considerations
- XCalibur Features at-a-Glance
- Unpacking the XCalibur
- Functional Description of the XCalibur
- Safety
- Tips for Setting Up the XCalibur

1.1 Regulatory Considerations

The XCalibur is a general laboratory module. Since it is not a medical device, it is not subject to FDA regulatory approval. The XCalibur uses only UL recognized components and bears the UL Recognized Component Mark:

The use of UL Recognized components in a product or system allows UL to focus the evaluation of the complete system on its intended end-use, and thus speeds up the evaluation of that product or system. For more information regarding UL certification of Tecan Systems' syringe pumps, please visit the Underwriters Laboratories Inc. website at http://www.ul.com/info/standard.htm. Tecan Systems' customer file number for the recognized component is E164638.

1.1.1 CE

As a module designed for incorporation into larger systems that require independent testing and certification, the XCalibur does not carry its own CE mark.

1.1.2 Radio Interference

The XCalibur can radiate radio frequency energy, which may cause interference to radio and television communications. Follow standard good engineering practices relating to radio frequency interference when integrating the XCalibur into electronic laboratory systems.

1.2 XCalibur Features at-a-Glance

The XCalibur is a compact syringe pump that is designed for OEM precision liquid handling applications. It has the following standard features and functions:

- Small and lightweight
- Syringe sizes from 50 μL to 5 mL
- Accuracy < 1.0% at full stroke
- Precision ≤ 0.05% at full stroke
- Standard dispense/aspirate resolution of 3,000 increments
- Microstep dispense/aspirate resolution of 24,000 increments
- 3-Port, 4-Port, Y-Block, T-Valve, 3-Port Distribution, 6-Port Distribution, and 9-Port Distribution valves
- Borosilicate glass, PCTFE and Teflon® fluid contact
- RS-232, RS-485 and CAN interface
- Programmable plunger speeds from 1.2 sec/stroke to 20 min/stroke, with ramps and on-the-fly speed changes
- Ball screw drive with a linear encoder for lost-step detection
- Manually movable syringe drive (power off)
- Pump diagnostics, self-test, and error reporting
- Auxiliary inputs and outputs
- Operates using a single 24V DC power supply

1.3 Unpacking the XCalibur

To unpack the module, follow these steps:

1. Remove the pump module(s) and accessories from the shipping cartons.
2. Check the contents against the packing slip to make sure that all the components are present.

1.3.1 ESD Considerations

The XCalibur is an electronic device that is sensitive to electrostatic discharge (ESD). Static discharge from clothing or other fixtures can damage these components. To prevent premature failure of pump components, the XCalibur should be handled using good ESD practices. These include, but are not limited to:

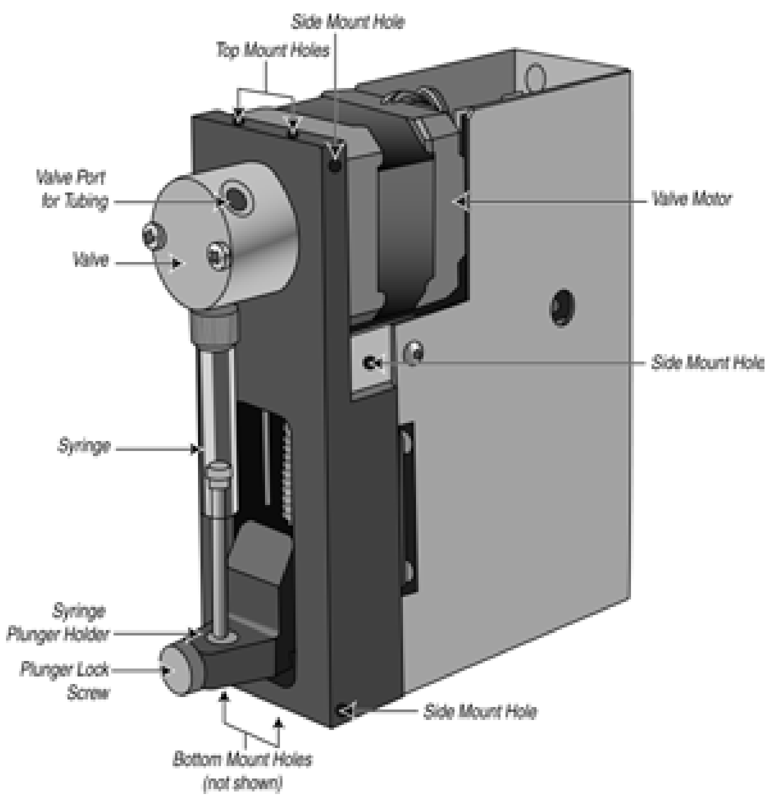
- Using wrist or ankle straps
- ESD mats or worktables
- ESD wax on the floor

Prepare an ESD-free work area before the chassis is grounded.

1.4 Functional Description of the XCalibur

The XCalibur uses a stepper-motor driven syringe and valve design to aspirate and dispense measured quantities of liquid. Both the syringe and the valve are replaceable. Functional descriptions and illustrations of each major XCalibur component are provided in the following sections.

Figure 1-1 *XCalibur Modular Digital Pump*



1.4.1 Syringe and Syringe Drive

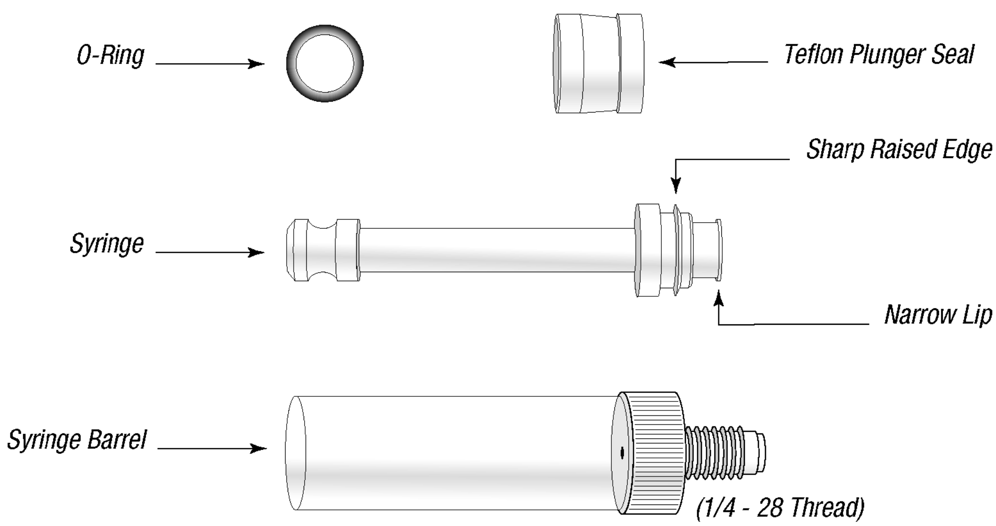
The syringe plunger is moved within the syringe barrel by a ball screw drive that incorporates a 1.8° stepper motor and linear encoder to detect lost steps.

The syringe drive has a 30 mm travel length and resolution of 3,000 increments (24,000 increments in fine positioning mode). When power is not applied to the pump, the syringe drive can be moved by pushing up or down firmly on the plunger holder assembly. This facilitates syringe removal.

The base of the syringe plunger is held to the drive by a knurled screw. The top of the syringe barrel attaches to the pump valve by a 1/4-28" fitting.

Figure 1-2, 'Syringe Components" shows the components of a typical syringe.

Figure 1-2 *Syringe Components*



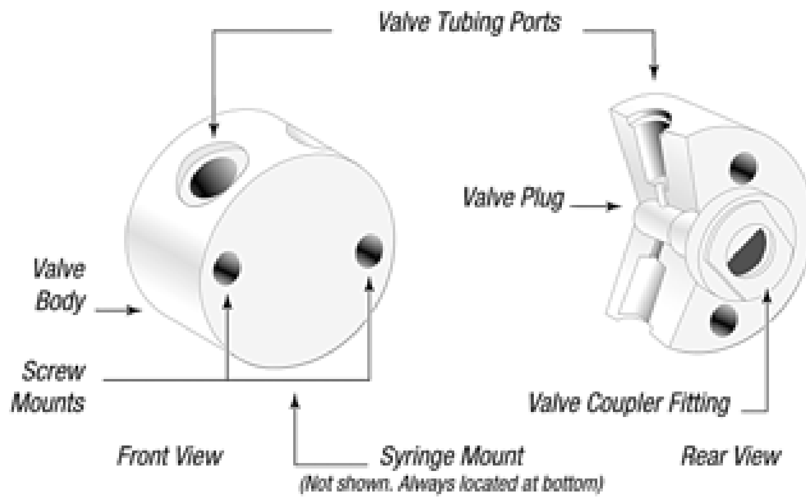
Syringes are available in these sizes: 50 µL, 100 µL, 250 µL, 500 µL, 1.0 mL, 2.5 mL, and 5.0 mL. For ordering information, see Appendix A, "Ordering Information."

1.4.2 Valve and Valve Drive

The valve is made of a PCTFE body and Teflon plug. The plug rotates inside the valve body to connect the syringe port to the various input and output ports. Additionally there is a bypass position. This position "bypasses" the syringe and connects the input and output ports. The bypass position is often used for flushing fluid lines. The valve is turned by a 1.8° stepper motor that has an encoder coupled to it for positioning feedback.

Figure 1-3 shows the components of a 3-port valve.

Figure 1-3 *3-Port Valve Components*

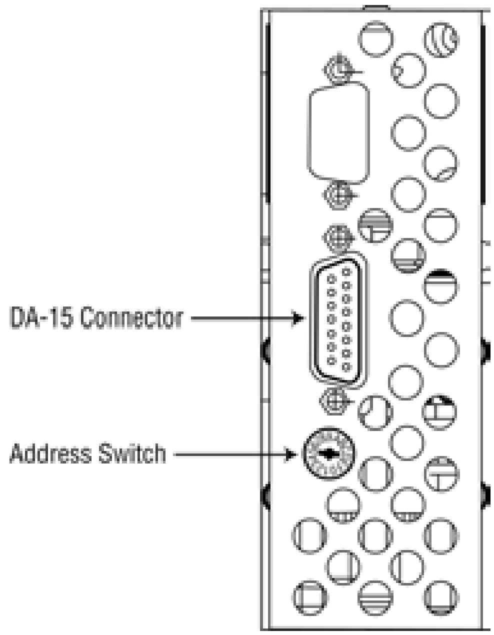


1.4.3 Printed Circuit Assembly

The printed circuit assembly (PCA) holds the microprocessor and circuitry to control the syringe and valve drive. The PCA provides connectors for electrical inputs and outputs as well as a communication address switch. For information on modes of operation, see Chapter 3, "Software Communication".

Figure 1-4 shows the accessible components on the printed circuit board assembly.

Figure 1-4 XCalibur Printed Circuit Assembly External Connectors



The XCalibur PCA has a DA-15 connector to handle power and communications. For more information on the printed circuit assembly inputs/outputs and the address switch, see Chapter 2, "Hardware Setup."

1.4.4 Communication Interfaces

Depending on the pump configuration, the XCalibur can communicate singly or in a multi-pump configuration through an RS-232, RS-485, or CAN (Controller Area Network) interface. For RS-232 and RS-485, baud rates of 9600 and 38400 are supported. For CAN, baud rates of 100K,125K, 250K, 500K, and 1M are supported.

For details on the communications interfaces, see Chapter 2, "Hardware Setup".

1.4.5 Multi-Pump Configurations

Up to fifteen (15) XCalibur pumps can be connected together in a *multi-pump configuration* (also called "daisy-chaining"). In this configuration each pump is addressed separately from a single terminal via its unique address, which is set using the address switch on the back panel of the pump.

Within a multi-pump configuration, the RS-485 communications bus is required, although the first pump in the chain may receive either RS-232 or RS-485 communications. For CAN communications, neither RS-232 nor RS-485 is required. For more information on setting addresses, see Chapter 2.

1.5 Safety

The Cavro® XCalibur Modular Digital Pump is designed for pipetting and dispensing operation in the 5 µL to 5 mL range. Any other use is considered improper and may result in damage to the pump and/or unreliable test results.

The XCalibur is designed to meet recognized technical regulations and is built with state-of-the-art components. Nevertheless, risks to users, property and the environment can arise when the module is used carelessly or improperly. Appropriate warnings in this Operating Manual serve to make the user aware of possible hazards.

1.5.1 Notices and Symbols

Warning Notices Used in this Manual

The triangle warning symbol indicates the possibility of personal injury if the instructions are not followed.

Specific symbols indicate the hazard to which a user is exposed. A few examples follow.

Toxic Substance

Chemical or biological hazards can be associated with the substances used or the samples processed with the XCalibur. Always be aware of possible hazards associated with these substances.

Explosion and Fire Hazard

Never process explosive or highly flammable liquids with the XCalibur.

Pinch Point, Mechanical Hazards

Automatically moving parts may cause injuries (crushing, piercing)

Attention

The general “Read This” symbol indicates the possibility of equipment damage, malfunction or incorrect process results, if instructions are not followed.

1.6 Tips for Setting Up the XCalibur

For complete information on setting up the XCalibur, see Chapter 2, "Hardware Setup" and “Chapter 3, "Software Communication".

Note: *Before performing any work with the XCalibur, first read this Operating Manual carefully.*

To ensure proper operation, follow these tips:

- Always set up and mount the pump in an upright position. Failure to do so can cause problems priming the system.
- Always run liquid through the syringe and valve when they are moving. Failure to do so can damage the sealing surfaces.
- Before running any organic solvents through the pump, see Appendix D, “Chemical Resistance Chart” for more information on chemical compatibility.
- Always power down the instrument when connecting or disconnecting pumps.

Caution! *Keep fingers out of the syringe slot while the pump is running. Failure to do so can cause injury.*

2 Hardware Setup

This chapter includes these sections describing the various parts of hardware setup:

- Power and Electrical Considerations
- Cabling
- Settings and Options
- Installing Components
- Mounting

2.1 Power and Electrical Considerations

The XCalibur requires a 24V DC power supply with a current rating of at least 1.5A, provided through a DA-15 connector. Tecan Systems recommends using one power cable for every two pumps to provide noise immunity, i.e., power should not be daisy-chained to more than two pumps.

2.1.1 Choosing a Power Supply

The 24V DC supply for a single XCalibur should meet the following basic requirements:

- Output voltage: 24V nominal ±2%
- Well-regulated power supplies are recommended, as operating pumps below 24V will affect performance.
- Output voltage regulation: ±1% with varying line (input voltage) and load
- Output voltage ripple: 100mV rms maximum at full load
- Conformance to required safety and EMI/RFI specifications

To meet the above basic requirements, the supply must incorporate either linear or switching regulation and must have adequate output filter capacitance.

A current-limiting power supply is recommended. Current limiting above 1.0A is acceptable, assuming that no additional equipment is operated from the supply.

If the power supply uses current feedback, the time-current foldback point must be sufficient to allow charging of a 470 μF capacitor without folding back. If an external capacitor is used, exercise care to ensure that the supply always starts after foldback, particularly at low AC line voltage.

2.1.2 Integrating a Power Supply

When a power supply is used to operate more than one XCalibur or other device, it must provide the total average current for all devices. The power supply and filter capacitance together must satisfy the total peak input current for all devices.

For example, if a system incorporates six XCalibur pumps with other equipment that together require 4 amps, a 10A power supply is satisfactory, provided the output filter capacitance in the supply is at least 10,000 μF:

6 x 0.85 = 5.1A; +4A = 9.1A (choose a 10A power supply)

If the power supply filter capacitance is less than 10,000 μF, use either additional external capacitance or a 15A power supply:

6 x 1.5 = 9.0A; +4A = 13A (choose a 15A power supply)

In this example, it is assumed that all the pumps and other equipment will sometimes operate simultaneously.

External equipment with inadequate bypass capacitance or that is inadequately sourced for current can cause overvoltage transients and sags, and can create unnecessary ripple current in the XCalibur. This can result in decreased component life. Additionally, it is possible for a regulated power supply to become unstable with certain loads and oscillate if adequate filter capacitance is not present. Some forms of oscillation can cause failures in the XCalibur. These issues can be avoided by using a properly designed commercial power supply.

Consideration should also be given to the wiring of the XCalibur and any additional devices. Wiring should be of sufficient gauge for the current, and as short as possible. Unless otherwise required by safety requirements, the power supply lines to the XCalibur should be 20AWG or heavier. Multiple XCaliburs can be daisy-chained, provided that the wire size and the power supply are adequate for the total current. In the example of the six XCaliburs above, use 18AWG wire if the units are daisy-chained. It is best if each pair is twisted or dressed together from the device to the supply. For more information on multi-pump cabling, see Section 2.2, Cabling.

To control power to the XCalibur, switch power to the power supply. Do not use a relay or switch contacts between the 24V supply and the XCalibur (i.e., do not switch DC input to the pump).

2.1.3 Switching Power Supplies

Be sure to check carefully the minimum load requirement of the power supply. Sometimes switching supplies have a minimum load requirement of up to 10% of the rated output current.

Note: *The XCalibur idle current is less than 10% of the full running current.*

For example, in a system with multiple XCalibur pumps, a 24V 5-amp switcher with a minimum load less that 500mA may not provide sufficient current when the XCalibur motors are idle and all other devices are in a low current state. If the

XCalibur is the only load on the 24V supply, a switcher should have a minimum load specification of 50mA or less. An appropriate external power resistor can be used to ensure that the minimum load is met.

2.2 Cabling

A single cable supplies both power and communications to each XCalibur. A unique address identifies each pump module. For more information, see “Address Switch Settings” later in this chapter. See also Chapter 3, "Software Communication".”

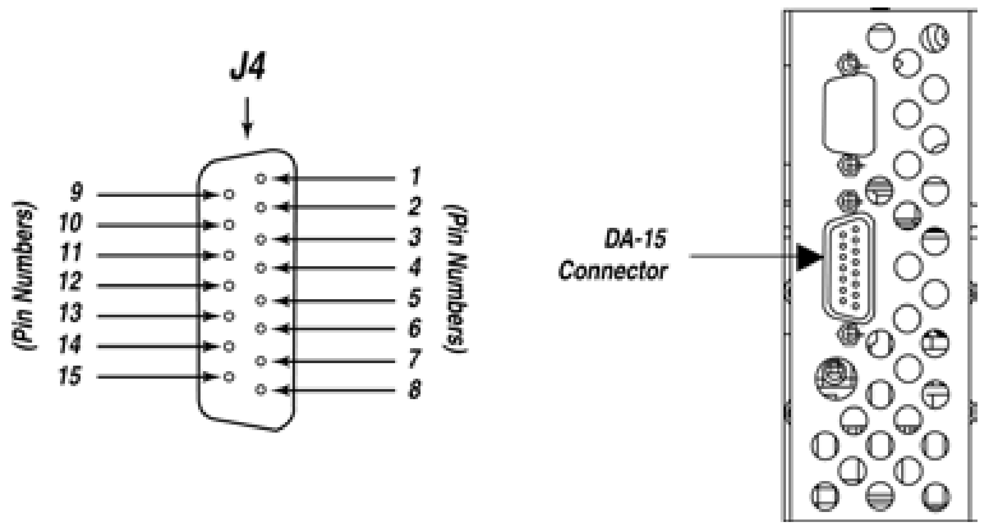
Power requirements are described in Section 2.1, Power and Electrical Considerations.

Table 2-1 *DA-15 Connector Pin Assignments*

Pin	Function	Remarks
1	24V DC	
2	RS-232 TxD line	Output data
3	RS-232 RxD line	Input data
4	Reserved	
5	CAN high signal line	
6	CAN low signal line	
7	Auxiliary input #1	TTL level
8	Auxiliary input #2	TTL level
9	Ground	Power and logic
10	Ground	Power and logic
11	RS-485 A line	Data +
12	RS-485 B line	Data -
13	Auxiliary output #1	TTL level
14	Auxiliary output #2	TTL level
15	Auxiliary output #3	TTL level

Figure 2-1 shows the pin positions of the DA-15 connector on the printed circuit assembly. This is a male connector that requires a female connector on the mating cable.

Figure 2-1 *DA-15 Connector Pins*



2.3 Communication Interfaces

The computer or controller communicates with the XCalibur through an RS-232 interface, RS-485 interface, or CAN (Controller Area Network) interface. Examples of cabling connections are shown in Figure 2-2, Figure 2-3, and Figure 2-4 on the following pages.

2.3.1 RS-232/RS-485 Interface

The RS-232 interface automatically converts the protocol to RS-485 for the benefit of any other devices which may be connected to the XCalibur's RS-485 communication bus (this constitutes the so-called "multi-drop" device configuration).

Note: *The RS-232 interface does not support hardware handshaking and requires only three lines: RXD, TXD, and Signal Ground.*

When using a multi-drop arrangement, up to 15 pumps can be addressed by the controller on the same communications bus. Take special care to ensure that the RS-485 A and B lines are not reversed. Refer to the cabling illustrations on the following pages. These illustrations show the multi-pump cabling for RS-232, RS-485, and CAN connections, respectively. Also shown is the external termination scheme for the RS-485 chain.

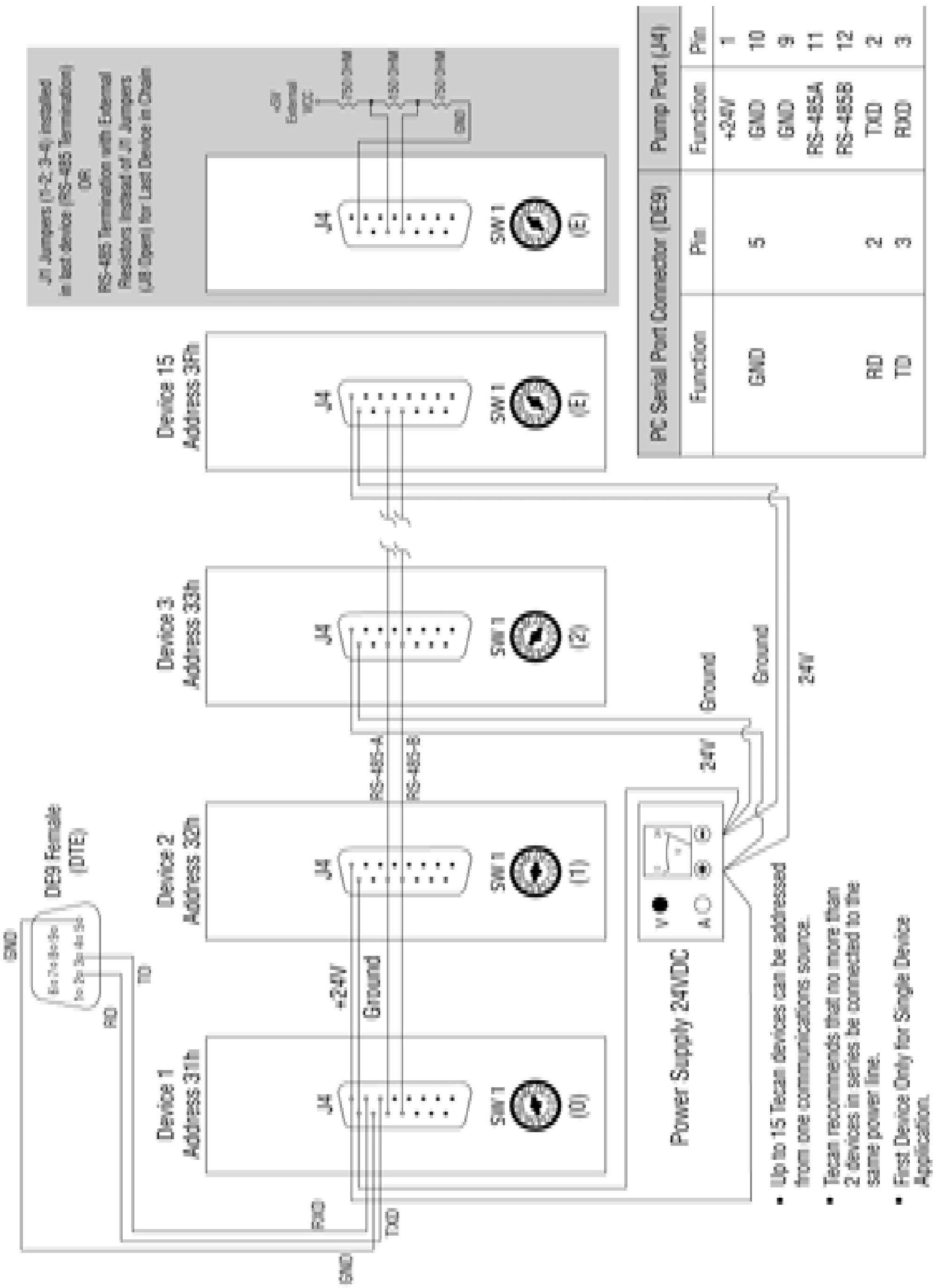
2.3.2 CAN Interface

The CAN interface is a two-wire serial system. The bus is driven differentially in a manner similar to RS-485. The major difference is in the protocol. The CAN protocol is designed to allow any device on the bus to send a message at any time. This is unlike other two-wire interfaces in which the slave devices can only transmit in response to a query. Using the CAN interface, the pump can send a message to inform the master that it has completed its task. Anti-collision detection (which reconciles problems that occur when two devices talk at once) is carried out by the CAN controller hardware.

Caution! *Always power off pumps before connecting to or disconnecting from the bus.*

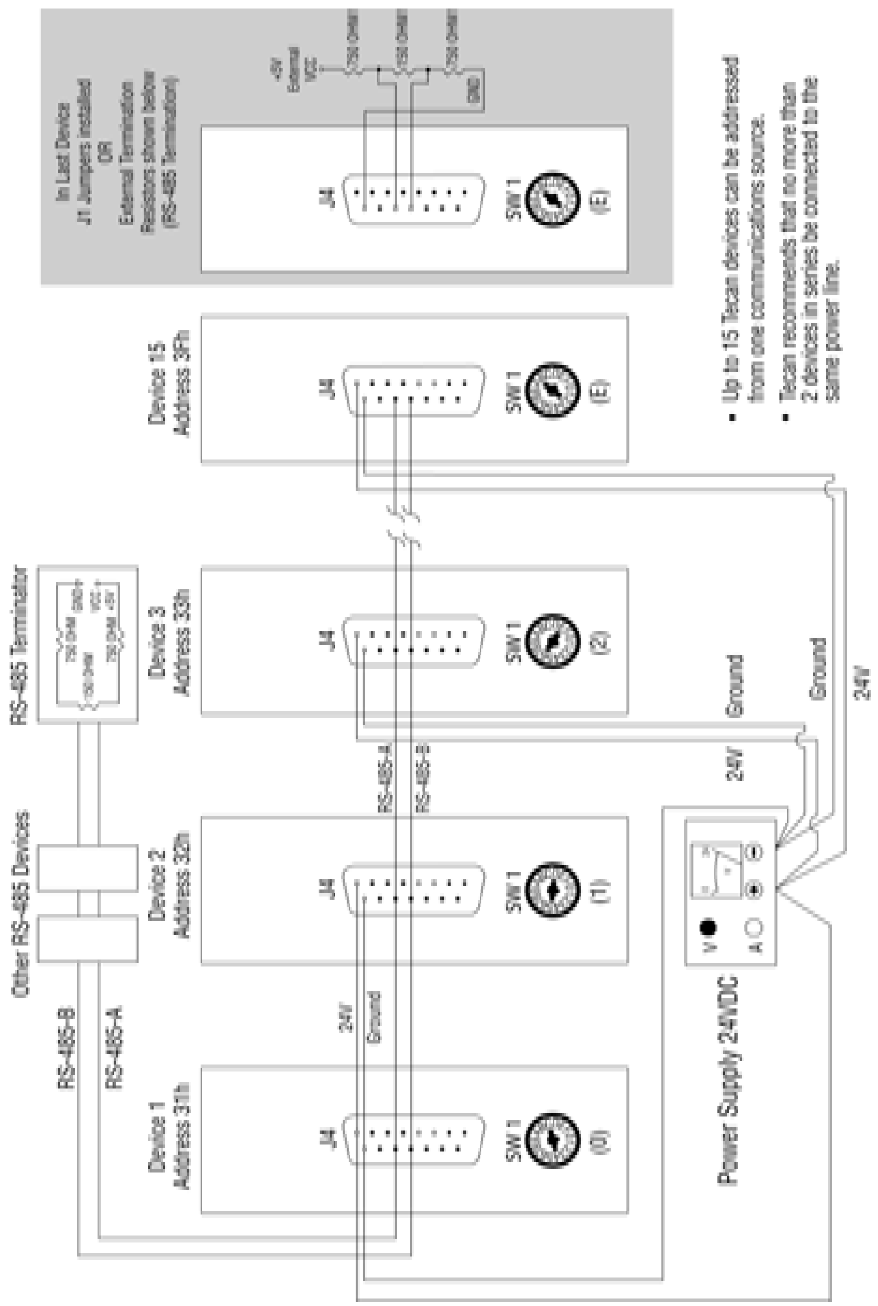
RS-232 Cabling

Figure 2-2 *RS-232 Multi-Pump Cabling*



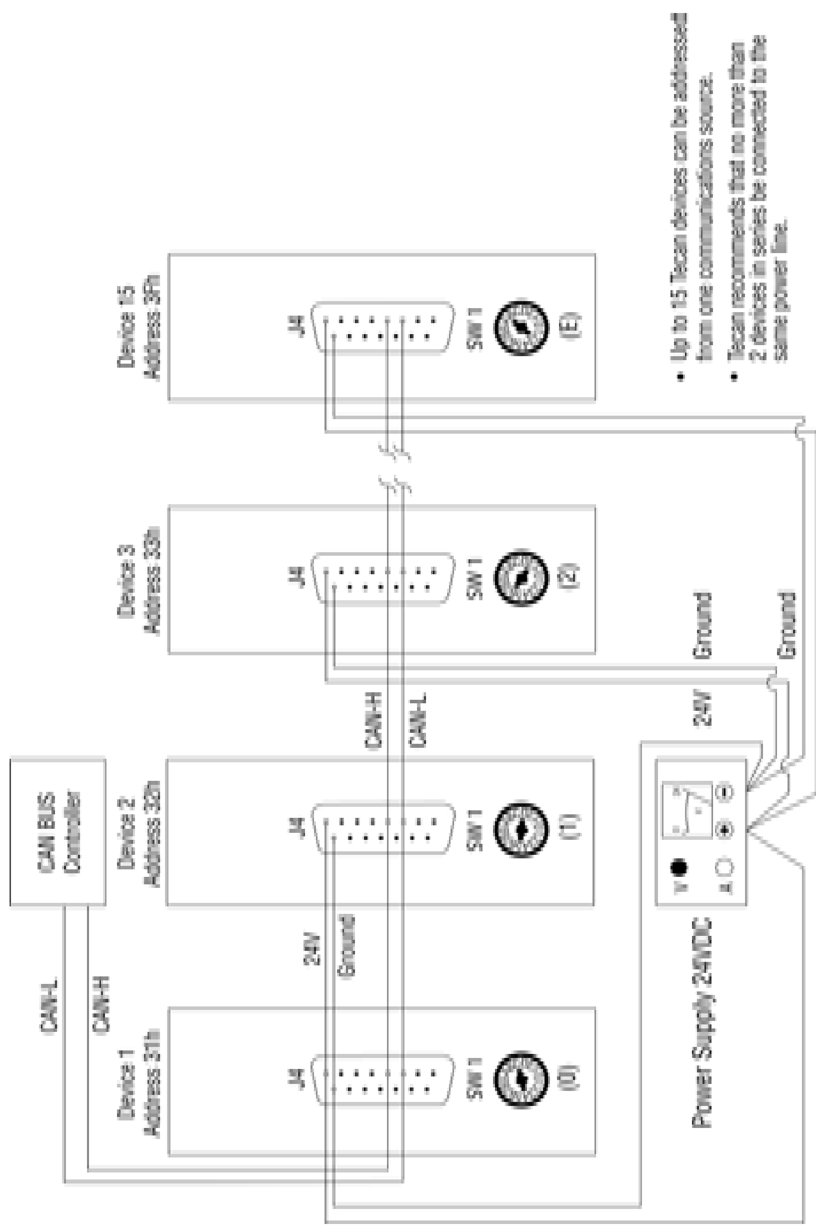
RS-485 Cabling

Figure 2-3 *RS-485 Multi-Pump Cabling*



CAN Cabling

Figure 2-4 *CAN Multi-Pump Cabling*



2.4 Settings and Options

2.4.1 Configuration Commands

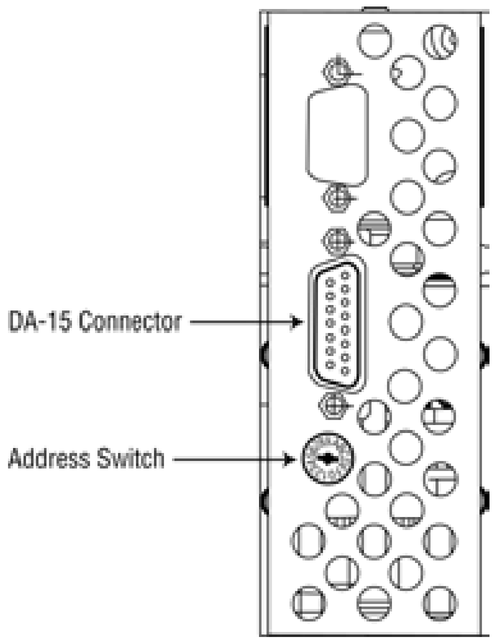
The XCalibur firmware allows the user to configure the pump for different modes of operation. The U commands (see Chapter 3 of this manual) are used to write the configuration information to the non-volatile memory and control the following options:

- **Valve type:** The pump can be configured to operate with different valve options (3-port, 4-port, T-valve, Y Block, 3-port distribution, 6-port distribution, and 9-port distribution).
- **Baud rate:** RS-232/RS-485 communication is possible at 9600 baud (default) and 38400 baud. CAN communication is possible at 100K baud (default), 125K baud, 250K baud, 500K baud, and 1M baud rates.
- **Non-Volatile Memory Auto Mode:** Allows the pump to run command strings out of the non-volatile memory.

2.4.2 Address Switch Settings

The address switch (see Figure 2-5, "Address Switch") is located on the lower left of the XCalibur back panel. It is used to give each XCalibur in a multi-pump configuration a unique or specific address, allowing the user to direct commands to specific pumps. The address switch has sixteen positions (numbered 0 through F). Fifteen positions (addresses 0 through E) are valid pump addresses.

Figure 2-5 *Address Switch*



To set the address switch:

To set the address switch, use a jeweler's screwdriver or small flat head screwdriver and turn the switch in either direction to the desired position.

Note: *Power cycle (or power up) the pump after setting the address switch.*

For information on the addressing schemes for different pump configurations, see Chapter 3, "Software Communication".

2.4.3 Self-Test

The "F" address switch position is used to activate the XCalibur self-test. Self-test causes the XCalibur to initialize, then cycle repeatedly through a series of plunger movements. The self-test cycles through speed codes 0 to 14. If an error condition occurs, the pump stops moving.

To run the self-test, set the address switch to position "F." Then supply power to the pump.

Caution! *Always run liquid through the syringe and valve. Failure to do so can damage the valve and syringe seal.*

Do not run self-test with a 5.0 mL syringe installed. Remove the valve and 5.0 mL syringe. Failure to do so can result in plunger overloads.

2.4.4 Inputs/Outputs

The XCalibur provides two auxiliary inputs and three auxiliary outputs that can be accessed through the DA-15 connector, J4. They provide TTL level signals. The outputs are controlled by the [J] command.

The auxiliary inputs are located on J4 pins 7 and 8. They can be read back using report commands ?13 and ?14. Additionally, the inputs can be used to externally trigger a command sequence using the [H] command. The commands are described in Chapter 3, "Software Communication."

The auxiliary outputs are located on J4, pins 13, 14, and 15.

2.5 Installing Components

2.5.1 Installing the XCalibur Valve

To install the XCalibur valve, follow these steps:

1 Remove as much fluid as possible from the system by cycling the pump and using air as the system fluid.

2 Initialize the pump using the [ZR] command so that the valve motor shaft is in the correct position.

3 Issue an [A3000R] command to move the plunger to the bottom of travel.

4 Remove the syringe and tubing.

5 Remove the two Phillips head screws on the front of the valve, then remove the valve from the pump.

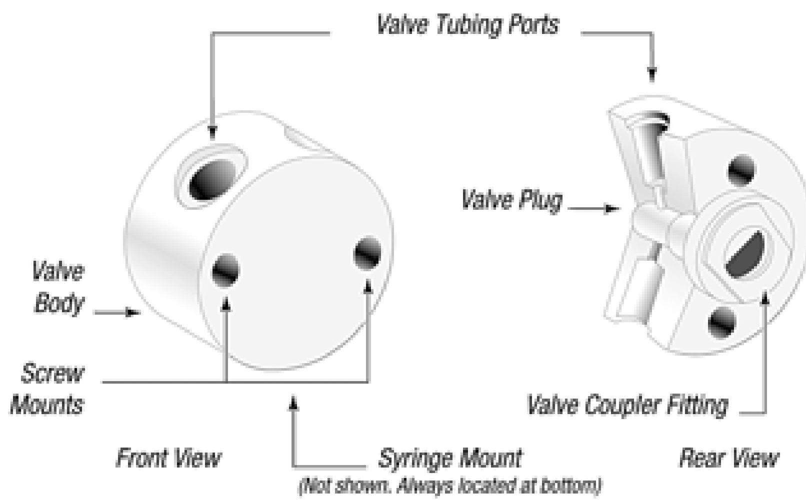
6 Install the new valve by placing it on the front panel so that the screw holes line up. The valve coupler fitting mates to the valve motor shaft. Replace the valve screws.

7 Install the syringe and pull the syringe plunger until it is above the carriage. Align the valve using the plunger as a guide, and tighten from 1/8 to 1/4 turn after the syringe touch-off.

8 Pull the syringe plunger all the way into the carriage and secure by tightening the plunger lock screw.

Caution! *Be sure to reconfigure the pump firmware when changing valve types. Failure to do so may damage the valve. See Section 3.3.2, Pump Configuration Commands, for instructions on reconfiguring the pump.*

Figure 2-6 *XCalibur Valve Installation (3-Port Valve Shown)*



2.5.2 Installing a Syringe

To install a syringe, follow these steps:

1 Initialize pump.

2 Loosen the plunger lock screw approximately three full turns.

3 Lower the plunger drive by sending the command [A3000R]. If power is not applied, the plunger drive can be manually lowered by pushing down firmly on the plunger holder assembly.

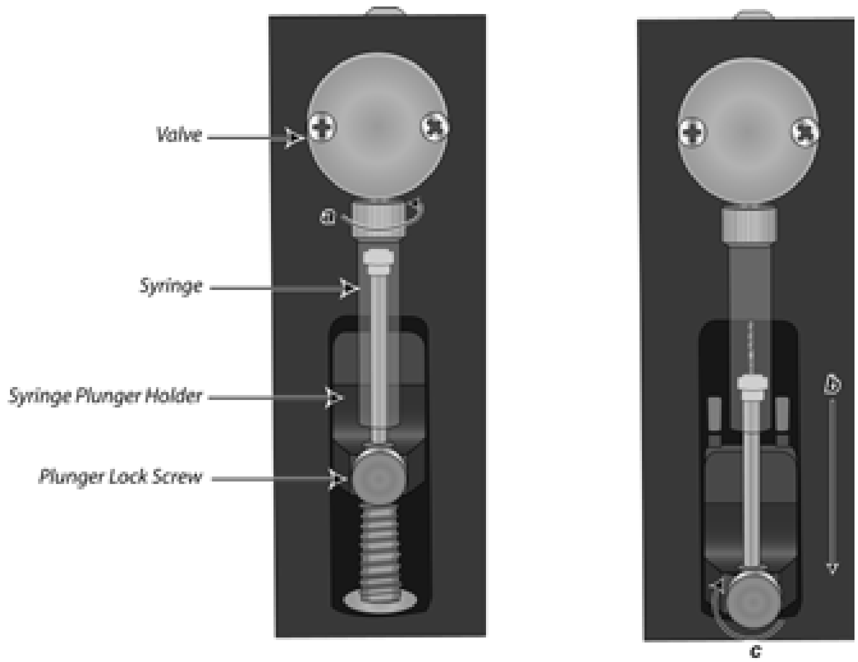
4 To install the syringe (as shown in Figure 2-7, "Syringe Installation"):

- Screw the syringe into the valve until you reach the touch-off point. Tighten from 1/8 to 1/4 turn.
- Pull the syringe plunger down to the carriage.
- Screw the syringe plunger into place.

5 Reinitialize the pump.

Note: *Make sure the plunger lock screw is securely tightened.*

Figure 2-7 *Syringe Installation*



Note: *To obtain optimal performance and maximum syringe life, follow the syringe cleaning and maintenance procedures described in Chapter 5 “Maintenance”. Technical Note #001 (PN730317) contains practical tips for the use and care of Tecan™ precision syringes.*

2.6 Mounting

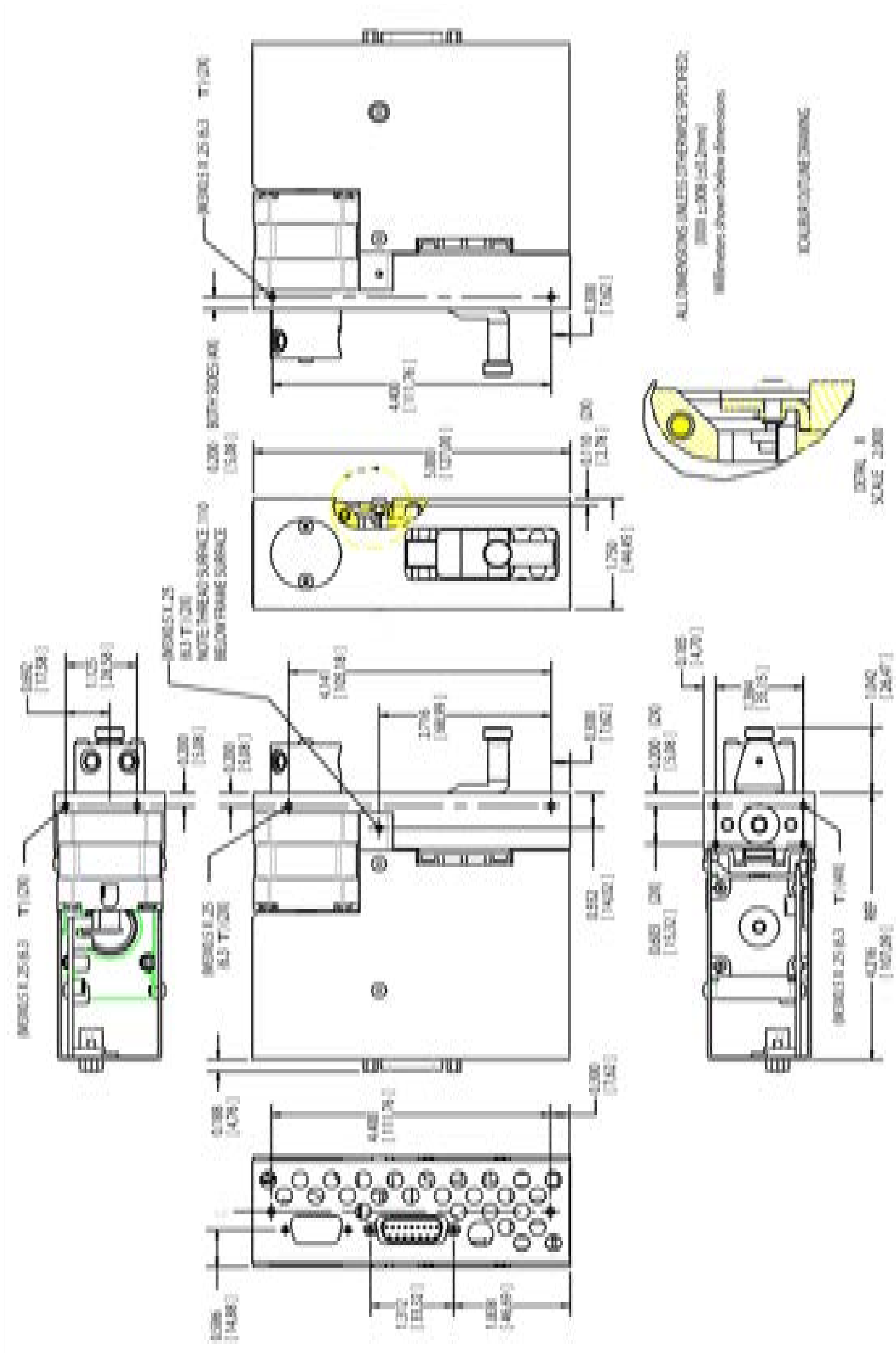
Numerous tapped M3 x 0.5 mounting holes provide the following options for mounting the XCalibur:

- from the bottom
- from the top
- from the sides

Note: *Always mount the pump in an upright position. Failure to do so can cause problems in priming the system.*

To facilitate mounting, see Figure 2-8, "XCalibur Threaded Mounting Holes" for the locations of the threaded mounting holes.

Figure 2-8 *XCalibur Threaded Mounting Holes*



3 Software Communication

This chapter describes how to communicate with the XCalibur: through an RS-232, RS-485, or CAN (Controller Area Network) interface.

This chapter includes these topics:

- XCalibur Addressing Scheme
- Communication Protocols
- Using the XCalibur Command Set
- Initialization
- Operating Commands
- Error Codes and Pump Status

3.1 XCalibur Addressing Scheme

As part of the communication protocol, an address for each pump must be specified. The user has the option of addressing a single pump, two pumps (dual device), four pumps (quad device), or all 15 pumps (all devices), depending on the address byte used. Each physical address in the address switch corresponds to a hexadecimal value, as shown in Table 3-1, Hexadecimal Addressing Scheme.

Table 3-1 *Hexadecimal Addressing Scheme*

Address (hex)		Device
RS-232/RS-485	**CAN**	
30	0	Master Address (master controller, personal computer, etc.)
31..3F	1..F	Addresses single device
41..4F	N/A	Addresses two devices at a time (dual device)
51..5D	N/A	Addresses four devices at a time (quad device)
5F	N/A	Addresses all devices on the bus

For example, an XCalibur with address switch set to 0 is addressed as device “31h” in the RS-232 or RS-485 communication protocol, hardware address 1 is addressed as device “32h,” and so on.

Table 3-2, Address Switch Settings in Hex (ASCII), shows the different address switch settings for each of these configurations.

Note: *When using the Pump:Link software to send commands to a device, use the ASCII address values in Table 3-2.*

Table 3-2 *Address Switch Settings in Hex (ASCII)*

Switch Setting	Single Device		Dual Device		Quad Device		All Devices	
	Hex Address	**ASCII Address**	**Hex Address**	**ASCII Address**	**Hex Address**	**ASCII Address**	**Address**	**Value to Send**
0	31	1	41	A	51	Q	5F	–
1	32	2						
2	33	3	43	C				
3	34	4						
4	35	5	45	E	55	U		
5	36	6						
6	37	7	47	G				
7	38	8						
8	39	9	49	I	59	Y		
9	3A	:						
A	3B	;	4B	K				
B	3C	<						
C	3D	=	4D	M	5D	]		
D	3E	>						
E	3F	?	4F	O				
F	Self Test							

The user can communicate with all pumps in the chain by using address “5Fh,” for example to initialize all pumps at once. Then each pump can be controlled independently by using addresses “31h” to “3Fh.”

Note: *Multiple address commands cannot be used to determine device status or to request reports. Each device must be queried separately to gather status or generate a report..*

3.2 Communication Protocols

Three communication protocols are available:

- OEM communications protocol
- Data Terminal (DT) protocol
- CAN protocol

The XCalibur firmware automatically detects the communication protocol.

The DT protocol can be run via an ASCII data terminal because no sequence numbers or checksums are used. For instructions on using a Microsoft Windows Terminal Emulator, see “Using DT Protocol with Microsoft Windows” in this chapter.

Note: *Tecan Systems recommends using the OEM protocol for RS-232 and RS-485 interfaces. It provides increased error checking through the use of checksums and sequence numbers.*

Once the XCalibur detects the OEM protocol, it will ignore the DT protocol until the next power cycle.

3.2.1 OEM Communication Protocol

OEM communication is a robust protocol that includes automatic recovery from transmission errors. Table 3-3, OEM Protocol describes each setting within the OEM communication protocol.

Table 3-3 *OEM Protocol*

Parameter	Setting
Character Format	
Baud rate	9600 or 38400
Data bits	8
Parity	None
Stop bit	1
Command Block (see “OEM Protocol Command Block Characters” for details)	
1	STX (^B or 02h)
2	Pump address
3	Sequence number
3+n	Data block (length n)

4+n	ETX (^C or 03h)
5+n	Checksum
Answer Block (see "OEM Protocol Answer Block Characters" for details)	
1	STX (^B or 02h)
2	Master address (0 or 30h)
3	Status code
3+n	Data block (length n)
4+n	ETX (^C or 03h)
5+n	Checksum

OEM Protocol Command Block Characters

The command block characters in the OEM communication protocol are described below. All characters outside the command block are ignored.

When developing a parsing algorithm, the programmer should key on the STX as the beginning of the answer block and the checksum (character after the ETX) as the end of the answer block.

STX (^B or 02h)

The STX character indicates the beginning of a command

Pump Address

The pump address is a hexadecimal number specific for each pump.

Sequence Number/Repeat Flag

The sequence number is a single byte that conveys both a sequence number (legal values: 0 to 7) and a bit-flag indicating that the command block is being repeated due to a communications breakdown. The sequence number is used as an identity stamp for each command block. Since it is only necessary that every message carry a different sequence number from the previous message (except when repeated), the sequence number may be toggled between two different values (e.g., "1" and "2") as each command block is constructed. During normal communication exchanges, the sequence number is ignored. If, however, the repeat flag is set, the pump compares the sequence number with that of the previously received command block to determine if the command should be executed or merely acknowledged without executing.

Note: *If the operator chooses not to use this option, the sequence number can be set to a fixed value of 1 (31h).*

The following two scenarios clarify this error detection mechanism.

Scenario 1.

1 The computer sends a command block stamped with sequence #1 to the pump.

2 The pump receives the command, sends an acknowledgement to the PC, and executes it.

3 Transmission of the acknowledgement message is imperfect; the PC does not receive it.

4 The PC waits 100 ms for the acknowledgement, then retransmits the command block with the sequence number left at 1 and the repeat bit set to indicate a retransmission.

5 The pump receives the transmission, identified as such by the repeat bit.

6 The pump checks the sequence number against that of the previously received command block. Noting a match, the pump sends an acknowledgement to the PC, but it does not execute the command (since it has already been executed).

7 The PC receives the acknowledgement and continues with normal communications.

8 The next command block is stamped with sequence #2 to indicate a new command.

Scenario 2.

1 The computer sends a command block stamped with sequence #1 to the pump.

2 The pump never receives the command due to a communication error and thus does not send an acknowledgement to the PC.

3 The PC waits 100 ms for the acknowledgement, then retransmits the command block with the sequence number left at 1 and the repeat bit set to indicate a retransmission.

4 The pump receives the retransmission, identified as such by the repeat bit.

5 The pump checks the sequence number against that of the previously received command block. Noting a mismatch, the pump recognizes this as a new command block and sends an acknowledgement to the PC. It then executes the command.

6 The PC receives the acknowledgement and continues with normal communications.

7 The next command block is stamped with sequence #2 to indicate a new command.

The sequence number/repeat byte is constructed as follows:

Bit #	7	6	5	4	3	2	1	0
Value	0	0	1	1	REP	SQ2	SQ1	SQ0

REP

0 for non-repeated / 1 for repeated

SQ0 – SQ2

Sequence value, as follows:

Sequence Value	SQ2	SQ1	SQ0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

Note: *Bits 4 through 7 are always fixed to the values shown.*

Data Block (length n)

The data block consists of the data or commands sent to the pump or host (this is an ASCII string). When the pump is responding to a move or [Q] command, the data block length is 0 (i.e., no data string exists).

ETX

The ETX character indicates the end of a command string.

Checksum

The checksum is the last byte of the message string. All bytes (excluding line synchronization and checksums) are XORed to form an 8-bit checksum. This is appended as the last character of the block. The receiver compares the transmitted value to the computed value. If the two values match, an error free transmission is assumed; otherwise, a transmission error is assumed.

OEM Protocol Answer Block Characters

The answer block characters in the OEM communication protocol are described below.

Only the unique answer block entries are listed in this section. For common commands and answer block commands (characters), see the previous section, “OEM Protocol Command Block Characters.”

Master Address

The master address is the address of the host system. This should always be 30h (ASCII value “0”).

Status and Error Codes

The status and error codes define pump status and signal error conditions. For a description of status and error codes, see “Error Codes and Pump Status” in this chapter.

3.2.2 Data Terminal (DT) Protocol

The DT protocol can be used easily from any terminal or terminal emulator capable of generating ASCII characters at 9600 baud, 8 bits, and no parity.

Table 3-4 *DT Protocol*

Character Format	
Parameter	**Setting**
Baud rate	9600 or 38400
Data bits	8
Parity	None
Stop bit	1
Command Block (see “DT Protocol Command Block Characters” for details)	
1	Start command (ASCII “/” or 2Fh)
2	Pump address
2+n	Data block (length n)
3+n	Carriage Return ([CR] or 0Dh)
Answer Block (see “DT Protocol Answer Block Characters” for details)	
1	Start answer (ASCII “/” or 2Fh)
2	Master address (ASCII “0” or 30h)
3	Status character

3+n	Data block (if applicable)
4+n	ETX (03h)
5+n	Carriage return (0Dh)
6+n	Line feed (0Ah)

DT Protocol Command Block Characters

The command block characters in the DT communication protocol are described below.

Start Block

The start character indicates the beginning of a message block.

Pump Address

The pump address is an ASCII character specific to each pump.

Data Block (length n)

The data block consists of the ASCII data or commands sent to the pump or host.

End Block

The end character indicates the end of a message block.

DT Protocol Answer Block Characters

The answer block characters comprising the DT communication protocol are described below.

Only unique answer block entries are listed in this section. For information on command and answer block commands (characters), see the previous section, “OEM Protocol Command Block Characters.”

Master Address

The master address is the address of the host system. This should always be 30h (ASCII “0”).

Status Character

The status and error codes define pump status and signal error conditions. See the description of the [Q] command in “Error Codes and Pump Status.”

Data Block

This is the response from all Report commands with the exception of the [Q] command.

Carriage Return (0Dh)/Line Feed (0Ah)

This character terminates the reply block.

3.2.3 Using DT Protocol with Microsoft Windows

The XCalibur can be controlled in DT protocol mode directly from the Microsoft Windows terminal accessory.

To communicate with the XCalibur using Windows 3.x, follow these steps:

1. Connect the XCalibur to a communications port of the PC (for example, COM1).
2. From the Microsoft Program Manager window, select **Terminal** from the Accessories group window.
3. Select the **Settings** menu, and choose **Communications**.
4. Select a baud rate of 9600, 8 data bits, 1 stop bit, no parity, communications port connector, and no flow control.
5. Click **OK**.
6. Set the pump address switch to 0 and remove all configuration jumpers in JP1-2 and JP1-4.
7. Power on the pump.
8. Type /1ZR<CR> to initialize the pump.
9. To run the pump, see the commands listed in “Using the XCalibur Command Set” in this chapter.

To communicate with the XCalibur using Windows 95/98/NT/2000/XP, follow these steps:

1. To connect the XCalibur to a communications port on the PC, first select the **Start Programs/Accessories/Communications Hyperterminal** menu and choose **Run**.
2. In the Run dialog box, type **Hyperterm.exe**. The Connection Description dialog box appears.
3. Enter a name for the connection and select an icon, then click **OK**. The Phone Number dialog box appears.
4. Select the following in the fields provided:

   Connect using: Direct to <communication port> (usually COM1 or COM2, depending on how the hardware is set up)

   Click **OK**. The COM Properties dialog box appears.
5. Select the following in the fields provided:
   - Bits per second: 9600
   - Data bits: 8
   - Parity: None
   - Stop bits: 1
   - Flow control: None

6 Click **OK**.
7 Select the **File** menu, and choose **Properties**. The Properties dialog box appears.
8 Select the **Settings** tab, and enter or select these options:
   – Function, arrow, and Control keys act as:
      • Select “Terminal keys”
   – Emulation:
      • Select “Autodetect”
      • Enter “500” in Backscroll buffer lines
   – Click the **ASCII Setup** button. The ASCII Setup dialog box appears.
9 Enter or select these options:
   – Select “Send line ends with line feed”
   – Select “Echo typed characters locally”
   – Enter a Line delay of “0”
   – Enter a Character delay of “0”
   – Select “Wrap lines that exceed terminal width”
10 Click **OK** to close the ASCII Setup dialog box, then click **OK** to close the Properties dialog box.
11 Set the pump address to 0 or the appropriate address.
12 The communication protocol is detected automatically.
13 Power on the pump and initialize it by typing /1ZR and pressing **Enter**.

   To run the pump, see the commands listed in “Using the XCalibur Command Set” in this chapter.

3.2.4 CAN Interface Communications

CAN (Controller Area Network) is a two-wire, serial communication bus. It eliminates polling sequences that verify task completion. Using CAN, the pumps asynchronously report to the master or host when they have finished the current task.

Note: *All Tecan XCalibur systems use CAN controller chips compatible with Phillips Semiconductor CAN bus specification, version 2.0.*

When using the CAN interface, termination resistors (120 ohm) are necessary at both ends of the bus. The pump does not provide CAN termination resistors.

CAN Messages

CAN messages consist of *frames*. Each frame has an 11-bit message Identifier (MID) and a 4-bit length identifier. The bits:

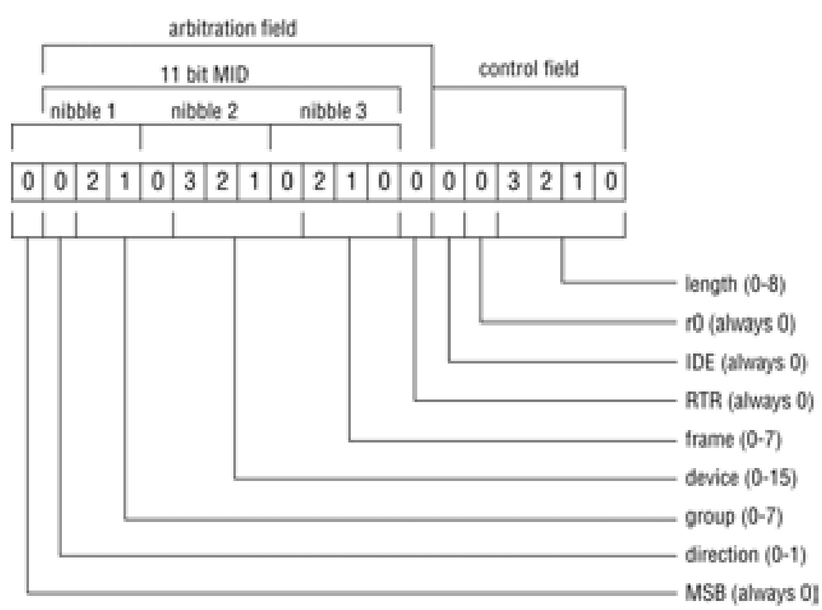
- Indicate to which device on the bus the message is directed
- Identify the message type
- Show the direction of the message (to or from the master device)

- Represent the length of the data block. Data blocks can be from zero to eight bytes in length. Any message that requires more than eight bytes must be sent in a series of multi-frame messages. The receiving unit then assembles the separate frames into one long string.

CAN Message Construction

Each message frame begins with the Message ID (MID). The data block (up to 8 bytes in length) follows the MID and length information. The MID makes up three nibbles that are transmitted first in a message frame. The bits are grouped as shown in Figure 3-1, 'CAN Message Structure".

Figure 3-1 *CAN Message Structure*



Direction

This is the direction bit. It lets the devices on the bus know whether the current message is to or from the master. "0" means that the message is from master to slave; "1" means the message is from the slave to the master.

Note: *Peer-to-peer messaging is not supported.*

Group

This is the group number (0 - 7). Each type device on the CAN bus has a group assignment. The XCalibur is assigned to group 2. The group number "1" is reserved for the boot request procedure.

Device

This is the address of the module in the particular group. Each group can have up to 16 devices. The address value is 0 - 15.

Frame

This lets the device know what type of message is coming. See “CAN Frame Types” in this chapter.

RTR

This bit is not used in Tecan Systems’ CAN implementation and should always be set to 0.

IDE

This will always be set to 0 for standard format frames.

r0

Reserved bit, set to 0.

Length

This is the length of the data block in the message. Data blocks can be from zero to eight bytes in length.

CAN Frame Types

The frame types allow each device to know what type of command is coming in and enables faster processing of commands. Pumps respond to the frame types described below.

“On-the-Fly” Commands (V and T), Type 0

Normal commands use a frame type 1 (i.e., “Action Commands”). Since commands sent over the CAN bus with a particular frame type must complete before a subsequent command using the same frame type can be issued, a different ID must be used when issuing an “on-the-fly” command. For this reason, “on-the-fly” commands must be issued over the CAN bus with a frame type of “0” (zero).

When issuing “on-the-fly” commands, the “frame type 0” commands will not generate completion messages and thus no pairing code is needed (these commands are simply acknowledged immediately).

Action Frames, Type 1

This frame type is used for action commands, such as Initialization commands, Movement commands, Valve commands, or to set pump operating parameters. All “task-type” commands are sent in this type message frame. When multi-frame messages are used to send an action command, this frame is the end message sent to the pump.

Common Commands, Type 2

This frame type is used for commands that are common to every device on the bus. The frame type is set to 2 and the command is a single ASCII character in the data block. The single ASCII character is described below.

Command	Description
0	Reset mode. This resets the pump and begins the boot request procedure.
1	Start loaded command. Just like sending an [R] command after a string has been loaded.
2	Clear loaded command. This clears out the command buffer.
3	Repeat last command. This command does the same thing as the [X] command.
4	Stop action immediately. This acts like a [T] command.

Multi-Frame Start Message, Type 3

This frame type lets the pump know that the next message will be longer than the 8-byte maximum for each frame. Subsequent frames will follow to complete the message.

Multi-Frame Data, Type 4

This frame type is used to identify a frame in the middle of a multi-frame message. The last frame of a multi-frame message for action commands must be type 1. The last frame of a multi-frame message response from the pump for report commands will be type 6.

Note: *There is no type 5 frame.*

Report/Answer Commands, Type 6

This frame type is used to get information back from the pump. It is similar in operation to the query commands (i.e., [?]) used in the OEM and DT protocols. The report command is one byte long and consists of one or more ASCII characters in the data block. Report commands in ASCII format are:

Command	Description
0	Report calculated plunger position in increments (standard/fine positioning)
1	Report linear encoder position in increments
3	Report current valve position in mnemonics
4	Report end speed in increments per second
6	Report start speed in increments per second

7	Report cutoff speed in increments per second
10	Report buffer status
12	Report number of backlash increments
13	Report status of input #1
14	Report status of input #2
15	Report the number of pump initializations
16	Report the number of plunger movements
17	Report the number of valve movements
18	Report the number of valve movements since last report
20	Report checksum
22	Report liquid sensor value *(Non-functional command implemented for the purpose of backward compatibility with the XP 3000 command set)*
23	Report firmware version
24	Report zero gap increments
29	Report current status

When the pump responds to a query, the first byte of the data block is the status byte. It is defined like the status byte in the RS-232 and RS-485 protocols. The next byte is a null character. The remaining six bytes are for the response in ASCII. If the pump is only reporting current status, the message is only two bytes long. If the reply consists of more than six bytes, multi-frame messages are used.

CAN Data Block

The data block tells the pump what to do. Pump commands are sent in ASCII just like in RS-232 or RS-485. For command strings that are more than eight bytes in length, multi-frame messages are used. This permits long program strings to be sent as with the other communications interfaces (remember that the XCalibur buffer size is 255 characters).

Handling of Pump Boot Requests

When the pump is first powered up or receives a system reset command (frame type, command 0), the pump notifies the host of this condition by sending a boot request message at one second intervals until it receives a proper response. The group number is 1 for the boot request message. The frame type is 2 when the pump sends messages to the host, and the frame type must be 0 when the host replies to the boot request.

Example 1. The pump is set to address 0

Pump sends:

Dir	Group	Device	Frame	RTR	Length
1	001	0000	010	0	0000

Host acknowledges:

Dir	Group	Device	Frame	RTR	Length	Node ID	Slave ID
0	001	0000	000	0	0010	0010 0000	0010 0000

Host acknowledges the boot request with:

Dir = 0	Host to slave	**Note**: Boot MID is the same for all nodes
Group = 1	Boot request response group	
Device = 0	Always 0 in boot response	
Frame = 0	Boot request response frame	
RTR = 0	Always 0	
Length = 2	Two data bytes in return message	

Node ID	Group ID (2) + Pump Address (0)	“ ”	00h	Must respond with Group & Address
Slave ID	Same as Node ID (hex 20)	“ ”	00h	

Example 2. The pump is set to address 6

Pump sends:

Dir	Group	Device	Frame	RTR	Length
1	001	0110	010	0	0000

Host acknowledges:

Dir	Group	Device	Frame	RTR	Length	Node ID	Slave ID
0	001	0000	000	0	0010	0010 0110	0010 0110

Host acknowledges the boot request with:

Dir = 0	Host to slave	**Note**: Boot MID is the same for all nodes
Group = 1	Boot request response group	
Device = 0	Always 0 in boot response	
Frame = 0	Boot request response frame	
RTR = 0	Always 0	
Length = 2	Two data bytes in return message	

Node ID	Group ID (2) + Pump Address (6)	"&"	Hex	26
Slave ID	Same as Node ID (hex 26)		Hex	26

The pump will save the Node ID to use for message filter Group ID.

Note: *The slave ID does not have to be the same as the node ID. The pump can be assigned any number between 0 and 0x7F (127) for the slave ID.*

CAN Host and Pump Exchanges

When a slave pump receives a command, finishes a command, encounters an error condition, or responds to a query, it sends an answer frame to the host using the same frame type as the command it belongs to. The answer frame format is device dependent. Generally, it will have the following format:

<MID><DLC><Answer>

<MID>

11-bit message identifier. The direction bit is 1. The group number and the frame type are the same as received. Device ID is the slave message ID assigned by the host.

<DLC>

4-bit data length code

<Answer>

Data bytes block. The first byte of the data block is always the status byte. It is defined as in Table 3-9, Error Codes and ASCII and Hexadecimal Values. The second byte is a null character. The remaining bytes contain the response in ASCII format. If the reply consists of more than six bytes, the multi-frame messages are used.

Note: *Only one command of a given frame type can be in progress at any one time; e.g., after issuing a command to a slave pump with frame type = 1, the master must wait for the answer with frame type = 1 before issuing the next command with frame type = 1. If the user insists on sending the command, a command overload status results.*

Several commands with different frame types can be in progress at the same time; e.g., an action command and a query command.

Following are typical exchanges between the host and slave for action commands, multi-frame commands, common commands, and query commands.

Action Command

The host commands [ZR] to a pump, and the pump is set to address 0.

Host sends:						
0	010	0000	001	0	0010	ZR
Dir	Group	Device	Frame type	RTR	DLC	Data bytes
Pump acknowledges:						
1	010	0000	001	0	0000	
Dir	Group	Device	Frame type	RTR	DLC	
After executing the command, pump reports status:						
1	010	0000	001	0	0010	<60h><00h>
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Note: *The mixed formats ASCII and hexadecimal are used in the data bytes block. The hexadecimal number is bracketed (< >). The rest of the fields are displayed in binary format.*

Multi-Frame Command

The host commands [Z2S5IA3000OgHD300G10G5R] to a pump, and the pump is set to address 0.

Host sends:

0	010	0000	011	0	1000	Z2S5IA30
Dir	Group	Device	Frame type	RTR	DLC	Data bytes
0	010	0000	100	0	1000	00OgHD30
Dir	Group	Device	Frame type	RTR	DLC	Data bytes
0	010	0000	001	0	0111	0G10G5R
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Pump acknowledges:

1	010	0000	001	0	0000
Dir	Group	Device	Frame type	RTR	DLC

After executing the command, pump reports status:

1	010	0000	001	0	0010	<60h><00h>
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Note: *For multi-frame commands, the pump only acknowledges the last frame.*

Common Command

After the host has sent command [A1000A0] to the pump, it sends command 1 of frame type 2 to a pump and makes the pump move. The pump is set to address 0.

Host sends:

0	010	0000	010	0	0001	1
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Query Command

The host commands 29 of frame type 6 to a pump, and the pump is set to address 1.

Host sends:

0	010	0001	110	0	0010	29
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Pump reports:

1	010	0001	110	0	0010	<60h><00h>
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Note: *For query commands, no acknowledge frame is needed.*

Report Command

The host sends command report 23 of frame type 6 to a pump, and the pump is set to address 1.

Host sends:

0	010	0001	110	0	0010	23
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Pump reports:

1	010	0001	011	0	1000	<60h><00h> 737230
Dir	Group	Device	Frame type	RTR	DLC	Data bytes
1	010	0001	110	0	0010	<20h> A
Dir	Group	Device	Frame type	RTR	DLC	Data bytes

Note: *This example corresponds to firmware part number 737230 revision A. Response to query will vary depending on part number and version.*

Note: *For a multi-frame reply, the start frame is type 3, the middle frame is type 4, and the last frame is type 6.*

3.3 Using the XCalibur Command Set

The XCalibur features a robust command set which allows a wide range of parameters to be defined by the user. Many of the commands have default values; however, the default values may not provide the optimal settings for your application. Take a moment to familiarize yourself with each command in order to obtain the best performance for your application.

For a quick summary of all commands, see Appendix G, "Command Quick Reference".

When problems are detected, the XCalibur sends an error code. The error codes are described in “Error Codes” at the end of this chapter.

Note: *Some commands are invalid in the CAN interface. For a list of these commands, see Appendix F, "CAN Communication Commands".*

3.3.1 Command Execution Guidelines

To use the commands properly, keep the following in mind:

- All commands, except Report commands and most Control commands, must be followed by an [R] (Execute) command.
- Single or multiple command strings can be sent to the pump.

  For example:
  - A single command such as [A3000R] moves the plunger to position 3000.
  - A *multi-command string* such as [IA3000OA0R] moves the valve to the input position, moves the plunger to position 3000, turns the valve to the output position, and finally returns the plunger to position 0.
- The pump’s command buffer holds a maximum of 255 characters. If a command is sent without the [R] (Execution) command, it is placed into the buffer without being executed. If a second command is sent before the first command is executed, the second command overwrites the first command (i.e., the first command string is erased).
- Once a command is executed, new commands are not accepted until the sequence is completed. Exceptions to this rule include interruptible (see “T Terminate Command” in this chapter) and Report commands.
- When a command is sent, the pump answers immediately. If an invalid command has been sent in a command string, the pump reports an error immediately. If there was an invalid parameter in the command, the pump will execute up to the invalid parameter, then stop. In the case of a [Q] (Query) command, the error is read back to the host computer.
- Always run liquid through the syringe and valve when issuing a Move command. Failure to do so may damage the valve and syringe seal.
- Keep fingers out of the syringe slot while the pump is running. Failure to do so can result in injury.

Command Syntax and Notes

The syntax for each command in the command set is:

<n>	Numerical value within a given range
0..6000	Range of numerical values allowed
(n)	Default value

Note:

- *Multiple values of <n> in a single command must be separated by commas*
- *Square brackets, [ ], are used to distinguish commands and should not be sent as part of the command strings.*
- *Commands are case-sensitive.*
- *Response time from the transmission of the checksum byte to transmission of the start character is less than 5 msec.*

3.3.2 Pump Configuration Commands

XCalibur pumps are preconfigured at the factory to the default settings. The firmware, however, allows the user to configure the pump to meet his or her specific requirements. Configuration options available to the user include resolution, backlash, valve type, and baud rate.

N <n> Set Microstep Mode Off/On

The [N] command enables or disables microstepping (fine positioning). The syntax for this command is:

[N<n>]

where <n> = 0 or 1 (0 is the default)

When <n> = 0, the fine positioning mode is off and the XCalibur uses the standard 3000 increments/full stroke. If <n> = 1, fine positioning mode is on and the XCalibur uses 24,000 increments/full stroke. Speed is programmed in increments per second.

K<n>   Backlash Increments

The [K] command sets the number of backlash increments. The syntax for this command is:

[K<n>]

where <n> = 0..31 in full step mode (12 is the default),
and <n> = 0..248 in fine positioning mode (96 is the default).

When the syringe drive motor reverses direction, the carriage will not move until the backlash due to mechanical play within the system is compensated. To provide this compensation, during aspiration, the plunger moves down additional increments, then backs up the set number of backlash increments. This ensures that the plunger is in the correct position to begin a dispense move. Note that a small volume of fluid flows out the "input" side of the valve during this operation.

U<n>   Write Pump Configuration to Non-Volatile Memory

The [U] command is used to write configuration information to the non-volatile memory. The pumps are configured during the manufacturing process but can be reconfigured at any time with the following [U] commands:

Table 3-5 *Write Pump Configuration Command Values*

Value<n>	Description
0	No Valve
1	3-Port valve
2	4-Port valve
3	3-Port distribution valve (face seal)
5	T Valve
7	6-port distribution valve
8	9-port distribution valve
9	Dual loop valve
11	3-Port distribution valve (plug)
30	Set Non-Volatile Memory Auto Mode
31	Clear Non-Volatile Memory Auto Mode
41	Set RS-232/RS-485 Baud rate to 9600
47	Set RS-232/RS-485 Baud rate to 38400
51	Set CAN Bus Baud rate to 100K
52	Set CAN Bus Baud rate to 250K
53	Set CAN Bus Baud rate to 500K

Table 3-5 Write Pump Configuration Command Values

Value<n>	Description
54	Set CAN Bus Baud rate to 1M
57	Set CAN Bus Baud rate to 125K

Note: *[U] commands take effect on the pump's next power-up.*

3.4 Initialization

3.4.1 Initialization Forces

Initialization moves the plunger to the top of the syringe, which is set to position 0. Also, the input and output positions of the valve are assigned depending on the initialization parameters.

The top of the syringe is recognized when upward movement of the plunger causes an overload condition.

The force at which the plunger presses against the top of the syringe can be controlled via a parameter after the Initialization command (possible values are 0, 1 and 2).

Table 3-6 lists the recommended initialization force for each type of syringe.

Caution! *To retain the integrity of the seal on smaller syringes, use a lower initialization force than that for larger syringes. The default initialization speed is 500 Hz.*

Table 3-6 Recommended Initialization Forces by Syringe

Syringes	Force
1.0 mL and larger	Full
250, 500 µL	Half
50, 100 µL	Third

k <n>   Syringe Dead Volume Command

The [k] command allows the setting of the number of increments that the plunger travels after initialization. This is to minimize dead volume. The syntax for this command is:

[k<n>]

where:

<n> = the offset in increments from zero position
<n> = 0..80   (50 is the default)
<n> = 0..640 in fine positioning mode (400 is the default)

Under default initializations, the plunger moves upward until it contacts the top of the syringe, causing a forced stall initialization. The plunger then moves downward and upward, leaving a small gap between the syringe seal and the top of the plunger. This small gap was designed so that the Teflon seal does not hit the top of the plunger each time the syringe moves to the “home” position. This maximizes the life of the syringe seal.

The [k] command must be followed by the Initialization command [Z], [Y], or [W]. Each time the unit is powered down, the “k” value will return to the default condition.

For example, to offset 10 increments away from the zero position, send the following commands:

– k10R
– ZR

3.4.2 Initialization Commands

Z <n_1, n_2, n_3>   Initialize Plunger and Valve Drive (CW Polarity)

The [Z] command initializes the plunger drive and homes the valve in a clockwise direction. Valve ports are numbered 1..X, starting in a *clockwise* direction at the first port after the syringe port. The default initialization speed is 500 pulses per second.

n_1 = Set initialization plunger force/speed
n_2 = Set initialization input port
n_3 = Set initialization output port

The parameters are described below.

Z Parameter	Value	Description
<n_1>	0	Initializes at full plunger force and at default initialization speed (default)
	1	Initializes at half plunger force and at default initialization speed
	2	Initializes at one-third plunger force and at default initialization speed
	10-40	Initializes at full force and at speed code <n_1>. See command <S> for a list of speed codes.
<n_2>	0	Sets initialization input port to port 1 (default)
	1..X	Sets initialization input port for distribution valves, where X is the number of ports on the valve.
<n_3>	0	Sets initialization output port to port X, where X is the number of ports on the valve. (default)
	1..X	Sets initialization output port for distribution valves, where X is the number of ports on the valve.

Y <n_1, n_2, n_3> Initialize Plunger and Valve Drive (CCW Polarity)

The [Y] command initializes the plunger drive and homes the valve in a *counter-clockwise* direction. Valve ports are numbered 1..X in a counter-clockwise direction starting with the first port after the syringe port. The default initialization speed is 500 pulses per second.

n_1 = Set initialization plunger force/speed
n_2 = Set initialization input port
n_3 = Set initialization output port

The parameters are described below.

Y Parameter	Value	Description
<n_1>	0	Initializes at full plunger force and at default initialization speed (default)
	1	Initializes at half plunger force and at default initialization speed
	2	Initializes at one-third plunger force and at default initialization speed
	10-40	Initializes at full force and at speed code <n_1>. See command <S> for a list of speed codes.

$<n_2>$	0	Sets initialization input port to port 1 (default)
	1..X	Sets initialization input port for distribution valves, where X is the number of ports on the valve.
$<n_3>$	0	Sets initialization output port to port X, where X is the number of ports on the valve. (default)
	1..X	Sets initialization output port for distribution valves, where X is the number of ports on the valve.

W$\lt n_1 \gt$ Initialize Plunger Drive

The [W] command initializes the plunger drive only (commonly used for valveless pumps). Because the valve is not initialized, only plunger force and/or speed can be set.The default initialization speed is 500 pulses per second.

n_1 = Set initialization plunger force/speed

The parameters are described below.

W Parameter	Value	Description
$<n_1>$	0	Initializes at full plunger force and at default initialization speed (default)
	1	Initializes at half plunger force and at default initialization speed
	2	Initializes at one-third plunger force and at default initialization speed
	10-40	Initializes at full force and at speed code $<n_1>$. See command <S> for a list of speed codes.

w<n_1, n_2> Initialize Valve Drive

The [w] command initializes the valve drive only. Because the plunger is not initialized, only the initialization port can be set.

n_1 = Set port

n_2 = Set valve homing and port numbering direction

The parameters are described below.

w Parameter	value	Description
<n_1>	1..X	Set initialization port, where X is the number of ports on the valve
<n_2>	0	Valve homes in a *clockwise* direction; valve ports numbered in a *clockwise* direction.
	1	Valve homes in a *counterclockwise* direction; valve ports numbered in a *counterclockwise* direction.

z Simulated Plunger Initialization

The [z] command simulates an initialization of the plunger drive, however, no mechanical initialization occurs. The current position of the linear encoder is set as the home position.

This command can be used after a plunger overload error, to regain control of the pump. After recovering from the overload condition using the [z] command, the pump must be reinitialized using the Z<n_1, n_2, n_3> or Y<n_1, n_2, n_3> commands to set the true home position.

Caution! *Incorrect use of this command can damage the device.*

3.5 Operating Commands

3.5.1 Valve Commands

Valve commands position the input and output channels to the specified ports. Similar valve commands cause different actions depending on whether you are using non-distribution valves or distribution valves.

With ***non-distribution valves***, any combination of two valve ports, including or excluding the syringe port, may be used. With ***distribution valves***, the syringe port is a common port, always included as one of the two valve ports in use.

The initialization command (Z, Y, or w) determines:

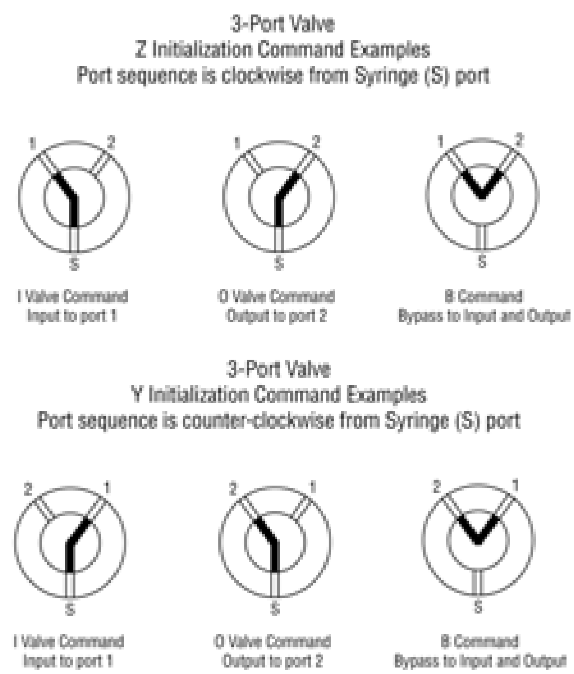
- the direction in which the valve homes during initialization (clockwise or counterclockwise)
- the direction in which the ports are numbered, starting with the syringe port (clockwise or counterclockwise)

After initialization, the direction in which the valve moves is specific to the valve type and command.

With ***non-distribution valves***, the I, O, B, or E command specifies the combination of valve ports to be connected. The valve moves following the shortest path available.

For example, in Figure 3-2, if the 3-port non-distribution valve has been initialized with the [Z] command, the ports will be numbered as shown in the top diagram (clockwise). Issuing an [O] command aligns the syringe port with port 2, as shown.

Figure 3-2 *Valve Position Examples for 3-Port Non-Distribution Valves*



With ***distribution valves***, the direction in which the valve moves is determined by the valve command. It will not necessarily follow the shortest path.

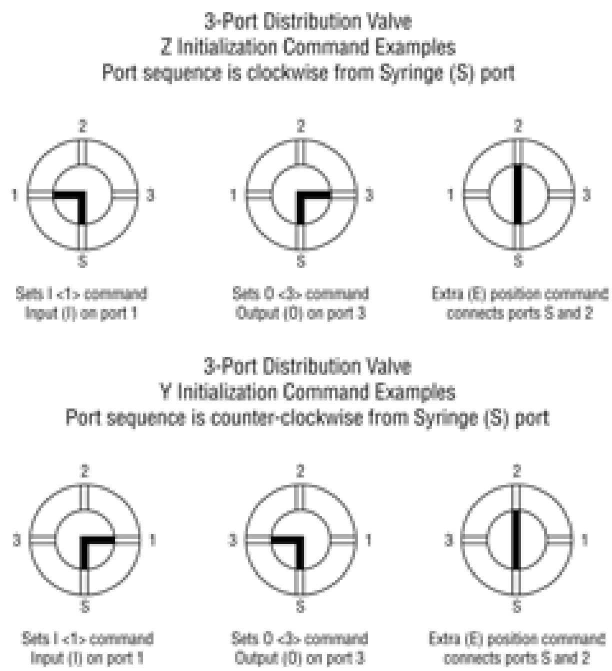
- The [I] command moves the valve in a clockwise direction.
- The [O] command moves the valve in a counterclockwise direction.

Note: *Use of [I] and [O] in distribution valves is by convention, and does not pertain to input or output characteristics.*

Because the syringe port is always a common port, in distribution valves, the [B] (Bypass) and [E] (Extra) commands are meaningless. However, the commands are available, to provide backward compatibility with earlier versions of firmware.

For example, in Figure 3-3, if the 3-port distribution valve has been initialized with the [Y] command, the ports will be numbered as shown in the bottom diagram (counterclockwise). Issuing an [O<3>] command will align the syringe port with port 3, as shown.

Figure 3-3 *Valve Position Examples for 3-Port Distribution Valves*



Following are more detailed descriptions of the various valve commands and what they do.

I *Move Valve to Input Position (Non-distribution Valves)*

The [I] command moves the valve to the input port set by the initialization command, following the shortest path.

I<n> *Move Valve Clockwise to Port n (Distribution Valves)*

The [I<n>] command sets the valve position to port [n], moving in a *clockwise* direction. This command is independent of input or output characteristics.

O *Move Valve to Output Position (Non-distribution Valves)*

The [O] command moves the valve to the output port set by the initialization command, following the shortest path.

O<n> Move Valve Counterclockwise to Port n (Distribution Valves)

The [O<n>] command sets the valve position to port [n], moving in a *counter-clockwise* direction. This command is independent of input or output characteristics.

B Move Valve to Bypass (Non-distribution Valves)

The [B] command connects the input and output positions, bypassing the syringe. The valve moves following the shortest path.

E Move Valve to Extra Position (4-Port Non-distribution Valve)

The [E] command connects the extra position in the 4-port valve, bypassing the syringe. The valve moves following the shortest path.

Note: *The [B] and [E] commands are useful when flushing fluid lines.*
If a Valve command is issued to a valveless pump, the command is ignored.

Caution! *When the valve is in the Bypass position, the syringe plunger will not move. Sending a Plunger Movement command causes an error 11 (plunger move not allowed).*

Figure 3-4 *Valve Position Examples for 4-Port Non-Distribution Valves*

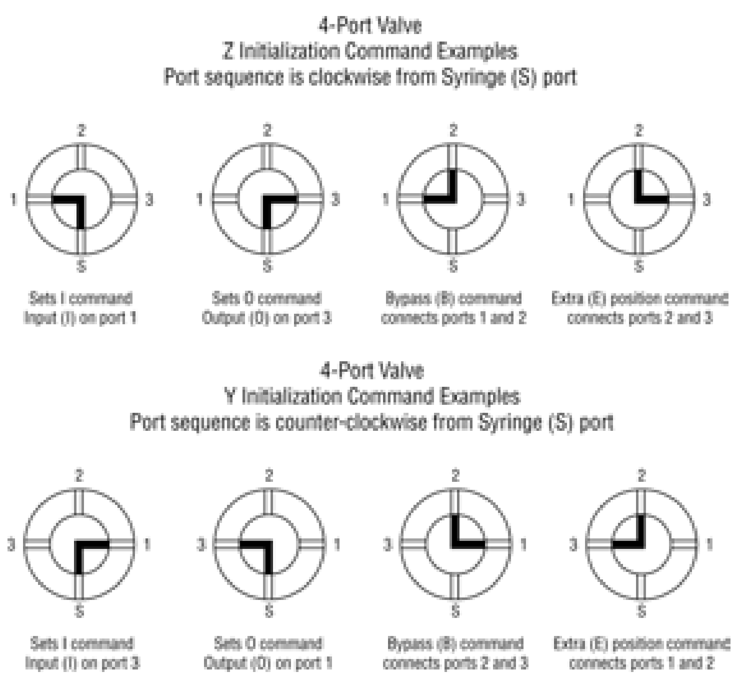


Figure 3-5 *Valve Position Examples for T Valves (Non-Distribution)*

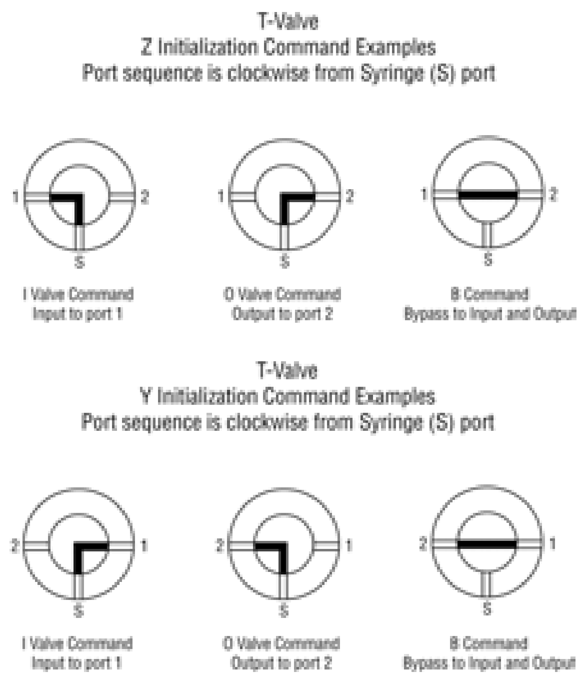


Figure 3-6 *Valve Position Examples for 6-Port Distribution Valves*

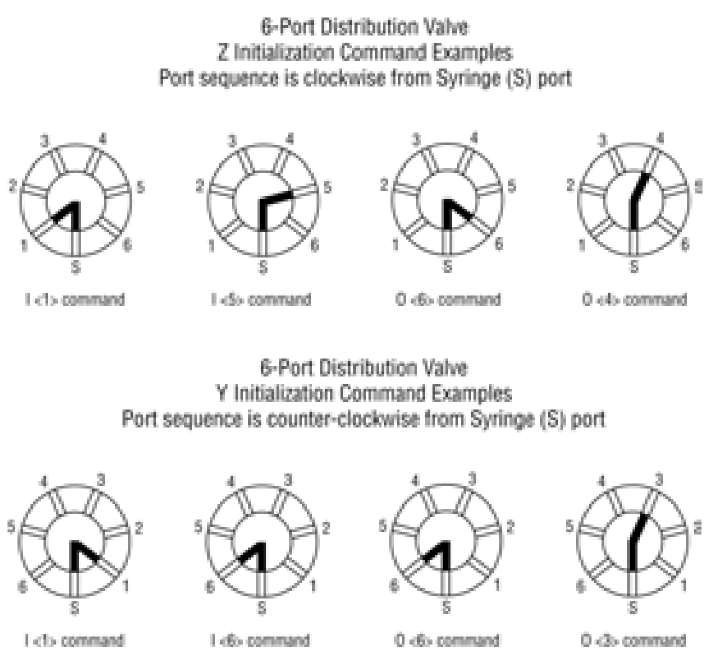
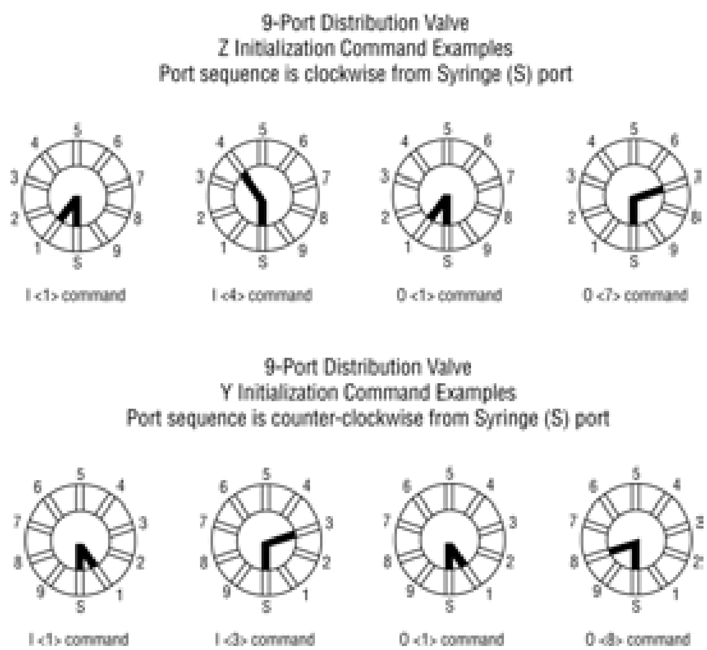


Figure 3-7 Valve Position Examples for 9-Port Distribution Valves



3.5.2 Plunger Movement Commands

A <n> Absolute Position

The [A] command moves the plunger to the absolute position <n>, where <n> = 0..3000 in standard mode and 0..24000 in fine positioning mode.

Command	<n> Parameter Value	Description
A	0-3000	Absolute position in full increments (N=0)
	0-24000	Absolute position in microsteps (N=1)

For example:

– [A300] moves the syringe plunger to position 300.
– [A600] moves the syringe plunger to position 600.

a <n> Absolute Position (Not Busy)

This is the same as the [A] command, except that the status bit within the reply string indicates that the pump is not busy.

P <n>   Relative Pickup

The [P] command moves the plunger down the number of increments commanded. The new absolute position is the previous position plus <n>, where
<n> = 0..3000 in standard mode and 0..24000 in fine positioning mode.

Command	<n> Parameter Value	Description
P	0-3000	Relative position in full increments (N=0)
	0-24000	Relative position in microsteps (N=1)

For example:

The syringe plunger is at position 0. [P300] moves the plunger down 300 increments. [P600] moves the plunger down an additional 600 increments to an absolute position of 900.

The [P] command will return error 3 (invalid operand) if the final plunger position is greater than 3150.

p <n>   Relative Pickup (Not Busy)

This is the same as the [P] command, except that the status bit of the reply string indicates that the pump is not busy.

D <n>   Relative Dispense

The [D] command moves the plunger upward the number of increments commanded. The new absolute position is the previous position minus <n>, where
<n> = 0..3000 in standard mode and 0..24000 in fine positioning mode.

Command	<n> Parameter Value	Description
D	0-3000	Relative position in full increments (N=0)
	0-24000	Relative position in microsteps (N=1)

For example:

The syringe plunger is at position 3000. [D300] will move the plunger up 300 increments to an absolute position of 2700.

The [D] command will return error 3 (invalid operand) if the final plunger position would be less than 0.

d <n> ***Relative Dispense (Not Busy)***

This is the same as the [D] command, except that the status bit of the reply string indicates that the pump is not busy.

3.5.3 Set Commands (Speed and Acceleration)

Set commands are used to control the speed of the plunger. Plunger movement is divided into three phases:

- **Ramping Up.** Plunger movement begins with the start speed and accelerates with the programmed slope to the constant or top speed.
- **Constant or Top Speed.** The plunger moves at the constant or top speed. Plunger speed can be programmed in Hz (half-increments/second) or in preprogrammed Set Speeds. The actual time the plunger travels is dependent on the ramping up and down. If the plunger move is short, it may never reach top speed.
- **Ramping Down.** The plunger will decelerate based on the programmed slope. To enhance fluid breakoff, the Cutoff command ([c]) can be used to define the end speed of the plunger just before it stops.

Note: *The Cutoff command is only active in a dispense move. During aspiration the move will end at the start speed [v].*

For each plunger move, the firmware calculates how many increments the plunger must travel during each phase in order to move the total number of increments commanded. If the plunger is moving at a rate less than 1024 Hz, the pump automatically microsteps to reduce the pulsation.

The top speed can be changed on the fly (while the plunger is moving) using the [v] command, providing the top speed is less than or equal to the start speed. Ramps are not included in on-the-fly speed changes; therefore, large speed changes (100 Hz to 1000 Hz) are not recommended.

Note: *Unless the top speed is less than or equal to the start or cutoff speed, always program the pump in order of the move: start speed [v], top speed [V], cutoff speed [c].*

Changing Speed on the Fly

Speed changes can be made while the syringe plunger is moving. This is called "changing speed on the fly."

Speeds can be decreased or increased between 5 and 1024 Hz (i.e., in the fine positioning region).

To change speed on the fly:

1 Issue speed commands with identical start and top speeds (e.g., [v100V100]), followed by a Plunger Move command. Ramping is not allowed in on-the-fly changes.

2 Issue a new top speed in the range 5 to 1024 (e.g. [V600]) while the plunger is moving, to change the speed on the fly.

Note: *When the move completes, speed values revert to original values (i.e., value sent on-the-fly is temporary).*

Note: *When changing speed on the fly in CAN, use frame type 0.*

L <n> Set Slope

During the beginning and end of a move, the plunger speed ramps up and down respectively. The ramp is programmed using the Slope command. It is calculated as <n> x 2.5 kHz/sec. The syntax for this command is:

[L<n>]

where <n> = 1..20 (14 is the default)

The corresponding slopes in pulses/sec^2 are listed below.

Slope Code	Pulses/sec^2 (KHz)
1	2500
2	5000
3	7500
4	10000
5	12500
6	15000
7	17500
8	20000
9	22500
10	25000
11	27500
12	30000
13	32500
14	35000
15	37500
16	40000

17	42500
18	45000
19	47500
20	50000

v <n> *Set Start Speed*

The [v] command sets the speed at which the plunger begins its movement, in pulses/sec. The plunger will then ramp up (slope) to the top speed. The start speed should always be less than the top speed.

Command	<n> Parameter Value	Default Value	Description
v	50-1000	900	Set start speed in pulses/sec

V <n> *Set Top Speed*

The [V] command sets the top speed in pulses/second. This command may be sent while a command string is already executing. (See section on Changing Speed on the Fly, earlier in this chapter.)

Command	<n> Parameter Value	Default Value	Description
V	5-6000	1400	Set top speed in pulses/sec

Note: *Syringes 2.5 mL and larger may require slower speeds. Users must determine the appropriate speeds for their applications.*

S <n> *Set Speed*

The [S] command sets a predefined top plunger speed, in pulses/sec. As <n> increases, the plunger speed decreases.

Command	<n> Parameter Value	Default Value	Description
S	0-40	11	Set plunger drive speed in pulses/sec

These speed settings do not cover the full range of speeds the plunger can travel. They are commonly used speeds provided for the convenience of the user. All times are approximate and will vary with different ramp speeds and cutoffs. Tecan Systems also provides a utility for performing theoretical speed calculations in Pump:Link Evaluation Software (in the Utility menu on the user interface). For information on determining timing for specific applications, see Appendix B, "Plunger Information".

The [S] command sets top speed without changing start speed, slope, and cutoff speed, except under the following conditions:

- If the start speed is higher than the (new) top speed, start speed is changed to equal the top speed.
- If the cutoff speed is higher than the (new) top speed, cutoff speed is changed to equal the top speed.

Speed codes, the Hz (pulses/second) equivalent, and seconds per stroke are listed below. Seconds/stroke values are based on default ramping.

Speed Code	Speed (pulses/sec or Hz)	Seconds/Stroke
0	6000	1.25
1	5600	1.30
2	5000	1.39
3	4400	1.52
4	3800	1.71
5	3200	1.97
6	2600	2.37
7	2200	2.77
8	2000	3.03
9	1800	3.36
10	1600	3.77
11	1400	4.30
12	1200	5.00
13	1000	6.00
14	800	7.50
15	600	10.00
16	400	15.00
17	200	30.00
18	190	31.58
19	180	33.33

Speed Code	Speed (pulses/sec or Hz)	Seconds/Stroke
20	170	35.29
21	160	37.50
22	150	40.00
23	140	42.86
24	130	46.15
25	120	50.00
26	110	54.55
27	100	60.00
28	90	66.67
29	80	75.00
30	70	85.71
31	60	100.00
32	50	120.00
33	40	150.00
34	30	200.00
35	20	300.00
36	18	333.33
37	16	375.00
38	14	428.57
39	12	500.00
40	10	600.00

Note: *To achieve maximum stroke time (20 minutes), a set speed [S] cannot be used. The pump must be programmed using the [V5] command.*

c <n> Cutoff Speed in Pulses/Second

The [c] command sets the speed at which the plunger ends its movement, in pulses/sec. The plunger will ramp down (slope) from the peak speed. The [c] command overwrites the [C] command.

Command	<n> Parameter Value	Default Value	Description
c	50-2700	900	Set cutoff speed in pulses/sec (standard and fine-positioning mode)

Note: *[c] is only valid in a dispense move. During aspiration, [c] = [v].*

C <n>   Cutoff Speed in Increments

During the last phase of a plunger move, the speed ramps down (as defined by the programmed slope) toward the cutoff speed [c]. When cutoff increments are specified, the plunger stops at <n> increments before reaching the cutoff speed. The total number of increments required by the plunger movement is maintained by adding <n> increments to the second phase (top speed) of the plunger move. The syntax of this command is:

[C<n>]

where <n> = 0..25 increments (0 is the default)

The [C] command overwrites the [c] command and resets cutoff speed to start speed.

For example, [C5] stops the plunger five increments short of the final speed. The total number of increments is automatically maintained by adding five increments to the second phase of plunger movement. In other words, the deceleration phase of the move is shortened by five increments and the constant speed phase is lengthened by five increments.

3.5.4 Interaction of Set Commands

The Start Speed [v], Top Speed [V], and Cutoff Speed [c] commands interact according to the following rules:

[v] ≤ [c] ≤ [V]

1 Start Speed should always be less than or equal to Top Speed. Changing the Start Speed will change the Cutoff Speed if Cutoff Speed is less than the Start Speed set. If the Start Speed [v] is greater than the Top Speed, the Start Speed will be set equal to the Top Speed.

2 Top Speed should always be greater than or equal to the Start Speed and Cutoff Speed. Changing the Top Speed will modify the Cutoff Speed and Start Speed if they were improper, but will not modify the stored Start Speed. For instance, values of 750, 100 and 1200 will cause the pump to run simply at the top speed of 100.

3 Cutoff Speed [c] should always be less than or equal to Top Speed [V] and greater than or equal to Start Speed [v]. Changing the Cutoff Speed will not modify the Start Speed or Top Speed. However, if Cutoff Speed is greater than Top Speed it will be ignored and the Cutoff Speed will be set equal to the

Top Speed. And if the Cutoff Speed is set less than Start Speed, it will be ignored and the Cutoff Speed will be set equal to the Start Speed.

3.5.5 Control Commands

R Execute Command or Program String

The [R] command tells the pump to execute a new or previously loaded but unexecuted command string. This command will also cause the resumption of a halted ("H") or terminated ("T") command string.

Commands containing [R] at the end of the string will execute immediately. If the command or program string is sent without the [R], it is placed in the command buffer.

Sending the [R] alone will execute the last unexecuted command in the buffer. Sending another [R] will not repeat the program string (i.e., the string has been executed).

Note: *The [R] command (frame type 1) is valid in CAN communication. An equivalent command is ASCII 1 for frame type 2.*

X Execute the Last Command or Program String

The [X] command repeats the last executed command or program string.

Note: *The [X] command (frame type 1) is valid in CAN communication. An equivalent command is ASCII 3 for frame type 2.*

G <n> Repeat Command Sequence

This command repeats a command or program string the specified number of times. If a GR or a G0R is sent, the sequence is repeated until a Terminate command [T] is issued. The G command can be used to nest up to 10 loops and can be repeated up to 30,000 times.

The syntax for this command is:

[G<n>]

where <n> = 0..30000

For example, [A3000A0G10R] moves the syringe plunger to position 3000 then back to position 0. This sequence is repeated 10 times.

g Mark the Start of a Repeat Sequence

The [g] command is used in conjunction with the [G] command. The [g] command marks the beginning of a repeat sequence (loop) that occurs within a program string (i.e., the entire string is not repeated). Both the [g] and [G] commands can be used to nest up to 10 loops.

Table 3-7, Example Program String shows the various segments of the command string [A0gP50gP100D100G10G5R].

Table 3-7 Example Program String

Command Segment	Description
A0	Move plunger to position 0.
g	Outer loop start.
P50	Move plunger down 50 increments.
g	Inner loop start.
P100	Move plunger down 100 increments.
D100	Move plunger up 100 increments.
G10	Inner loop, repeat 10 times.
G5	Outer loop, repeat five times.
R	Execute command string.

M <n> Delay Command Execution

The [M] command delays execution of a command in milliseconds to the closest multiple of five. This command is typically used to allow time for liquid in the syringe and tubing to stop oscillating, thereby enhancing precision. The syntax for this command is:

[M<n>]

where <n> = 0..30,000 milliseconds

H <n> Halt Command Execution

The [H] command is used within a program string to halt execution of the string. To resume execution, an [R] command or TTL signal must be sent.

The syntax for this command is:

[H<n>]

where <n> = 0..2

Two TTL inputs are available, input 1 (J4 pin 7) and input 2 (J4 pin 8). They control execution as follows:

<n> = 0	Waits for [R] or either input 1 or 2 to go low
<n> = 1	Waits for [R] or input 1 to go low
<n> = 2	Waits for [R] or input 2 to go low

Note: *If the value of <n> is not specified, <n> defaults to 0.*

The status of the TTL input lines can also be read using [?13]and [?14]. These commands are described in “Report Commands” later in this chapter.

T Terminate Command

The [T] command terminates plunger moves in progress ([A], [a], [P], [p], [D], and [d]), control loops, and delays [M].

Note: *The [T] command will not terminate Valve Move commands.*

The [T] command will terminate both single commands and program strings. If a program string is terminated before completion, the [R] (Execution) command will resume the program string. If the command was terminated due to a problem or error, the pump must be reinitialized.

Caution! *When a plunger move is terminated, lost increments may result. Reinitialization is recommended following termination.*

Note: *The [T] command (frame type 0) is valid in CAN communication. An equivalent command is ASCII 4 for frame type 2.*

J <n> Auxiliary Outputs

The [J] command sets the TTL output lines.

The syntax for this command is:

[J<n>]

where <n> = 0..7 (0 is the default)

The XCalibur provides three TTL outputs on J4 (pins 13, 14, and 15) that correspond to outputs 1, 2, and 3. They are controlled as shown in the following table:

Command	Output 3 (Pin 15)	Output 2 (Pin 14)	Output 1 (Pin 13)
J0	0	0	0
J1	0	0	1
J2	0	1	0
J3	0	1	1
J4	1	0	0
J5	1	0	1
J6	1	1	0
J7	1	1	1

0 = low; for example, Gnd
1 = high, for example, +5V DC

3.5.6 Non-Volatile Memory (EEPROM) Commands

The non-volatile memory in the XCalibur can store a program string thus providing the user with the option of computer-free operation. The pump can be configured to run stored programs using the U<30> command. See “Pump Configuration Commands” earlier in this chapter.

s <n> Load Program String into Non-Volatile Memory

The non-volatile memory in the XCalibur can store a program string thus providing the user with the option of computer-free operation.

The [s] command is placed at the beginning of a program string to load the string into the non-volatile memory. The syntax for this command is:

[s<n>]

where <n> = 0..14

Up to 15 program strings (numbered 0 through 14) can be loaded into the non-volatile memory. Each string can use up to 128 characters. For example, [IA3000OA0R] requires 10 bytes.

Example Program String: [s8ZS1gIA3000OA0GR]

Command Segment	Description
s8	Loads string into program 8 of non-volatile memory (Address switch position 8)
Z	Initializes pump
S1	Sets plunger speed
g	Marks start of loop
I	Turns valve to input position
A3000	Moves plunger to position 3000
O	Turns valve to output position
A0	Moves plunger to position 0
G	Endlessly repeats loop
R	Executes command string

e <n>   Execute Non-Volatile Memory Program String

Non-volatile memory command strings are executed by sending an [e] command. The executing program string can be terminated using the [T] command.

[e<n>]

where <n> = 0..14 (the string number)

Note: *An Initialization command should always be included in the non-volatile memory command string if the pump will be used in standalone mode.*

U30   Set Run from Non-Volatile Memory Auto Mode

The [U30] command sets the “Run from Non-Volatile Memory Auto Mode” flag in the non-volatile memory and begins operating the pump in stand alone mode. The pump will run one of 15 command strings <n> as selected by the address switch,

where <n> = 0..E

U31   Clear Run From Non-Volatile Memory

The [U31] command clears the “Run from Non-Volatile Memory Auto Mode” flag in the EEPROM and begins operating in the default mode.

Linking Program Strings in the Non-Volatile Memory

Non-volatile memory program strings can be linked by ending one program string with an [e] command that refers to a second program string.

Example Program Strings:

[slZgIA3000OA0G5e2R]

[s2gIA3000OgHD300G10GR]

The first string loads an initialization and prime sequence into program 1 of the non-volatile memory (address switch position 1). It then links to string 2 in the non-volatile memory.

The second string loads an aspirate and dispense sequence into program 2 of the non-volatile memory. The second non-volatile memory program string fills the syringe, then performs 10 dispenses of 300 increments each. The dispenses are triggered by an [R] command. This string is repeated endlessly until the pump is powered down.

On power-up the pump will automatically initialize, prime and perform the multiple dispenses until it is again powered down.

3.5.7 Non-Functional Commands

^<n> ***Set Threshold Value for Fluid Detection***

The XCalibur pump does not have a liquid sensor board under the valve. This command is non functional and if sent the pump will always respond with a ready status.

If the pump is queried for the Threshold Value for Fluid Detection it will respond with 255. (255 = very dry)

Note: *The ^ command was added to the XCalibur command set to make it backward compatible with the XP 3000.*

3.5.8 Report Commands

Report commands do not require an [R] command.

Note: *All Report commands are invalid in CAN communication. The frame type 6 is provided to retrieve information from the pump. For more information, see Appendix F, "CAN Communication Commands".*

? ***Report Absolute Plunger Position***

The [?] command reports the absolute position of the plunger in increments [0..3000], [0..24000 in fine positioning mode].

?1 ***Report Start Speed***

The [?1] command reports the start speed in pulses/sec [50..1000].

?2 ***Report Top Speed***

The [?2] command reports the top speed in pulses/sec [5..6000].

?3 ***Report Cutoff Speed***

The [?3] command reports the cutoff speed in pulses/sec [50..2700].

Note: *Velocities reported back may not reflect the exact programmed value due to rounding within the control routine.*

?4 ***Report Actual Position of Plunger***

The [?4] command reports the actual position of the linear encoder in increments.

?6 Report Valve Position

The [?6] command reports the valve position in mnemonics (i = input, o = output, and b = bypass) for non-distribution valves.

For distribution valves, the [?6] command reports numerical values 1..X, where X is the number of distribution valve ports.

?10 or F Report Command Buffer Status

The [?10] or [F] command reports the command buffer status. If the buffer is empty, the pump returns status code 0. If the buffer is not empty, the pump returns a 1. If a program string is sent to the pump without an [R] command, the string is loaded into the buffer and the buffer status becomes 1. An [R] command will then execute the command stored in the buffer.

0 = empty
1 = commands in buffer

?12 Report Number of Backlash Increments

The [?12] command reports the number of backlash increments as set by the “K” command.

?13 Report Status of Auxiliary Input #1 (J4, Pin 7)

0 = low
1 = high

?14 Report Status of Auxiliary Input #2 (J4, Pin 8)

0 = low
1 = high

?15 Report Number of Pump Initializations

Command [?15] reports the number of pump initializations. This value cannot be reset.

?16 Report Number of Plunger Movements

Command [?16] reports the number of plunger moves. This value cannot be reset.

?17 Report Number of Valve Movements

Command [?17] reports the number of valve movements. This value cannot be reset.

?18 or % Report Number of Valve Movements (Since Last Report)

The [?18] or [%] command reports the number of valve movements since the last [?18] or [%] command.

?20 or # Report Firmware Checksum

The [?20] or [#] command reports back the firmware checksum. The checksum is the same for all part numbers at the same revision level.

?22 or * Report Current Value From Valve Fluid Sensor

The [?22] or [*] command has been implemented for backward compatibility with the XP 3000. This query will always respond with 255.

255 = very dry

?23 or & Report Firmware Version

The [?23] or [&] command reports the firmware part number and version in ASCII characters.

?24 Report the Zero Gap increments

The [?24] command reports the value set by the “k” command.

?29 or Q Report the Device Status

The [?29] command reports device status (error code) for CAN communications mode only.

The [Q] command reports device status for serial communication mode only.

?76 Report Pump Configuration

The [?76] command reports pump configuration in ASCII text.

3.6 Error Codes and Pump Status

The [Q] command is used for serial communication and reports error codes and pump status (ready or busy). The user should send a [Q] command before sending a program string or individual command to ensure that the pump has completed the previous command successfully.

Note: *[Q] is the only valid method for obtaining pump status in serial mode.*

Note: *The Query command is invalid in CAN communication.*

The response to the [Q] command (the status byte) provides two items of information: Pump status (bit 5) and error code (bits 0-3).

3.6.1 Status Bit

Bit 5 is the status bit. It indicates when the pump is busy or not busy. The designations for bit 5 are listed below.

Status Bit 5	Description
X = 1	Pump is ready to accept new commands.
X = 0	Pump is busy and will only accept Report and Terminate commands.

In response to uppercase Move commands ([A], [P] and [D]), the [Q] command reports that the pump is busy. In response to lowercase Move commands ([a], [p] and [d]), the [Q] command reports that the pump is not busy. Additionally, commands addressed to multiple pumps at once cannot be used to obtain pump status; pumps must be queried separately.

Note: *Although the answer block for other commands contains a status bit, it should not be used for determining pump status. A [Q] command is the only valid method to determine if the pump is busy. The error information in the status byte of the answer block is always valid.*

3.6.2 Error Codes

Error codes describe problem conditions that may be detected in the XCalibur (excluding error code 0). Error codes are returned in the least significant four bits of the status byte. If an error occurs, the pump stops executing commands, clears the command buffer, and inserts the error code into the status byte.

Some errors continue to appear, such as syringe overloads, until they are cleared by the Initialization command. On a plunger overload, the device will not execute another valve or syringe Move command until it is reinitialized. The last error has precedence in the status byte. For example, if a command overflow occurs, an error 15 results. If the next command causes an error #3, the status byte reflects the error #3 (invalid operand).

Table 3-8 *Error Codes*

Error Code	Description
0 (00h)	Error Free Condition.
1 (01h)	Initialization error. This error occurs when the pump fails to initialize. Check for blockages and loose connections before attempting to reinitialize. The pump will not accept commands until it has been successfully initialized. This error can only be cleared by successfully initializing the pump.
2 (02h)	Invalid Command. This error occurs when an unrecognized command is issued. Correct the command and operation will continue normally.
3 (03h)	Invalid Operand. This error occurs when an invalid parameter (<n>) is given with a command. Correct the parameter and pump operation will continue normally.
4 (04h)	Invalid Command Sequence. This error occurs when the command structure is incorrect while using the <s> or <e> commands.
6 (06h)	EEPROM Failure. This error occurs when the EEPROM is faulty. If you receive this error, please call Tecan Systems Technical Service.
7 (07h)	Device Not Initialized. This error occurs when the pump is not initialized. To clear the error, initialize the pump.
9 (09h)	Plunger Overload. This error occurs when movement of the syringe plunger is blocked by excessive backpressure. The pump must be reinitialized before normal operation can resume. This error can only be cleared by reinitializing the pump.
10 (0Ah)	Valve Overload. This error occurs when the valve drive loses increments by blockage or excess backpressure. The pump must be reinitialized before normal operation can resume. Sending another Valve command reinitializes the valve and sets it to the correct location. Continual valve overload errors are an indication the valve should be replaced.
11 (0Bh)	Plunger Move Not Allowed. When the valve is in the bypass or throughput position, Plunger Movement commands are not allowed.
15 (0Fh)	Command Overflow. This error occurs when action commands are sent to the pump before it has completed the current action. Commands in the buffer must be executed before more commands can be sent.

3.6.3 Error Types

The pump handles errors differently, depending on the error type. There are four error types, which are described below.

Immediate Errors

These include “Invalid Command” (error 2), “Invalid Operand” (error 3), “Invalid Command Sequence” (error 4), and “Plunger Move Not Allowed” (error 11). After the command is sent, the answer block immediately returns an error. Once a valid command is sent, the pump will continue to function normally. Since the [Q] command is a valid command, the pump will not return an error. In this case, the [Q] command is not required.

Note: *There is no need to reinitialize the pump following this error type.*

Initialization Errors

These include “Initialization errors” (error 1) and “Device not Initialized” (error 7). If the pump fails to initialize or if an Initialization command has not been sent, subsequent commands will not be executed.

To ensure that the pump initializes successfully, send a [Q] command after the Initialization command.

- If the [Q] command indicates both a successful initialization and that the pump is ready, subsequent Move commands can be sent.
- If the [Q] command indicates the pump has not initialized, the pump must be reinitialized until the [Q] command indicates successful initialization.
- If initialization is not successful, a “Device Not Initialized” error is returned as soon as the next Move command is sent. A successful reinitialization must be executed before subsequent commands can be sent.

Overload Errors

These include the “Plunger Overload” and “Valve Overload” errors (errors 9 and 10). If the pump returns either a plunger or valve overload, the pump must be reinitialized before continuing. If another command is sent without reinitializing the pump, another overload error will be returned when the next Move command is issued. The [Q] command clears the error; however, if a successful initialization has not occurred, an initialization error is returned.

Command Overflow Error

This is error 15, and it occurs if a Move command, Set command (except [V]), or Valve command is sent while the plunger is moving. The pump ignores the command and issues an error 15. The [Q] command allows the controller to determine when the command is complete and the pump is ready to accept new commands.

Note: *There is no need to reinitialize the pump following this error type.*

Report commands, Control commands, and the Top Speed command [V] will not return an error 15. Report and Control commands are considered valid commands during a Move. Because the pump can change speed while the plunger is moving in the 5-1024 Hz range, the [V] commands will not return a “Command Overflow” error.

Caution! *All errors reported by the pump should be captured by the user software and the physical cause corrected before continuing operation. Failure to do so may result in damage to the pump or adversely affected pump performance, and void the warranty*

Table 3-9 *Error Codes and ASCII and Hexadecimal Values*

Status Byte	Hex # if Bit 5 =		Dec # if Bit 5 =		Error Code	
7 6 5 4 3 2 1 0	**0**	**or 1**	**0**	**or 1**	**Number**	**Error**
0 1 X 0 0 0 0 0	40h	60h	64	96	0	No Error
0 1 X 0 0 0 0 1	41h	61h	65	97	1	Initialization
0 1 X 0 0 0 1 0	42h	62h	66	98	2	Invalid Command
0 1 X 0 0 0 1 1	43h	63h	67	99	3	Invalid Operand
0 1 X 0 0 1 0 0	44h	64h	68	100	4	Invalid Command Seq.
0 1 X 0 0 1 0 1	45h	65h	69	101	5	Unused
0 1 X 0 0 1 1 0	46h	66h	70	102	6	EEPROM Failure
0 1 X 0 0 1 1 1	47h	67h	71	103	7	Device not Initialized
0 1 X 0 1 0 0 1	49h	69h	73	105	9	Plunger Overload
0 1 X 0 1 0 1 0	4Ah	6Ah	74	106	10	Valve Overload
0 1 X 0 1 0 1 1	4Bh	6Bh	75	107	11	Plunger Move Not Allowed
0 1 X 0 1 1 1 1	4Fh	6Fh	79	111	15	Command Overflow

Error Reporting Examples

[A4000R]	Returns an error immediately after the command; when queried ([Q] command), does not return an error.
[A3000A3500R]	Moves to position 3000, then stops. A [Q] command returns an error.
[E2000R]	Returns an invalid command error immediately. The pump status is “Not Busy.”
[A3000E2000R]	Returns an invalid command error immediately. The pump is “Not Busy.”
Valve in Bypass [A1000R]	Returns an error immediately; when queried ([Q] command), does not return an error.

4 Setting Up the XCalibur for Your Application

The XCalibur is capable of providing precision pumping in a wide variety of hardware and fluid systems. The interplay of fluid viscosity, aspiration and dispense speeds, and system geometry (syringe size, tubing inner diameter, and valve inner diameter) determine the behavior of the XCalibur in a particular application. Following is a description of the hardware, fluid, and pump control parameters to be evaluated and optimized in managing these interdependencies for optimal pump performance.

4.1 Glossary

air gap

A small volume of air at the end of the output tubing or sandwiched between two fluids in the pump system tubing. Air gaps may be created by aspirating air (programmed air gaps) or by the spring action of the fluid system (inertial air gaps).

aspirate/dispense tubing

Connects the valve output port (1/4-28 thread or M6 fitting) to a sample source and destination. To ensure good breakoff, aspirate/dispense tubing tends to have a smaller I.D. than reagent tubing, and a necked-down or tapered end.

backlash

Mechanical play in the syringe drive created by accumulated mechanical clearances.

backpressure

The pressure which must be exceeded to move fluid through tubing. Backpressure is created by a combination of fluid inertia and friction.

breakoff

Describes how the last droplet of fluid exits the end of the output tubing following a dispense. Rapid or sharp breakoff means that the droplet exits cleanly with high inertia.

breakup

Undesired air gaps created by overly rapid aspiration.

carryover

Contamination of a volume of fluid by residual fluid from a previous aspiration or dispense. Carryover causes variability in final volume and concentration.

cavitation

Formation of air bubbles due to rapid pressure changes. Often caused by aspirating fluid into the syringe too quickly.

dilution effect

Reduction in sample or reagent concentration, caused by contact with system fluid or residual fluid from a previous aspiration or dispense.

I.D. ("inner diameter")

Diameter of the constraining wall of a fluid path.

priming

Completely filling the pump tubing and syringe with bubble-free fluid to allow sustained, reproducible pumping action. The air in an unprimed line acts as a spring, adversely affecting accuracy and precision.

reagent tubing

Connects the valve input port (1/4-28 thread or M6 fitting) to a reagent source. Reagent tubing is used to fill the pump syringe; it tends to have a larger I.D. than aspirate/dispense tubing, and a blunt-cut end which extends into the reagent.

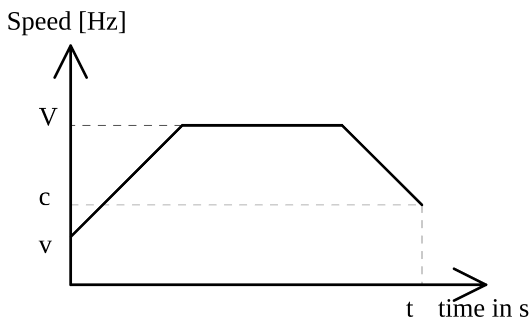
system fluid

A fluid used to prime the pump system that does not act as sample or reagent. Typically the system fluid is de-ionized water or a wash buffer and is isolated from sample or reagent fluid by an air gap to avoid intermixing.

syringe speed profile

Typically, the syringe plunger begins moving slowly, then ramps up to top speed. This allows the plunger to start moving gradually, without overloading the motor, and still provide maximum flowrate. The syringe plunger stops by ramping down in speed. This results in the most reproducible fluid breakoff for accurate dispensing.

Figure 4-1 *Syringe Speed*



start speed (v)

The speed at which the syringe plunger starts moving.

top speed (V)

The maximum speed at which the syringe plunger moves.

cutoff speed (c)

The speed of the syringe plunger just before stopping.

slope (L)

Acceleration (deceleration) of the syringe plunger between start speed, top speed, and cutoff speed.

volume calculation

The volume aspirated or dispensed when the syringe plunger moves a specified number of increments depending on the syringe size. To determine the number of increments required to aspirate or dispense a given volume, use the following formula:

$$\text{\# of increments} = \frac{\text{(pump resolution) x volume}}{\text{(syringe size)}}$$

For example, to aspirate 100 µL using an XCalibur pump with 1 mL syringe, move the plunger as follows:

$$\text{\# of increments} = \frac{3000 \text{ increments x } 100\ \mu L}{1 \text{ mL x } 1000\ \mu L/mL} = 300 \text{ increments}$$

4.2 Optimizing XCalibur Performance

Caution! *Run the pump only in the upright position. Do not move the pump valve or syringe plunger without first wetting or priming the pump.*

For command details, see Chapter 3, “Software Communication.”

To optimize XCalibur performance, follow these value:

1 Check chemical compatibility.

Check the chemical compatibility chart in Appendix D, “Chemical Resistance Chart,” to determine if the fluids in your application are compatible with the XCalibur syringe and valve materials. If not, a system fluid is required. Complete the optimization procedure with the fluids you will use in your final system.

Note that the system fluid is used to prime the syringe and tubing from inlet to outlet. After the tubing is primed (and before any sample or reagent is aspirated), an air gap must be taken into the aspirate/dispense tubing to separate the system fluid from subsequently aspirated sample or reagent. Air gaps should be aspirated slowly to avoid break-ups, and they should be one-tenth the volume of the aspirated fluid—or at least 10 µL—to avoid any dilution effect. Similar air gaps should separate each aspirated fluid when performing multiple aspirates with no intervening dispenses, in order to prevent premature mixing and/or contamination. In addition, the aspirate/dispense tubing must be long enough to hold the total aspirate volume without coming in contact with the valve or syringe.

2 Select syringe size.

Determine your volume and flowrate requirements. Select a syringe that accommodates the smallest and largest volumes to be dispensed without refill, as well as the desired flowrate (see Flowrate Ranges). While smaller syringes allow better accuracy and precision, a larger syringe allows more aliquots when multiple aspirations or multiple dispenses are required, and they allow better breakoff and longer seal life.

Table 4-1 *Flowrate Ranges*

Syringe Size	Minimum Flowrate (mL/min)	Maximum Flowrate (mL/min)
50 µL	0.0025	2.6
100 µL	0.0050	5.23
250 µL	0.012	13.1
500 µL	0.025	26.2
1 mL	0.050	52.3
5 mL	0.25	261.6

3 Select tubing.

In tubing selection, the general rule is that smaller syringes work best with smaller I.D. tubing and larger syringes with larger I.D. tubing. The 3-port XCalibur valve has an internal I.D. of 0.059" (approx. 1/16"). For aspirate/dispense tubing a thermal-drawn tip or tapered tip is most common, providing good breakoff and excellent accuracy and precision for most applications. A necked-down tip may be used when aspirating very small volumes of sample, i.e., 1 - 5 µL. A blunt-cut tip is better suited for large volume applications. For tubing recommendations, see Table 4-2, Tubing Recommendations; for a description of the various types of tubing, see Appendix A, "Ordering Information"."

Table 4-2 *Tubing Recommendations*

Syringe Size	Aspirate/Dispense Tubing P/N	Reagent Tubing P/N
50 µL, 100 µL, 250 µL	5133	721370
	5723	721370
500 µL, 1 mL, 2.5 mL	5133	4609
	720595	5729
	720597	721370
5 mL	4333	720592
	720595	721370

4 Make pump connections.

Connect power and communications cables to the pump, install syringe and tubing. Place the end of the input tubing in a reservoir of particle-free fluid; place the end of the output tubing in a waste reservoir.

5 Check communications to the pump.

– Open the Pump:Link program to the XP 3000 menu (full page), or use your own communications program.

– Send the command [&] to read the pump's firmware revision number. Successful communication will return the revision number and a "Ready" status.

Possible errors:

– No response. Check for loose or incorrectly connected cables, or connection to the wrong computer COM port. Retry.

6 Initialize pump and set initialization speed.

The following information assumes that your input tubing connects to the right valve port. If your input tubing connects to the left valve port, exchange [Y] for all instances of [Z] in the following commands.

– Send the command [ZR] to initialize the pump. Successful initialization will move the syringe plunger to the position "0" (fully dispensed) and return a "Ready" status.

Possible errors:

– Error 1 (initialization error). Check for tubing blockage and reinitialize. If you are using very narrow I.D. tubing or pumping a viscous fluid, the initialization speed may need to be reduced.

- This is accomplished (only if using a 1 mL or larger syringe) by sending the command [Z16R] (initializes at full-force, reduced speed). Repeat with decreasing initialization speed (increase “Z_” value) until the pump successfully initializes.

7 Prime the syringe.

- Send the command [IA3000OA0R] to pull fluid through the valve input position and into the syringe.
- Inspect the pump tubing and syringe for bubbles and re-prime until all bubbles are completely gone.

  If bubbles remain after several priming strokes, disassemble the syringe and clean it with alcohol. Also check to ensure the fittings are tight and the syringe is tight within the Teflon fitting.
- Re-prime.

Possible errors:

- Error 9 (plunger overload). See step 8.

8 Check aspirate/dispense.

Send the command [IA3000OA0R] to aspirate a full syringe stroke (3000 increments) from input and dispense it to output. Successful execution will move the syringe plunger to position “3000” then back to “0,” then it will return a “Ready” status.

Possible errors:

- Error 9 (plunger overload). The stepper motor is unable to move the syringe plunger, probably because of excessive backpressure caused by excessive flowrate, narrow tubing I.D., or valve or tubing blockage. Note whether the error occurred during aspiration or dispensing. To differentiate between blockage and flowrate limitation, reduce syringe plunger speed by sending the command [S12IA3000OA0R]. Repeat with decreasing plunger speed (increase “S_” value) until the pump aspirates and dispenses successfully.

9 Set start speed and top speed.

The XCalibur plunger speed can be controlled from 1.2 seconds per stroke to 20 minutes per stroke (top speed) using the [S] or [V] commands. (The [V] command allows a slightly larger speed range.) As a general rule, aspiration should be slow (to avoid cavitation) and dispense fast (to promote breakoff). Since cavitation and breakoff will affect both accuracy and precision, speed settings may be optimized separately for aspiration and dispense.

Using aspirate/dispense commands, set start speed [v] and top speed [V] to meet application throughput goals.

- Send the command [v50IA3000OA0R]. Repeat with increasing start speed (increase “v_” value) to find the maximum value.
- Send the command [v*x*V*x*IA3000OA0R] to set top speed equal to start speed (*x*). Repeat with increasing top speed (increase “V_” value) to the maximum value that does not overload the plunger or cause cavitation.

Now optimize start speed and top speed for dispensing using a similar approach.

10 Set cutoff speed and slope.

Using aspirate/dispense commands, set slope [L] and cutoff speed [c] to attain reproducible breakoff. Note that cutoff speed controls only dispensing.

To optimize the slope, send the command [v*x*V*x*L14IA3000OA0R]. Repeat with modified slope (“L_” value) to achieve the overall time suited to your application without plunger overload.

To optimize the cutoff speed, start with the maximum cutoff speed allowed for your application (the lower of 2700 Hz or the top speed). Send the command [c*x*IA3000OA0R] and monitor the dispense for plunger overload or any splattering of the fluid dispensed outside of the dispense vessel. If any of these conditions occur, lower the cutoff speed until the pump can dispense the fluid with clean breakoff.

Another condition that affects breakoff is the formation of inertial air gaps. This is seen as a small air gap inside the tubing at the tip. This occurs to a greater extent on larger reagent syringes, and it enhances the breakoff of liquid from the tip of the tubing. If an inertial air gap is not desired in the application, lowering the cutoff speed and/or the top speed will remove the inertial air gap. However, this may not give a clean breakoff of the fluid.

In some instances it may not be possible to improve fluid breakoff. Clean breakoff is important to accuracy and precision; it is a concern especially when using slow speeds because drops will usually adhere to the tip.

For example, using a 2.5 mL reagent syringe (P/N 5133, dispense tubing and de-ionized water with a surfactant added):

– [S24IA3000OA0R] - will leave a drop on the tip
– [S24IA3000OA5S1A0R] - no drop will be left
– [V100IA3000OA0R] - will leave a drop on the tip
– [V100IA3000OA5V5500A0R] - no drop will be left

Increasing the cutoff speed and ramp (slope) may also improve the fluid breakoff. Smaller I.D. tubing may improve breakoff, especially for smaller syringes.

Note: *It may not be possible to achieve good fluid breakoff under any circumstance, especially with syringes smaller than 500 µL or with some fluids.*

4.3 Helpful Hints

To maintain pump performance, keep the following in mind when operating the XCalibur:

- Wipe up all spills immediately.
- Pumping cold fluids may cause leaks, the result of differing coefficients of expansion of Teflon and glass. Leaks may occur when pumping fluids that are at or below 15°C (61°F).
- To reduce the amount of carryover, a ratio of three parts reagent to one part sample is recommended.

- Before pumping any organic solvent, please refer to the “Chemical Resistance Chart” in Appendix D of this manual. Using organic solvents may reduce tubing and seal life.

5 Maintenance

Although required maintenance may vary with your application, the following procedures are recommended for optimal performance of the XCalibur.

Perform maintenance tasks in these intervals:
- daily
- weekly
- periodically

5.1 Daily Maintenance

To ensure proper operation of the XCalibur, perform these tasks daily:
- Inspect the pump(s) for leaks, and correct any problems.
- Wipe up all spills on and around the pump.
- Flush the pump(s) thoroughly with distilled or deionized water after each use and when the pump is not in use.

Note: *Do not allow the pump(s) to run dry for more than a few cycles.*

5.2 Weekly Maintenance

The fluid path of the XCalibur must be cleaned weekly to remove precipitates such as salts, eliminate bacterial growth, and so on. Any of the three following cleaning procedures can be used:
- Weak detergent
- Weak acid and base
- 10% bleach

The procedures using these solutions are described in the following sections.

5.2.1 Weak Detergent Cleaning

To clean the pump with weak detergent, follow these steps:

1. Prime the pump with a weak detergent solution (e.g., 2% solution of CONTRAD®, or RoboScrub) and allow the solution to remain in the pump with the syringe fully lowered for 30 minutes.
2. After the 30-minute period, remove the reagent tubing from the detergent and cycle all the fluid from the syringe and tubing into a waste container.

3. Prime the pump a minimum of 10 cycles with distilled or de-ionized water. Leave the fluid pathways filled for storage.

Note: *CONTRAD® 100 can be purchased through Fisher Scientific. Order catalog number 04-355-27 for a 1 gallon container.*

Note: *RoboScrub is a phosphate-free detergent for cleaning and conditioning liquid handling systems. RoboScrub is available from Tecan (PN 70-736) in a 16 oz. container.*

5.2.2 Weak Acid-Base-Sequence Cleaning

To clean the pump with weak acid and base, follow these steps:

Prime the pump with 0.1 N NaOH and allow the solution to remain in the pump(s) for 10 minutes with the syringes fully lowered.

1. Flush the pump with distilled or deionized water.
2. Prime the pump with 0.1 N HCl, and allow the solution to remain in the pump for 10 minutes with the syringes fully lowered.
3. After a 10-minute period, remove the reagent tubing from 0.1 N HCl solution and cycle all the fluid from the syringes and tubing into a waste container.
4. Prime the pump a minimum of 10 cycles with distilled or deionized water.

5.2.3 10% Bleach Cleaning

To clean the pump with 10% bleach, follow these steps:

1. Make a solution of 10% bleach by adding one part of commercial bleach to nine parts of water.
2. Prime the pump with the 10% bleach and allow the solution to remain in the pump with the syringes fully lowered for 30 minutes.
3. After the 30-minute period, remove the reagent tubing from 10% bleach solution and cycle all the fluid from the syringes and tubing into a waste container.
4. Prime the pump a minimum of 10 cycles with distilled or deionized water.

5.3 Periodic Maintenance

Tubing, syringe seals, and valves require periodic maintenance. If they become worn, you are likely to notice these symptoms:

- Poor precision and accuracy
- Variable or moving air gap
- Leakage

If any of these symptoms occurs and it is not obvious which component is causing the problem, it is easiest and most economical to replace one component at a time in the following order:

1 input and output tubing

2 plunger seal

3 valve

The frequency of replacement will depend on the duty cycle, fluids used, and instrument maintenance.

5.3.1 Quality Control Assurance

Check the accuracy and precision of the XCalibur on a regular basis.

Tecan Systems recommends checking both accuracy and precision gravimetrically, using an analytical balance with the capability to measure to 0.1 mg. Gravimetric measurements should be corrected for the specific gravity of water at the ambient temperature.

The syringe can be checked by programming in the desired volume and determining the weight of fluid dispensed.

To determine precision and accuracy, run a minimum of 20 replicates. The Mean, Standard Deviation and Coefficient of Variation (see formula below) can then be calculated. The calculations to determine accuracy must take into account the specific gravity of water, which is dependent upon temperature. In addition, to prevent a false reading caused by fluid adhering to the tip of the aspirate tubing, a small amount of surfactant should be added to the water (e.g., Fluorad® at a 0.01% concentration).

% Coefficient of Variation = (Standard Deviation/Mean) * 100

$$\textbf{\%CV} = \left(\frac{\sqrt{\frac{1}{n-1}\left\{ \sum_{i=1}^{n} X_i^2 - n\overline{X}^2 \right\}}}{\overline{X}} \right) * 100$$

$$\textbf{\% Accuracy} = \left[\frac{\left(\frac{\overline{X}}{sg} \right) * 100}{Vol_{expected}} \right] - 100$$

where:

sg = specific gravity of H_20 @ 25°C = 0.99707

$Vol_{expected}$ = Expected volume to be dispensed

n = number of replicate

X = individual result

X = mean of all results

5.3.2 Replacing Dispense or Reagent Tubing

To replace dispense or reagent tubing, follow these steps:

1. To remove the tubing, use a 5/16" wrench and gently loosen the fittings.
2. Unscrew the fittings and remove the tubing.
3. To install new tubing, insert the fitting into the valve and tighten it finger tight.
4. Using a 5/16" wrench, turn the fitting another ¼ to ½ turn.

5.3.3 Replacing a Syringe

To replace a syringe, follow these steps:

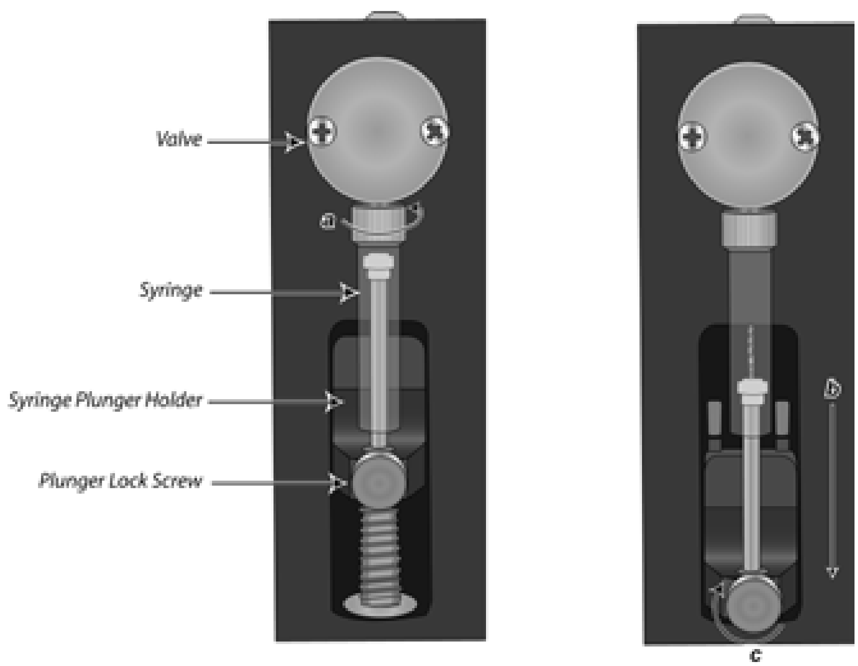
1. Initialize the pump.
2. Loosen the plunger lock screw approximately three full turns.
3. Lower the plunger drive by sending the command [A3000R]. If power is not applied, the plunger drive can be manually lowered by pushing down firmly on the plunger holder assembly.

4 To install the syringe (as shown in Figure 5-1):
   – Screw the syringe into the valve until you reach the touch-off point. Tighten from 1/8 to 1/4 turn.
   – Pull the syringe plunger down to the carriage.
   – Screw the syringe plunger into place.

5 Re-initialize the pump.

Note: *Make sure the plunger lock screw is securely tightened.*

Figure 5-1 *Syringe Replacement*



5.3.4 Replacing the Reagent Syringe Seals

Note: *See Chapter 2, "Hardware Setup", for an illustration of the syringe components.*

To replace the reagent syringe seals, follow these steps:

1 Remove the syringe from the pump.

2 Remove the syringe plunger from the barrel.

3 Using a single edged razor or precision knife, carefully slice the old seal lengthwise and remove them from the plunger.

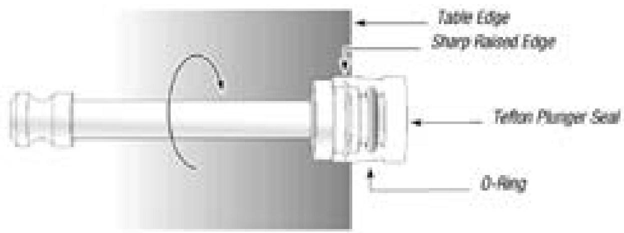
4 Replace the “O”-ring and wet the new ‘O” ring and plunger tip with distilled or deionized water.

5 Place the seal on a flat surface with the open end facing up. Press the plunger tip firmly into the hole until it snaps into position.

6 Lay the plunger on a flat table top, and position it so that the seal (from the “O”-ring up) hangs over the edge.

7 Slowly roll the plunger along the table edge pressing firmly on the portion of the seal below the “O”-ring. See Figure 5-2, ’Syringe Seal Assembly”

Figure 5-2 *Syringe Seal Assembly*



8 Rotate the plunger three complete turns. This is necessary to make the sharp raised edge of the plunger bite into the seal for a secure fit.

9 Wet the seal with distilled or deionized water, then insert the plunger/seal assembly into the glass barrel.

Note: *With the exception of black seals, syringe sizes 250 μL, 500 μL, 1 mL, 2.5 mL, and 5.0 mL have “O”-rings.*

Caution! *Black seals should be lubricated with a small amount of silicon oil before inserting the plunger/seal assembly into the glass barrel. Failure to do so can cause the glass barrel to break.*

5.3.5 Replacing the XCalibur Valve

To replace the XCalibur valve, follow these steps:

1 Remove as much fluid as possible from the system by cycling the pump and using air as the system fluid.

2 Initialize the pump using the [ZR] command so that the valve motor shaft is in the correct position.

3 Issue an [A3000R] command to move the plunger to the bottom of travel.

4 Remove the syringe and tubing.

5 Remove the two Phillips head screws on the front of the valve, then remove the valve from the pump.

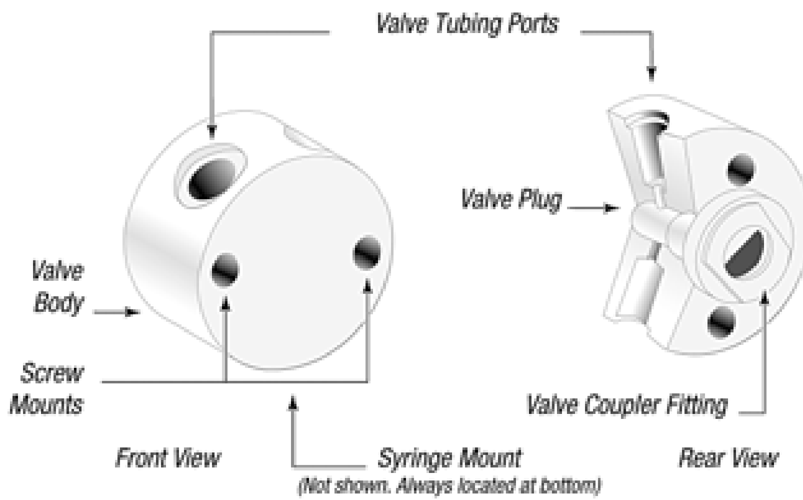
6 Install the new valve by placing it on the front panel so the screw holes line up. The valve coupler fitting mates to the valve motor shaft. Replace the valve screws.

7 Install the syringe and pull the syringe plunger until it is above the carriage.

8 Align the valve using the plunger as a guide and tighten from 1/8 to 1/4 turn after the syringe touch-off.

9 Pull the syringe plunger all the way into the carriage and secure by tightening the plunger lock screw.

Figure 5-3 *XCalibur Valve Replacement (3-Port Valve Shown)*



5.4 On-Site Replacements

5.4.1 Replacing the Printed Circuit Assembly (PCA)

To replace the printed circuit board assembly, follow these steps:

1 Power off the pump.

2 Remove the back panel by unscrewing the three hex side panel screws and the two standoff screws holding the DA-15 connectors.

3 Remove the hex screw that holds the printed circuit board to the pump.

4 Note the cable connection locations and unplug the cables from the board.

5 Plug the cables into the new board.

6 Install the new board and screw it into place.

7 Reinstall the back panel using the three back panel screws and the two standoff screws for the DA-15 connector. (There are four standoff screws for 485/CAN pumps using DE-9 connectors.)

8 Power on and reinitialize the pump.

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6 Technical Service

For information or questions regarding ordering or operating the XCalibur Syringe Pump, please contact Tecan Systems Technical Service using one of the methods listed below.

By phone	408-953-3100 or 800-231-0711
By fax	408-953-3101
By e-mail	helpdesk-sy@tecan.com

Technical support is available 7:00 a.m. to 5:30 p.m. PST, Monday – Friday.

Our mailing address is:

Tecan Systems, Inc.
2450 Zanker Road
San Jose, CA 95131
USA

When calling for technical service, have the following information ready:

- Part number
- Serial number
- Model type
- Description of the problem

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A Ordering Information

This appendix is a summary of available XCalibur configurations, other Tecan Systems liquid handling components, and spare parts for the XCalibur.

A.1 Available Configurations

The available configurations and their respective part numbers are listed below.

Table A-1 *XCalibur Configurations*

Description	Valve Type	Communication Interface	
		RS-232/485	**RS-485/CAN**
XCalibur with 120° 3-port valve, ¼-28	Plastic	737292	737291
XCalibur with 120° 3-port valve, M6	Plastic	737294	737293
XCalibur with 90° 4-port valve, ¼-28	Plastic	737296	737295
XCalibur with 90° 4-port valve, M6	Plastic	737298	737297
XCalibur with T valve, ¼-28	Plastic	737340	737344
XCalibur with T valve, M6	Plastic	737342	737346
XCalibur with Y Block valve, ¼-28	Plastic	737290	737288
XCalibur with Y Block valve, M6	Plastic	737289	737287
XCalibur with 90° 3-Port Distribution, ¼-28	Plastic	736627*	736625*
XCalibur with 90° 3-Port Distribution, M6	Plastic	736631*	736629*
XCalibur with 3-Port, ¼-28	Ceramic	737466*	737459*
XCalibur with 3-Port Distribution, ¼-28	Ceramic	737468*	737461*
XCalibur with 6-Port Distribution, ¼-28	Ceramic	737470*	737463*
XCalibur with 9-Port Distribution, ¼-28	Ceramic	737472*	737465*

** Part numbers followed by an asterisk(*) have been reserved pending release. Please check with your local Tecan Systems representative for availability.*

A.2 XCalibur Spare Parts

The following spare parts are available:

- Syringes
- Seals
- Valves
- Printed Circuit Boards
- Interconnect Tubing
- Pump Evaluation Accessories
- Miscellaneous Parts

A.2.1 Syringes

Table A-2 *Syringes*

Part Number	**Description**
725676	Syringe, 50 µL
725682	Syringe, 100 µL
725589	Syringe, 250 µL
725590	Syringe, 500 µL
725591	Syringe, 1.0 mL
730141	Syringe, 1.0 mL black seal
725592	Syringe, 2.5 mL
728357	Syringe, 2.5 mL, black seal
725593	Syringe, 5.0 mL
729936	Syringe, 5.0 mL, black seal
728655	Syringe, 5.0 mL, special epoxy

A.2.2 Seals and Seal Kits

Table A-3 *Seals*

Part Number	Description
730127	Seal, 50 µL (4/pkg)
730128	Seal, 100 µL (4/pkg)
730129	Seal, 250 µL (4/pkg)
730130	Seal, 500 µL (4/pkg)
730131	Seal, 1.0 mL (4/pkg)
730203	Seal, 1.0 mL, black (4/pkg)
730132	Seal, 2.5 mL, (4/pkg)
728413	Seal, 2.5 mL, black (1/pkg)
730133	Seal, 5.0 mL (4/pkg)
729975	Plunger, 5.0 mL, black seal (1 per pkg.)

A.2.3 Valves

Table A-4 *Valves*

Part Number	Description
Plastic Valves	
729370	Valve, 120° 3-Port (1/4-28" fitting)
731305	Valve, 120° 3-Port (M6 fitting)
736658	Valve, 90° 4-Port (1/4-28" fitting)
736656	Valve, 90° 4-Port (M6 fitting)
736759	Valve, T (1/4-28" fitting)
736766	Valve, T (M6 fitting)
736329	Valve, Y Block (1/4-28" fitting)
736328	Valve, Y Block (M6 fitting)
736615	Valve, 90° 3-Port Distribution (1/4-28" fitting)/plug
736613	Valve, 90° 3-Port Distribution (M6 fitting)/plug

Ceramic Valves	
737498*	Ceramic Valve, 3-Port (1/4-28" fitting)
737496*	Ceramic Valve, 3-Port Distribution (1/4-28" fitting)
737492*	Ceramic Valve, 6-Port Distribution (1/4-28" fitting)
737494*	Ceramic Valve, 9-Port Distribution (1/4-28" fitting)

** Part numbers followed by an asterisk(*) have been reserved pending release. Please check with your local Tecan Systems representative for availability.*

A.2.4 Printed Circuit Board Assemblies

Table A-5 *Printed Circuit Board Assembly and RS485 Converter Board Assembly*

Part Number	Description
737271	PCA, XCalibur 232/485
737273	PCA, XCalibur 485/CAN

A.2.5 Interconnect Tubing

Table A-6 *Tubing*

Part Number	Description	Material	Length (Inches)	Units	Tube Ends
1067	Reagent tube	TFE	16"	.063	1/4-28" to blunt cut
4333	Aspirate/Dispense tube	TFE	33"	.055	Necked
4410	Aspirate/Dispense tube	FEP	40"	.031	Thermal drawn
4609	Reagent tube	FEP	12"	.027	1/4-28" to blunt cut
5133	Aspirate/Dispense tube	FEP	29"	.031	Thermal drawn
5723	Aspirate/Dispense tube	FEP	33"	.031	Necked
5729	Reagent tube	TFE	21"	.031	1/4-28" to blunt cut
5402	Aspirate/Dispense coiled tube	FEP	64"	.027	Thermal drawn
6865	Interconnect tube	FEP	3"	.054	1/4-28" to 1/4-28"
720592	Reagent tube	TFE	61.5"	.063	1/4-28" to blunt cut

Part Number	Description	Material	Length (Inches)	Units	Tube Ends
720595	Aspirate/Dispense tube	FEP	61.5"	.055	Necked
720597	Aspirate/Dispense tube	FEP	60"	.031	Thermal drawn
721370	Reagent tube	TFE	27"	.055	1/4-28" to blunt cut
722540	Reagent tube	FEP	36"	.076	M6 to blunt cut
724169	Aspirate/Dispense tube	FEP	33"	.027	Thermal drawn, M6
724170	Reagent tube	TFE	27"	.051	M6 to blunt cut
724275	Aspirate/Dispense tube	FEP	22"	.051	1/4-28" to M6
724780	Aspirate/Dispense tube	FEP	39"	.076	1/4-28" to 1/4-28"
725788	Interconnect tube	FEP	8"	.051	1/4-28" to 1/4-28"
725876	Aspirate/Dispense tube	FEP	30"	.059	1/4-28" to M6
725896	Interconnect tube	TFE	20"	.060	1/4-28" to 1/4-28"
726172	Aspirate/Dispense tube	TFE	24"	.060	1/4-28" to 1/4-28"

Note: *Custom tubing is available upon request.*

A.2.6 Pump Evaluation Accessories

Table A-7 *Evaluation Software*

Part Number	Description
727899	Pump:Link Software [package includes manual, programmer’s kit, 3.5" diskettes (4)]
723914	AC power supply, 24V (120V). Evaluation, two pumps.
723942	AC power supply, 24V (220V). Evaluation, two pumps.
725744	DA-15 adapter. (Order two adapters per power supply).

A.2.7 Miscellaneous Parts

Table A-8 *Miscellaneous Parts*

Part Number	Description
1590	Fitting, Tube, 0.076 ID, (2/pk)
1589	Fitting, Tube, 0.138 ID, (2/pk)
724757	Wrench, 5/16" and 9/64"
733085	Manual, Operator’s XCalibur
725731	Packaging
725772	Connector, DA-15
973309	Fitting, Tube, 0.085 ID, M6
973308	Fitting, Tube, 0.100 ID, M6
973307	Fitting, Tube, 0.125 ID, M6

A.3 Other Tecan Systems Products

A.3.1 RSP 9000 Robotic Sample Processor

An XYZ robotic arm module, the RSP 9000 automates OEM liquid handling applications and is available with one or two arms, liquid level sensing, and step loss detectors on all three axes. The electronics support a number of auxiliary devices including diluters, valves, I/O boards, disposable tips, and multi-channel probes.

A.3.2 MSP 9250/9500 Mini Sample Processors

One- or two-arm robotic benchtop workstations designed for automating sample preparation or assay methods. Tecan Systems’ modular component technology allows both flexibility and quick customization. A variety of liquid-handling modules and a choice of standard cap-piercing, disposable tip, or multi-channel probes are available. All instruments include liquid-level sensing and step-loss detection.

A.3.3 Cavro® XE 1000 Modular Digital Pump

A simple, compact, economical pump module, the Cavro® XE 1000 is designed for high volume OEM instrument manufacturers who need to perform pipetting and diluting functions such as reagent additions or aspirating and dispensing fluids.

A.3.4 Cavro® XLP 6000 Modular Digital Pumps

An advanced stepper motor driven syringe pump designed for OEM precision liquid handling applications, the Cavro® XLP 6000 automates pipetting, diluting, and dispensing with excellent accuracy and precision over a wide range of speeds using a variety of syringe sizes. The XLP 6000 is an intelligent device, programmable through an RS-232, RS-485 or CAN interface, and it operates from a single 24 V DC power supply.

The XLP 6000 with 9-port distribution valve minimizes the amount of space needed to distribute up to eight fluids in a system.

A.3.5 Cavro® XL 3000 Series Multi-Channel Pumps

These pumps are based on the single channel Cavro® XL 3000 and are available in 2, 4, 6, or 8 channels. Each channel has an independently operated solenoid valve and can accommodate syringes ranging from 500 µL to 2.5 mL. The pumps use an RS-232 or RS-485 interface and a simple command set. They can aspirate and dispense fluids and are specifically designed for OEM applications in the liquid handling, instrumentation, and systems markets.

A.3.6 Cavro® XL Series Smart Valve

A compact, stepper motor driven module for OEM liquid handling applications, the Cavro® Smart Valve is available with 3-, 4-, or 6-port valves. It uses the same communication characteristics as the Cavro® XL 3000 Modular Digital Pump: RS-232 or RS-485 interfaces and a choice of two communication protocols. Up to fifteen devices can be addressed individually from a single communication port. The Smart Valve uses a single 24 V DC power supply and contains a buffered output which can be used to drive an additional relay or solenoid.

A.3.7 Cavro® XL Series Smart Peristaltic Pump

A compact, eight roller unit with 1, 2, 3, or 4 channels. Cavro® Smart Pump modules are stepper motor driven and are designed to provide highly reproducible flow rates with minimum pulsing and long tubing life. The SP modules use the same interface characteristics as the XL 3000 Modular Digital Pump: RS-232 or RS-485 interfaces and a choice of two communication protocols. Up to fifteen devices can be addressed individually from a single communication port. The

Smart Pump uses a single 24 V DC power supply and contains a buffered output which can be used to drive an additional relay or solenoid.

A.3.8 Cavro® Smart I/O Board

The Cavro® Smart I/O board is a microprocessor driven PC board that allows the operation of a number of I/O ports from an external serial line. The board can be controlled by RS-232 or RS-485. It can also be placed on an RS-485 bus with other Tecan Systems pumps and smart devices. The I/O signal is CMOS (0-5 volts). I/O lines include 16 inputs, 16 outputs, and four analog inputs. The board uses a standard Cavro OEM communications protocol.

A.3.9 Cavro® Universal MiniWash

A compact, OEM module for rapidly aspirating or dispensing fluids, this module consists of a control board and a small diaphragm pump attached to a small mounting frame (similar to the Cavro® Smart Valve). The module has many uses including: as a pump for aspirating and/or dispensing fluids with a wash head; for rapidly pumping fluid through a dispense probe for washing; and as a pump for moving fluid in and out of the Active Wash Station.

A.3.10 Accessories and Consumables

Tecan Systems provides a full range of accessories and consumables to keep your instrumentation in tip-top shape. These include consumables such as probes and syringes, seal kits, tubing and valves or accessories such as I/O boards, linear drive boards, or enhancement kits for your system.

A.4 Mating Connector Suppliers

Tecan Systems does not sell mating connectors beyond those found on its evaluation power supply. For customer convenience, a list of DA-15 mating connectors and their suppliers is provided below.

Table A-9 *DA-15 Mating Connectors*

Manufacturer	Description	Manufacturing Part Number
Cable Connector, Receptacle		
AMP	15 pin female - solder cup, receptacle	747909-2
Cinch	15 pin female - solder cup, receptacle	DA-15S
Cable Connector, Housing		
AMP	Plastic housing with locks	207908-4
Cinch	Plastic housing with locks	SDH-15GL-CS
Circuit Board Connectors		
AMP	15 pin female - straight for .62 to .93 mm thick PCB	745411-1
Flat Ribbon		
3M	15 pin female - 15 pin flat ribbon receptacle	89815-8000
3M	15 pin female - strain relief	3448-8D15A

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B Plunger Information

B.1 Typical Plunger Force

Tecan Systems specifies that all new XCalibur Pumps running at a speed of 5600 Hz, will lift a 15-pound weight attached to the plunger drive pin. Tecan Systems cannot warrant the pump for use beyond these specifications

B.2 Plunger Time Calculations

Following are calculations for determining XCalibur plunger speeds. Four different cases are presented below.

1. Start, top, and cutoff speeds are equal, or top speed is less than 50 Hz.
2. Typical move with ramp up, constant speed and ramp down.
3. Move is too small to reach cutoff speed.
4. Move is too small to reach top speed.

Note: *Plunger move times are calculated assuming backlash compensation has been set to zero. K<n> where <n> = 0.*

B.2.1 Symbol Definitions

Table B-1 *Symbol Definitions*

Symbol	Name	Range (n)	Unit
v <n>	Start Speed	50..1000	Pulses/sec or Hz
V<n>	Top Speed	5..6000	Pulses/sec or Hz
c<n>	Cutoff Speed	50..2700	Pulses/sec or Hz
L<n>	Slope	1..20	n*2500 pulses/sec^2 or Hz
A	Move Distance	0..3150 0..25200	Full increments Microsteps
t_1	Ramp Up Time		Seconds
t_2	Constant Speed Time		Seconds

Symbol	Name	Range (n)	Unit
t_3	Ramp Down Time		Seconds
t	Total Move Time	$t_1+t_2+t_3$	Seconds
A_1	Ramp Up increments		Half increments
A_2	Ramp Up increments		Half increments
A_3	Ramp Up increments		Half increments

Note:

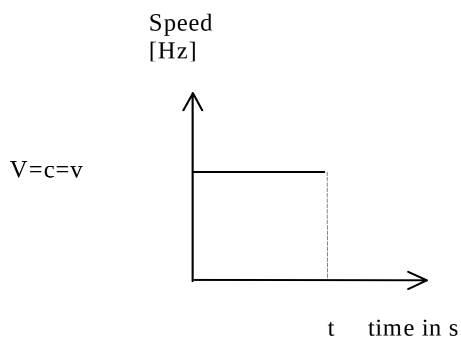
- *Cutoff speed cannot be less than start speed.*
- *During aspiration, v is used in place of c.*
- *The XCalibur uses 3000 full increments per stroke.*

B.2.2 Move Calculations

Case 1. Start, Top, and Cutoff Speeds are Equal or Top Speed is Less than 50 Hz

Case 1 is used when $v = V = c$ or $V = <50$

Diagram of move:



Calculation:

v = 900 Hz   L = 14

V = 900 Hz   A = 3000 full increments

c = 900 Hz

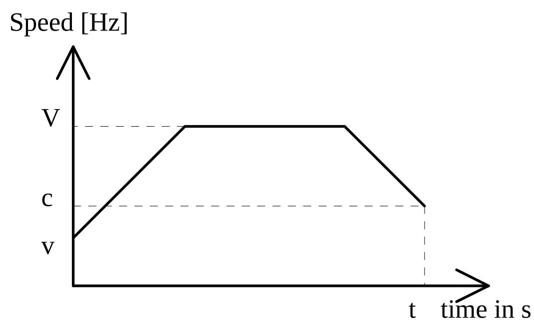
Total Move Time:

$$t = \frac{2 * A}{V} = \frac{2 * 3000}{900} = 6.67 \text{ seconds}$$

Case 2. Ramp Up, Constant Speed, Ramp Down

Case 2 is used when $A_1 + A_3 < 2A$

Diagram of Move:



Calculation:

v = 50 Hz L = 14

V = 5800 Hz A = 3000 full increments

c = 500 Hz

Ramp Up increments

$$A_1 = \frac{V^2 - v^2}{2L} = \frac{5800^2 - 50^2}{2 * 14 * 2500} = 481 \text{ half increments}$$

Ramp Down increments

$$A_3 = \frac{V^2 - c^2}{2L} = \frac{5800^2 - 500^2}{2 * 14 * 2500} = 477 \text{ half increments}$$

If $A_1 + A_3 < 2A$ (481 + 477 < 6000) then:

Ramp Up Time

$$t_1 = \frac{V - v}{L} = \frac{5800 - 50}{14 * 2500} = .16 \text{ seconds}$$

Ramp Down Time

$$t_3 = \frac{V - c}{L} = \frac{5800 - 500}{14 * 2500} = .15$$ seconds

Constant Speed increments

$$A_2 = 2A - A_1 - A_3 = 2 * 3000 - 481 - 477 = 5042$$ half increments

Constant Speed Time

$$t_2 = \frac{A_2}{V} = \frac{5042}{5800} = .87$$ seconds

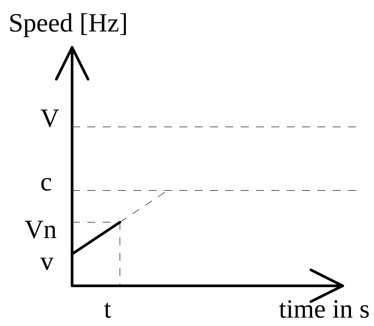
Total Move Time

$$t = t_1 + t_2 + t_3 = .16 + .87 + .15 = 1.18$$ seconds

Case 3. Move Too Small to Reach Cutoff Speed

Case 3 is used when Vn < c

Diagram of Move:



Calculation:

v = 50 Hz   L = 14

V = 5800 Hz   A = 5 full increments

c = 900 Hz

Theoretical Top speed

$$Vn = \sqrt{4AL + v^2} = \sqrt{4*5*14*2500+50^2} = 838 \text{ Hz}$$

If $Vn < c$ then:

Total Move Time

$$t = \frac{Vn - v}{L} = \frac{838-50}{14*2500} = .023 \text{ seconds}$$

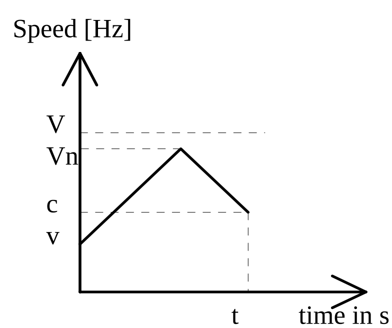
Ramp Up increments

$A_1 = A = 5$ full increments

Case 4. Move Too Small to Reach Top Speed

Case 4 is used when Vn < V and Vn > c

Diagram of Move:



Calculation:

v = 50 Hz	L = 14
V = 5800 Hz	A = 350 full increments
c = 900 Hz	

Top speed

$$Vn = \sqrt{2AL + \frac{v^2 + c^2}{2}} = \sqrt{2*350*14*2500 + \frac{50^2 + 900^2}{2}} = 4991 \text{ Hz}$$

Total Move Time

$$t = \frac{1}{L}(2Vn - v - c) = \frac{1}{L}(2*4991 - 50 - 900) = .26 \text{ Hz}$$

C ASCII Chart of Codes for U.S. Characters

Table C-1 *ASCII Chart of Codes for U.S. Characters*

Decimal	Hexadecimal	Character or Function	Decimal	Hexadecimal	Character or Function
0	00	none	65	41	A
1	01	SOH	66	42	B
2	02	STX	67	43	C
3	03	ETX	68	44	D
4	04	EOT	69	45	E
5	05	ENQ	70	46	F
6	06	ACK	71	47	G
7	07	BEL	72	48	H
8	08	BS	73	49	I
9	09	HT	74	4A	J
10	0A	LF	75	4B	K
11	0B	VT	76	4C	L
12	0C	FF	77	4D	M
13	0D	CR	78	4E	N
14	0E	SO	79	4F	O
15	0F	SI	80	50	P
16	10	DLE	81	51	Q
17	11	DC1	82	52	R
18	12	DC2	83	53	S
19	13	DC3	84	54	T
20	14	DC4	85	55	U
21	15	NAK	86	56	V
22	16	SYN	87	57	W
23	17	ETB	88	58	X
24	18	CAN	89	59	Y

Decimal	Hexadecimal	Character or Function	Decimal	Hexadecimal	Character or Function
25	19	EM	90	5A	Z
26	1A	SUB	91	5B	[
27	1B	ESC	92	5C	\ (backslash)
28	1C	FS	93	5D	]
29	1D	GS	94	5E	^ (control)
30	1E	RS	95	5F	— (emdash)
31	1F	US	96	60	` (tick)
32	20	SP	97	61	a
33	21	!	98	62	b
34	22	"	99	63	c
35	23	#	100	64	d
36	24	$	101	65	e
37	25	%	102	66	f
38	26	&	103	67	g
39	27	' (apostrophe)	104	68	h
40	28	(	105	69	i
41	29	)	106	6A	j
42	2A	*	107	6B	k
43	2B	+	108	6C	l
44	2C	, (comma)	109	6D	m
45	2D	- (en dash)	110	6E	n
46	2E	. (period)	111	6F	o
47	2F	/	112	70	p
48	30	0	113	71	q
49	31	1	114	72	r
50	32	2	115	73	s
51	33	3	116	74	t
52	34	4	117	75	u

Decimal	Hexadecimal	Character or Function	Decimal	Hexadecimal	Character or Function
53	35	5	118	76	v
54	36	6	119	77	w
55	37	7	120	78	x
56	38	8	121	79	y
57	39	9	122	7A	z
58	3A	:	123	7B	{ (left brace)
59	3B	;	124	7C	| (vertical bar)
60	3C	<	125	7D	} (right brace)
61	3D	=	126	7E	~ (tilde)
62	3E	>	127	7F	DEL
63	3F	?			
64	40	@			

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D Chemical Resistance Chart

The information provided in Table D, which starts on the following page, has been supplied to Tecan Systems by other reputable sources and is to be used ONLY as a guideline. Before permanent installation, test the equipment with the chemicals under the specific conditions of your application.

Ratings of chemical behavior listed in this chart apply to a 48-hr exposure period; Tecan Systems has no knowledge of possible effects beyond this period. Tecan Systems does not warrant (neither express or implied) that the information in this chart is accurate or complete or that materials are suitable for any purpose.

Caution! *Failure to test chemicals used in individual applications with the XCalibur may result in damage to the pump and/or test results.*

DANGER! *Variations in chemical behavior during handling due to factors such as temperature, pressure and concentration can cause equipment to fail, even though it passed an initial test.* ***SERIOUS INJURY MAY RESULT****. Use suitable guards and/or personal protection when handling chemicals.*

The materials listed in are used in the following areas of the XCalibur:

Table D-1 *Plastic Materials Used in Tecan Pumps*

Telfon® (PTFE, TFE, FEP)	Tubing, Valve Plug, Seal
PCTFE	Valve Body
Polypropylene	Fittings for Tubing

Ratings – Chemical Effect

A = Excellent

B = Good – Minor Effect, slight corrosion or discoloration

C = Fair – Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur.

D = Severe Effect, not recommended for **ANY** use.

N/A = Information Not Available

Explanation of Footnotes

1. Satisfactory to 72°F (22°C)
2. Satisfactory to 120°F (48°C)

Chemical	PCTFE	Teflon	Polypropylene
Acetaldehyde	A- Excellent	A- Excellent	C1-Fair
Acetamide	A- Excellent	A- Excellent	A2-Excellent
Acetate Solvent	A1- Excellent	A- Excellent	C1-Fair
Acetic Acid	A- Excellent	A- Excellent	A2-Excellent
Acetic Acid 20%	A- Excellent	A- Excellent	A2-Excellent
Acetic Acid 80%	A- Excellent	A- Excellent	A2-Excellent
Acetic Acid, Glacial	A2- Excellent	A- Excellent	A2-Excellent
Acetic Anhydride	A- Excellent	A- Excellent	B2-Good
Acetone	A- Excellent	A- Excellent	A-Excellent
Acetyl Chloride (dry)	A- Excellent	A- Excellent	D-Severe Effect
Acetylene	A- Excellent	A- Excellent	D-Severe Effect
Acrylonitrile	N/A	A- Excellent	B2-Good
Adipic Acid	N/A	A- Excellent	B2-Good
Alcohols:Amyl	A- Excellent	A- Excellent	A-Excellent
Alcohols:Benzyl	A- Excellent	A- Excellent	A-Excellent
Alcohols:Butyl	N/A	A- Excellent	A2-Excellent
Alcohols:Diacetone	B1- Good	A- Excellent	A1-Excellent
Alcohols:Ethyl	A- Excellent	A- Excellent	A1-Excellent
Alcohols:Hexyl	N/A	A- Excellent	A1-Excellent
Alcohols:Isobutyl	N/A	A2- Excellent	A2-Excellent
Alcohols:Isopropyl	N/A	A2- Excellent	A-Excellent
Alcohols:Methyl	A1- Excellent	A- Excellent	A1-Excellent
Alcohols:Octyl	N/A	N/A	A-Excellent
Alcohols:Propyl	N/A	A- Excellent	A-Excellent
Aluminum Chloride	A- Excellent	A- Excellent	A-Excellent
Aluminum Chloride 20%	A- Excellent	A- Excellent	A-Excellent
Aluminum Fluoride	N/A	A- Excellent	A-Excellent
Aluminum Hydroxide	A1- Excellent	A- Excellent	A-Excellent
Aluminum Nitrate	A1- Excellent	A- Excellent	A1-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Aluminum Potassium Sulfate 100%	A- Excellent	A- Excellent	A-Excellent
Aluminum Sulfate	A- Excellent	A- Excellent	A-Excellent
Amines (General)	A- Excellent	A2- Excellent	B2-Good
Ammonia, anhydrous	A- Excellent	A- Excellent	A-Excellent
Ammonia, Aqueous	A- Excellent	A- Excellent	A-Excellent
Ammonia Nitrate	N/A	A- Excellent	A1-Excellent
Ammonium Acetate	N/A	A- Excellent	A2-Excellent
Ammonium Bifluoride	N/A	A- Excellent	A-Excellent
Ammonium Carbonate	N/A	A- Excellent	A-Excellent
Ammonium Chloride	A- Excellent	A- Excellent	A-Excellent
Ammonium Hydroxide	A- Excellent	A- Excellent	A-Excellent
Ammonium Nitrate	A- Excellent	A- Excellent	A-Excellent
Ammonium Oxalate	N/A	N/A	A1-Excellent
Ammonium Persulfate	A- Excellent	A- Excellent	B2-Good
Ammonium Phosphate, Dibasic	A- Excellent	A2- Excellent	B-Good
Ammonium Phosphate, Monobasic	N/A	A- Excellent	B-Good
Ammonium Phosphate, Tribasic	N/A	A- Excellent	B-Good
Ammonium Sulfate	A- Excellent	A- Excellent	B-Good
Ammonium Thiosulfate	N/A	N/A	N/A
Amyl Acetate	A1- Excellent	A- Excellent	B2-Good
Amyl Alcohol	A- Excellent	A- Excellent	B-Good
Amyl Chloride	A- Excellent	A- Excellent	B-Good
Aniline	A2- Excellent	A- Excellent	B-Good
Aniline Hydrochloride	N/A	A- Excellent	B1-Good
Antifreeze	N/A	N/A	B-Good
Antimony Trichloride	A- Excellent	A- Excellent	B1-Good
Aqua Regia (80% HCl, 20% HNO3)	A- Excellent	A- Excellent	C1-Fair
Arochlor 1248	A1- Excellent	A- Excellent	D-Severe Effect
Aromatic Hydrocarbons	N/A	N/A	D2-Severe Effect

Chemical	PCTFE	Teflon	Polypropylene
Arsenic Acid	N/A	A- Excellent	A-Excellent
Arsenic Salts	N/A	N/A	B1-Good
Asphalt	A- Excellent	A1- Excellent	A2-Excellent
Barium Carbonate	A- Excellent	A- Excellent	A-Excellent
Barium Chloride	A- Excellent	A- Excellent	A-Excellent
Barium Cyanide	N/A	A1- Excellent	D-Severe Effect
Barium Hydroxide	A- Excellent	A- Excellent	A-Excellent
Barium Nitrate	A- Excellent	A- Excellent	A-Excellent
Barium Sulfate	A- Excellent	A- Excellent	A-Excellent
Barium Sulfide	N/A	A- Excellent	A-Excellent
Benzaldehyde	A- Excellent	A1- Excellent	A1-Excellent
Benzene	B- Good	A- Excellent	B1-Good
Benzene Sulfonic Acid	N/A	A- Excellent	B1-Good
Benzoic Acid	A- Excellent	A2- Excellent	A2-Excellent
Benzol	A- Excellent	A- Excellent	A2-Excellent
Benzonitrile	A2- Excellent	A2- Excellent	A1-Excellent
Benzyl Chloride	N/A	N/A	A2-Excellent
Bleach Solutions	A- Excellent	A- Excellent	C1-Fair
Borax (Sodium Borate)	A- Excellent	A- Excellent	A-Excellent
Boric Acid	A- Excellent	A- Excellent	A-Excellent
Bromine Water	A- Excellent	A- Excellent	C1-Fair
Butadiene	A- Excellent	A2- Excellent	B1-Good
Butane	A- Excellent	A- Excellent	D-Severe Effect
Butanol (Butyl Alcohol)	A1- Excellent	A2- Excellent	B2-Good
Butyl Amine	D- Severe Effect	A2- Excellent	B1-Good
Butyl Ether	A1- Excellent	A1- Excellent	D-Severe Effect
Butyl Phthalate	A1- Excellent	A2- Excellent	B-Good
Butylacetate	A1- Excellent	A- Excellent	D-Severe Effect
Butylene	B1- Good	A- Excellent	D-Severe Effect

Chemical	PCTFE	Teflon	Polypropylene
Butyric Acid	A- Excellent	A- Excellent	A2-Excellent
Calcium Bisulfate	N/A	N/A	A1-Excellent
Calcium Bisulfide	A- Excellent	A- Excellent	A-Excellent
Calcium Bisulfite	A- Excellent	A- Excellent	A-Excellent
Calcium Carbonate	N/A	A- Excellent	A-Excellent
Calcium Chloride	A- Excellent	A- Excellent	A-Excellent
Calcium Hydroxide	A- Excellent	A- Excellent	A-Excellent
Calcium Hypochlorite	B1- Good	A- Excellent	A-Excellent
Calcium Nitrate	A1- Excellent	A2- Excellent	A-Excellent
Calcium Oxide	N/A	A- Excellent	A-Excellent
Calcium Sulfate	A- Excellent	A- Excellent	A-Excellent
Carbon Bisulfide	N/A	N/A	D-Severe Effect
Carbon Tetrachloride	A1- Excellent	A- Excellent	D-Severe Effect
Carbon Tetrachloride (dry)	D- Severe Effect	A- Excellent	D-Severe Effect
Carbon Tetrachloride (wet)	A1- Excellent	A- Excellent	B1-Good
Carbonated Water	N/A	A- Excellent	A1-Excellent
Carbonic Acid	A- Excellent	A- Excellent	A-Excellent
Chloric Acid	A- Excellent	A- Excellent	D-Severe Effect
Chlorine Water	A- Excellent	A- Excellent	A-Excellent
Chlorine, Anhydrous Liquid	B2- Good	A- Excellent	D-Severe Effect
Chloroacetic Acid	A2- Excellent	A- Excellent	A2-Excellent
Chlorobenzene (Mono)	A1- Excellent	B- Good	D-Severe Effect
Chlorobromomethane	N/A	A- Excellent	A1-Excellent
Chloroform	A1- Excellent	A1- Excellent	D-Severe Effect
Chlorosulfonic Acid	A2- Excellent	A- Excellent	D-Severe Effect
Chromic Acid 10%	A- Excellent	A- Excellent	A1-Excellent
Chromic Acid 30%	A- Excellent	A- Excellent	A1-Excellent
Chromic Acid 5%	A- Excellent	A- Excellent	A1-Excellent
Chromic Acid 50%	A2- Excellent	A- Excellent	B2-Good

Chemical	PCTFE	Teflon	Polypropylene
Citric Acid	A2- Excellent	A- Excellent	A-Excellent
Citric Oils	N/A	N/A	A1-Excellent
Clorox® (Bleach)	A- Excellent	A- Excellent	A2-Excellent
Copper Chloride	A- Excellent	A- Excellent	A-Excellent
Copper Cyanide	N/A	A- Excellent	A-Excellent
Copper Nitrate	A- Excellent	A- Excellent	A-Excellent
Copper Sulfate >5%	A- Excellent	A- Excellent	A-Excellent
Copper Sulfate 5%	A- Excellent	A- Excellent	A-Excellent
Cresols	A1- Excellent	N/A	D-Severe Effect
Cresylic Acid	N/A	A- Excellent	D-Severe Effect
Cupric Acid	A2- Excellent	A- Excellent	B2-Good
Cyanic Acid	N/A	A- Excellent	N/A
Cyclohexane	A- Excellent	A- Excellent	D-Severe Effect
Cyclohexanone	A1- Excellent	A- Excellent	C1-Fair
Detergents	A- Excellent	A- Excellent	A-Excellent
Diacetone Alcohol	B1- Good	A- Excellent	A1-Excellent
Dichlorobenzene	N/A	A- Excellent	B1-Good
Dichloroethane	A2- Excellent	A1- Excellent	D-Severe Effect
Diesel Fuel	A1- Excellent	A- Excellent	C1-Fair
Diethyl Ether	C- Fair	A- Excellent	D-Severe Effect
Diethylamine	A1- Excellent	A- Excellent	B1-Good
Diethylene Glycol	N/A	A- Excellent	A-Excellent
Dimethyl Aniline	A- Excellent	A- Excellent	A2-Excellent
Dimethyl Formamide	A2- Excellent	A- Excellent	A2-Excellent
Diphenyl	B1-Good	A- Excellent	D-Severe Effect
Diphenyl Oxide	N/A	A- Excellent	D-Severe Effect
Epsom Salts (Magnesium Sulfate)	A- Excellent	A- Excellent	A-Excellent
Ethane	A1- Excellent	A- Excellent	D-Severe Effect
Ethanol	A- Excellent	A- Excellent	A-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Ethanolamine	D- Severe Effect	A1- Excellent	A1-Excellent
Ether	B1- Good	A- Excellent	D-Severe Effect
Ethyl Acetate	A1- Excellent	A- Excellent	A-Excellent
Ethyl Benzoate	A1- Excellent	A- Excellent	D-Severe Effect
Ethyl Ether	A1- Excellent	A- Excellent	D-Severe Effect
Ethyl Sulfate	A- Excellent	A- Excellent	D-Severe Effect
Ethylene Bromide	B- Good	A- Excellent	D-Severe Effect
Ethylene Chloride	A1- Excellent	A- Excellent	D-Severe Effect
Ethylene Chlorohydrin	A- Excellent	A- Excellent	B1-Good
Ethylene Diamine	D- Severe Effect	A- Excellent	B2-Good
Ethylene Dichloride	A1- Excellent	A- Excellent	D-Severe Effect
Ethylene Glycol	A- Excellent	A- Excellent	A-Excellent
Ethylene Oxide	A2- Excellent	A- Excellent	C1-Fair
Fatty Acids	A- Excellent	A- Excellent	A-Excellent
Ferric Chloride	A2- Excellent	A- Excellent	A-Excellent
Ferric Nitrate	A1- Excellent	A- Excellent	A-Excellent
Ferric Sulfate	A1- Excellent	A- Excellent	A-Excellent
Ferrous Chloride	B1- Good	A- Excellent	A-Excellent
Ferrous Sulfate	N/A	A- Excellent	A-Excellent
Fluoboric Acid	B1-Good	A- Excellent	A-Excellent
Fluorine Liquid	N/A	N/A	D-Severe Effect
Fluorosilicic Acid	A1- Excellent	A- Excellent	A-Excellent
Formaldehyde 100%	N/A	A- Excellent	A-Excellent
Formaldehyde 40%	A- Excellent	A- Excellent	A-Excellent
Formic Acid	A- Excellent	A- Excellent	A1-Excellent
Freon 113	A1- Excellent	A- Excellent	D-Severe Effect
Freon 12	A1- Excellent	A- Excellent	A1-Excellent
Freon 22	A1- Excellent	A- Excellent	A1-Excellent
Freon® 11	A1- Excellent	A- Excellent	A1-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Fuel Oils	A- Excellent	A- Excellent	B1-Good
Furan Resin	A1- Excellent	A- Excellent	D-Severe Effect
Furfural	D- Severe Effect	A- Excellent	D-Severe Effect
Gallic Acid	A1- Excellent	A- Excellent	A-Excellent
Gasoline (high-aromatic)	A1- Excellent	A- Excellent	A1-Excellent
Glucose	N/A	A- Excellent	A-Excellent
Glycerin	A- Excellent	A- Excellent	A-Excellent
Glycolic Acid	A1- Excellent	A- Excellent	A-Excellent
Heptane	A- Excellent	A- Excellent	D-Severe Effect
Hexane	A- Excellent	A- Excellent	C1-Fair
Hydraulic Oil (Petro)	A1- Excellent	A- Excellent	D-Severe Effect
Hydrazine	N/A	A- Excellent	D-Severe Effect
Hydrobromic Acid 100%	A- Excellent	A- Excellent	D-Severe Effect
Hydrobromic Acid 20%	A- Excellent	A- Excellent	A-Excellent
Hydrochloric Acid 100%	A- Excellent	A- Excellent	A1-Excellent
Hydrochloric Acid 20%	A- Excellent	A- Excellent	A2-Excellent
Hydrochloric Acid 37%	A- Excellent	A- Excellent	A2-Excellent
Hydrofluoric Acid 100%	B- Good	A- Excellent	D-Severe Effect
Hydrofluoric Acid 20%	A- Excellent	A- Excellent	B-Good
Hydrofluosilicic Acid 100%	B- Good	A- Excellent	A-Excellent
Hydrofluosilicic Acid 20%	A- Excellent	A- Excellent	A-Excellent
Hydrogen Peroxide 10%	A- Excellent	A- Excellent	A1-Excellent
Hydrogen Peroxide 100%	B- Good	A- Excellent	D-Severe Effect
Hydrogen Peroxide 30%	B- Good	A- Excellent	A1-Excellent
Hydrogen Peroxide 50%	A- Excellent	A- Excellent	C2-Fair
Hydrogen Sulfide (Aqueous)	A1- Excellent	A- Excellent	B2-Good
Hydroxyacetic Acid 70%	A1- Excellent	A- Excellent	A-Excellent
Iodine	A1- Excellent	A- Excellent	A1-Excellent
Iodine (in alcohol)	NA	A- Excellent	A1-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Isooctane	A1- Excellent	A- Excellent	A1-Excellent
Isopropyl Acetate	N/A	A- Excellent	B1-Good
Isopropyl Ether	A1- Excellent	A- Excellent	D-Severe Effect
Kerosene	A- Excellent	A- Excellent	B1-Good
Ketones	A1- Excellent	A- Excellent	B1-Good
Lacquer Thinners	A2- Excellent	A- Excellent	D-Severe Effect
Lacquers	A1- Excellent	A- Excellent	D-Severe Effect
Lactic Acid	A- Excellent	A- Excellent	A-Excellent
Lead Acetate	A- Excellent	A- Excellent	A-Excellent
Lead Nitrate	N/A	A- Excellent	A-Excellent
Lead Sulfamate	N/A	B- Good	A2-Excellent
Ligroin	N/A	A- Excellent	D-Severe Effect
Linoleic Acid	N/A	A- Excellent	D-Severe Effect
Lithium Chloride	N/A	A- Excellent	A2-Excellent
Lithium Hydroxide	N/A	A- Excellent	A2-Excellent
Lye: Ca(OH)2 Calcium Hydroxide	A2- Excellent	A- Excellent	A2-Excellent
Magnesium Bisulfate	N/A	A- Excellent	A2-Excellent
Magnesium Carbonate	N/A	A1- Excellent	A-Excellent
Magnesium Chloride	A- Excellent	A- Excellent	A-Excellent
Magnesium Hydroxide	A1- Excellent	A- Excellent	A-Excellent
Magnesium Nitrate	N/A	A- Excellent	A-Excellent
Magnesium Oxide	N/A	A- Excellent	N/A
Magnesium Sulfate (Epsom Salts)	A- Excellent	A- Excellent	A-Excellent
Maleic Acid	N/A	A- Excellent	A-Excellent
Maleic Anhydride	N/A	A- Excellent	D-Severe Effect
Malic Acid	N/A	A- Excellent	B-Good
Manganese Sulfate	A1- Excellent	A- Excellent	A-Excellent
Mercury	A1- Excellent	A- Excellent	A-Excellent
Methanol (Methyl Alcohol)	A2- Excellent	A- Excellent	A1-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Methyl Acetate	A1- Excellent	A- Excellent	B1-Good
Methyl Acetone	N/A	A- Excellent	N/A
Methyl Acrylate	A1- Excellent	A- Excellent	C1-Fair
Methyl Bromide	A1- Excellent	A- Excellent	D-Severe Effect
Methyl Butyl Ketone	N/A	A- Excellent	D-Severe Effect
Methyl Cellosolve	N/A	A- Excellent	A2-Excellent
Methyl Chloride	A1- Excellent	A- Excellent	D-Severe Effect
Methyl Dichloride	N/A	A- Excellent	N/A
Methyl Ethyl Ketone	A1- Excellent	A- Excellent	A1-Excellent
Methyl Isobutyl Ketone	A- Excellent	A- Excellent	D-Severe Effect
Methyl Isopropyl Ketone	N/A	A- Excellent	D-Severe Effect
Methyl Methacrylate	N/A	A- Excellent	A-Excellent
Methylamine	A1- Excellent	A- Excellent	D-Severe Effect
Methylene Chloride	A1- Excellent	A- Excellent	D-Severe Effect
Mineral Spirits	A1- Excellent	A- Excellent	D-Severe Effect
Monochloroacetic acid	A2- Excellent	A- Excellent	A2-Excellent
Monoethanolamine	D- Severe Effect	A- Excellent	A1-Excellent
Morpholine	A1- Excellent	A- Excellent	N/A
Motor oil	A- Excellent	A- Excellent	A1-Excellent
Naphthalene	A- Excellent	A- Excellent	B1-Good
Nickel Chloride	A2- Excellent	A- Excellent	A1-Excellent
Nickel Nitrate	A2- Excellent	A- Excellent	A-Excellent
Nickel Sulfate	A- Excellent	A- Excellent	A-Excellent
Nitric Acid (20%)	A1- Excellent	A- Excellent	A1-Excellent
Nitric Acid (50%)	A1- Excellent	A- Excellent	A1-Excellent
Nitric Acid (5-10%)	A1- Excellent	A- Excellent	A-Excellent
Nitric Acid (Concentrated)	A1- Excellent	A- Excellent	D-Severe Effect
Nitrobenzene	A- Excellent	A- Excellent	B1-Good
Nitrous Acid	B- Good	A- Excellent	D-Severe Effect

Chemical	PCTFE	Teflon	Polypropylene
Oil Crude, Sour	A- Excellent	A- Excellent	B1-Good
Oil Crude, Sweet	A- Excellent	A- Excellent	C1-Fair
Oil Mineral	A- Excellent	A- Excellent	A1-Excellent
Oleic Acid	A1- Excellent	A- Excellent	B2-Good
Oleum 100%	A1- Excellent	A- Excellent	D-Severe Effect
Oxalic Acid (cold)	A- Excellent	A- Excellent	A2-Excellent
Ozone	A1- Excellent	A- Excellent	D-Severe Effect
Palmitic Acid	N/A	A- Excellent	A1-Excellent
Perchloroethylene	A1- Excellent	A- Excellent	D-Severe Effect
Petrolatum	N/A	A- Excellent	B2-Good
Petroleum	A- Excellent	A- Excellent	B2-Good
Phenol (10%)	A- Excellent	A- Excellent	A1-Excellent
Phosphoric Acid (>40%)	A- Excellent	A- Excellent	A-Excellent
Phosphoric Acid (40%)	A- Excellent	A- Excellent	A-Excellent
Phosphoric Acid (crude)	A2- Excellent	A- Excellent	A1-Excellent
Phosphoric Acid Anhydride	N/A	A- Excellent	A1-Excellent
Phosphorus	N/A	A- Excellent	B1-Good
Phosphorus Trichloride	A- Excellent	A- Excellent	D-Severe Effect
Photographic Developer	A- Excellent	A- Excellent	A2-Excellent
Photographic Solutions	A- Excellent	A- Excellent	A-Excellent
Phthalic Acid	N/A	A- Excellent	A1-Excellent
Phthalic Anhydride	A- Excellent	A- Excellent	D-Severe Effect
Picric Acid	A1- Excellent	A- Excellent	A1-Excellent
Potash (Potassium Carbonate)	A1- Excellent	A- Excellent	A-Excellent
Potassium Bicarbonate	A2- Excellent	A- Excellent	A1-Excellent
Potassium Bromide	A1- Excellent	A- Excellent	A-Excellent
Potassium Chlorate	A2- Excellent	A- Excellent	A-Excellent
Potassium Chloride	A2- Excellent	A- Excellent	A-Excellent
Potassium Chromate	N/A	A- Excellent	A-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Potassium Cyanide Solutions	A1- Excellent	A- Excellent	A-Excellent
Potassium Ferricyanide	A1- Excellent	A- Excellent	A-Excellent
Potassium Ferrocyanide	A1- Excellent	A- Excellent	A-Excellent
Potassium Hydroxide (Caustic Pot-ash)	A1- Excellent	A- Excellent	A-Excellent
Potassium Hypochlorite	A1- Excellent	A- Excellent	B-Good
Potassium Iodide	N/A	A- Excellent	A-Excellent
Potassium Nitrate	A1- Excellent	A- Excellent	A-Excellent
Potassium Oxalate	N/A	A- Excellent	A1-Excellent
Potassium Permanganate	A1- Excellent	A- Excellent	A1-Excellent
Potassium Sulfate	A1- Excellent	A- Excellent	A-Excellent
Potassium Sulfide	A1- Excellent	A- Excellent	A-Excellent
Propane (liquefied)	A1- Excellent	A- Excellent	B-Good
Pyridine	A1- Excellent	A- Excellent	A1-Excellent
Pyrogallic Acid	A1- Excellent	A- Excellent	A1-Excellent
Resorcinal	A1- Excellent	A- Excellent	A2-Excellent
Salicylic Acid	A1- Excellent	A2- Excellent	A2-Excellent
Salt Brine (NaCl saturated)	A- Excellent	A2- Excellent	A-Excellent
Sea Water	A- Excellent	A- Excellent	A-Excellent
Silver Bromide	A- Excellent	A2- Excellent	N/A
Silver Nitrate	A1- Excellent	A- Excellent	A-Excellent
Soap Solutions	N/A	A- Excellent	A-Excellent
Sodium Acetate	A1- Excellent	A- Excellent	A-Excellent
Sodium Aluminate	N/A	A- Excellent	A1-Excellent
Sodium Benzoate	N/A	A- Excellent	A-Excellent
Sodium Bicarbonate	A- Excellent	A- Excellent	A-Excellent
Sodium Bisulfate	A2- Excellent	A- Excellent	A-Excellent
Sodium Bisulfite	A1- Excellent	A- Excellent	A-Excellent
Sodium Borate (Borax)	A- Excellent	A- Excellent	A-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Sodium Bromide	A1- Excellent	A- Excellent	A-Excellent
Sodium Carbonate	A- Excellent	A- Excellent	A-Excellent
Sodium Chlorate	A1- Excellent	A- Excellent	A-Excellent
Sodium Chloride	A1- Excellent	A- Excellent	A-Excellent
Sodium Chromate	A1- Excellent	A- Excellent	A-Excellent
Sodium Cyanide	A1- Excellent	A- Excellent	A-Excellent
Sodium Ferrocyanide	N/A	A- Excellent	A-Excellent
Sodium Fluoride	A1- Excellent	A1- Excellent	A-Excellent
Sodium Hydrosulfite	N/A	A- Excellent	A-Excellent
Sodium Hydroxide (20%)	A- Excellent	A- Excellent	A-Excellent
Sodium Hydroxide (50%)	A- Excellent	A- Excellent	A-Excellent
Sodium Hydroxide (80%)	A- Excellent	A- Excellent	A-Excellent
Sodium Hypochlorite (<20%)	A- Excellent	A- Excellent	A2-Excellent
Sodium Hypochlorite (100%)	A- Excellent	A- Excellent	A1-Excellent
Sodium Hyposufite	A- Excellent	A- Excellent	A-Excellent
Sodium Metaphosphate	N/A	A- Excellent	A-Excellent
Sodium Metasilicate	N/A	A- Excellent	A-Excellent
Sodium Nitrate	A1- Excellent	A- Excellent	A-Excellent
Sodium Perborate	A1- Excellent	A- Excellent	A-Excellent
Sodium Peroxide	A1- Excellent	A- Excellent	A-Excellent
Sodium Polyphosphate	N/A	A- Excellent	A-Excellent
Sodium Silicate	A1- Excellent	A- Excellent	A-Excellent
Sodium Sulfate	A- Excellent	A- Excellent	A-Excellent
Sodium Sulfide	A1- Excellent	A- Excellent	A-Excellent
Sodium Sulfite	N/A	N/A	A-Excellent
Sodium Tetraborate	A- Excellent	A- Excellent	A-Excellent
Sodium Thiosulfate (hypo)	A- Excellent	A- Excellent	A-Excellent
Stannic Chloride	A- Excellent	A- Excellent	A-Excellent
Stannous Chloride	A1- Excellent	A- Excellent	A-Excellent

Chemical	PCTFE	Teflon	Polypropylene
Starch	A1- Excellent	A- Excellent	A-Excellent
Stearic Acid	N/A	A- Excellent	A1-Excellent
Styrene	N/A	A- Excellent	D-Severe Effect
Sulfur Chloride	A1- Excellent	A- Excellent	D-Severe Effect
Sulfur Dioxide	N/A	A- Excellent	C1-Fair
Sulfur Trioxide	A1- Excellent	A- Excellent	D-Severe Effect
Sulfuric Acid (10-75%)	A- Excellent	A- Excellent	A-Excellent
Sulfuric Acid (75-100%)	A- Excellent	A- Excellent	B1-Good
Sulfurous Acid	A1- Excellent	A- Excellent	A2-Excellent
Sulfuryl Chloride	N/A	A- Excellent	D-Severe Effect
Tartaric Acid	A2- Excellent	A- Excellent	A-Excellent
Tetrachloroethane	A1- Excellent	A- Excellent	C1-Fair
Tetrachloroethylene	A1- Excellent	A- Excellent	D-Severe Effect
Tetrahydrofuran	A1- Excellent	A- Excellent	C1-Fair
Toluene (Toluol)	B2- Good	A- Excellent	D-Severe Effect
Trichloroacetic Acid	A1- Excellent	A- Excellent	A2-Excellent
Trichloroethane	A1- Excellent	A- Excellent	D-Severe Effect
Trichloroethylene	B2- Good	A- Excellent	D-Severe Effect
Trichloropropane	A1- Excellent	A1- Excellent	N/A
Tricresylphosphate	N/A	A- Excellent	A1-Excellent
Triethylamine	A1- Excellent	A- Excellent	D-Severe Effect
Trisodium Phosphate	N/A	A- Excellent	A-Excellent
Turpentine	A- Excellent	A- Excellent	D-Severe Effect
Urea	N/A	A- Excellent	A-Excellent
Uric Acid	N/A	A- Excellent	A1-Excellent
Urine	N/A	A1- Excellent	A-Excellent
Varnish	A- Excellent	A- Excellent	A1-Excellent
Vinyl Acetate	N/A	A2- Excellent	D-Severe Effect
Vinyl Chloride	N/A	A2- Excellent	D-Severe Effect

Chemical	PCTFE	Teflon	Polypropylene
Water, Deionized	A1- Excellent	A2- Excellent	A-Excellent
Water, Distilled	A- Excellent	A- Excellent	A-Excellent
Water, Fresh	A- Excellent	A- Excellent	A-Excellent
Water, Salt	A- Excellent	A- Excellent	A-Excellent
Xylene	A- Excellent	A- Excellent	C1-Fair
Zinc Chloride	A1- Excellent	A- Excellent	A-Excellent
Zinc Hydrosulfite	N/A	A1- Excellent	A1-Excellent
Zinc Sulfate	A- Excellent	A- Excellent	A-Excellent

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E XCalibur Physical Specifications

Table E-1 *XCalibur Physical Specifications*

Note: *Specifications listed here are subject to change without notice.*

Dimensions	Height	5.0 in (127 mm)
	Width	1.8 in (45.7 mm)
	Depth	4.5 in (114.3 mm) from front panel to connector
	Weight	1.78 lbs (0.808 kg)
Resolution		3,000 increments in standard mode and 24,000 increments in fine positioning mode
Plunger Drive	Principle	Ball screw drive with linear encoder for step loss detection
	Travel	30 mm
	Plunger Speed	Variable from 1.2 secs/stroke to 20 min/stroke
Syringes	Sizes	50 µL, 100 µL, 250 µL, 500 µL, 1.0 mL, 2.5 mL and 5.0 mL
	Barrel Material	Borosilicate glass
	Plunger Material	Stainless steel
	Seal Material	Virgin Teflon (PTFE, TFE) and UHMWPE (Black seals)
	Precision	≤0.05% CV at full stroke (at 23° C with 1 µL syringe, using de-ionized water)) ≤0.5% CV at 10% stroke (at 23° C with 1 µL syringe, using de-ionized water)
	Accuracy	<1% at full stroke
Valve Drive	Turn time	≤250 ms between adjacent ports
	Drive	Stepper motor with optical encoder for positioning feedback

Valves	Materials	Plastic plug: Teflon Plastic body: PCTFE Ceramic Stator/Rotor: Alumina
	Fittings	1/4-28 and M6 tubing fittings 1/4-28" syringe fitting
	Valve Options	120° 3-port 90° 4-port 3-port distribution Y block T valve 6-port distribution 9-port distribution
Power Requirements	Voltage	24V DC ± 2%
	Current	1.5 A (peak)
Interface	Type	RS-232, RS-485 and CAN
	Baud Rate	9600 or 38400 (RS-232 and RS-485) 100K, 125K, 250K, 500K and 1M (CAN)
	Format	Data bits: 8 Parity: No Stop bit: 1 Half duplex
Communications	Addressing	Up to 15 individual addresses available
	Communications	Data terminal and OEM protocol (with error recognition)
Firmware		◆ Programmable ramps ◆ Programmable plunger speeds ◆ Programmable delays ◆ Programmable loops ◆ Change speed on the fly ◆ Terminate moves ◆ Diagnostics ◆ Absolute or relative positions ◆ Programmable non-volatile memory
Inputs		Two TTL level inputs with 4.7k pull-ups
Outputs		Three outputs, CMOS (HC) level

Environmental	Operating temperature (mechanism)	59°F (15°C) to 104°F (40°C)
	Operating humidity (mechanism)	20-80% RH at 104°F (40°C)
	Storage temperature	-4°F (-20°C) to 149°F (65°C)
Safety and Regulatory Compliance		The XCalibur is a UL recognized component: Tecan Systems' UL customer file number is E164638.

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F CAN Communication Commands

Command Type	Command	Valid/Invalid	CAN Equivalent
Initialization	Z, Y	Valid	None
Initialization	z	Valid	None
Plunger Movement	A, a, P, p, D, d	Valid	None
Valve	I, O, B	Valid	None
Valve	E, ^	Valid	None
Set	S, V, v, C, c, L, K, k	Valid	None
Command for microstep-enabled firm-ware	N	Valid	None
Control	G, g, M, H	Valid	None
Control	X	Valid	Frame type = 2 Command = “3” (ASCII)
Control	R	Valid	Frame type = 2 Command = “1” (ASCII)
Control	T	Valid	Frame type = 2 Command = “4” (ASCII)
Control	Reset	Invalid	Frame type = 2 Command = “0” (ASCII)
Control	Clear loaded command	Invalid	Frame type = 2 Command = “2” (ASCII)
Control	J, s, e, b, U	Valid	None
Report	?	Invalid	Frame type = 6 Command = “0” (ASCII)
Report	?1	Invalid	Frame type = 6 Command = “6” (ASCII)
Report	?2	Invalid	Frame type = 6 Command = “4” (ASCII)
Report	?3	Invalid	Frame type = 6 Command = “7” (ASCII)
Report	?4	Invalid	Frame type = 6 Command = “1” (ASCII)

Command Type	Command	Valid/Invalid	CAN Equivalent
Report	?5	Invalid	Frame type = 6 Command = “2” (ASCII)
Report	?6	Invalid	Frame type = 6 Command = “3” (ASCII)
Report	?7	Invalid	Frame type = 6 Command = “6” (ASCII)
Report	?8	Invalid	Frame type = 6 Command = “4” (ASCII)
Report	?9	Invalid	Frame type = 6 Command = “7” (ASCII)
Report	?10 through ?24	Invalid	Frame type = 6 Command = “10” through “24” (ASCII)
Report	F	Invalid	Frame type = 6 Command = “10” (ASCII)
Report	&	Invalid	Frame type = 6 Command = “23” (ASCII)
Report	Q	Invalid	Frame type = 6 Command = “29” (ASCII)
Report	#	Invalid	Frame type = 6 Command = “20” (ASCII)
Report	%	Invalid	Frame type = 6 Command = “18” (ASCII)
Report	$	Invalid	Frame type = 6 Command = “19” (ASCII)
Report	*	Invalid	Frame type = 6 Command = “22” (ASCII)

G Command Quick Reference

G.1 Pump Configuration Commands

Command	Values of <n>	Description
N	0 = fine positioning mode off 1 = fine positioning mode on	Enables or disables microstepping (fine positioning)
U	0 = No Valve 1 = 3-Port Valve 2 = 4-Port Valve 3 = 3-Port Distribution Valve (face seal) 4 = T Valve 7 = 6-Port Distribution Valve 8 = 9-Port Distribution Valve 9 = Dual loop valve 11 = 3-Port Distribution Valve (plug) 30 = Set Non-Volatile Memory Auto Mode 31 = Clear Non-Volatile Memory Mode 41 = Set RS baud rate to 9600 47 = Set RS baud rate to 38400 51 = Set CAN baud rate to 100K 52 = Set CAN baud rate to 250K 53 = Set CAN baud rate to 500K 54 = Set CAN baud rate to 1M 57 = Set CAN baud rate to 125K	Writes configuration information to non-volatile memory.
K	0..31 in full step mode (default 12) 0..248 in fine positioning mode (default 96)	Sets number of backlash increments.

G.2 Initialization Commands

Command	Values of <n>	Description
Z	<n_1> 0 = initializes at full plunger force 1 = initializes at half plunger force 2 = initializes at one-third plunger force 10 – 40 = initializes at the defined speed	Initializes the plunger drive and homes the valve in a *clockwise* direction.
	<n_2> 0 = Set initialization input port to Port 1 1..X = Set initialization input port for distribution valves, where X is the number of ports on the valve	Sets initialization input port
	<n_3> 0 = Set initialization output port to Port X 1..X = Set initialization output port for distribution valves, where X is the number of ports on the valve	Sets initialization output port
Y	<n_1> 0 = initializes at full plunger force 1 = initializes at half plunger force 2 = initializes at one-third plunger force 10 – 40 = initializes at the defined speed	Initializes the plunger drive and homes the valve in a *counterclockwise* direction.
	<n_2> 0 = Set initialization input port to Port 1 1..X = Set initialization input port for distribution valves, where X is the number of ports on the valve	Sets initialization input port
	<n_3> 0 = Set initialization output port to Port X 1..X = Set initialization output port for distribution valves, where X is the number of ports on the valve	Sets initialization output port
W	<n_1> 0 = initializes at full plunger force 1 = initializes at half plunger force 2 = initializes at one-third plunger force 10 – 40 = initializes at the defined speed	Initializes the plunger drive only (commonly used for valveless pumps).

Command	Values of <n>	Description
w	<n_1> 1..X = Set initialization port where X is the number of ports on the valve	Initializes the valve drive only.
	<n_2> 0 = Valve moves in a *clockwise* direction; valve ports numbered in a *clockwise* direction. 1 = Valve moves in a *counterclockwise* direction; valve ports numbered in a *counterclockwise* direction.	Initializes the valve drive only.
z		Simulates initialization and sets the current position of the linear encoder as the home position
k	0..80 in standard mode (50 default) 0..640 in fine positioning mode (400 default)	Set zero gap (increments)

G.3 Valve Commands

Command	Description
I	Moves valve to input position
O	Moves valve to output position
B	Moves valve to bypass position
E	Moves valve to extra position

G.4 Plunger Movement Commands/Status Bit Reports

Command	Value of <n>	Description	Status
A <n>	0..3,000 0..24,000 in fine positioning mode	[A]bsolute Position	Busy
a <n>	0..3,000 0..24,000 in fine positioning mode	[a]bsolute Position	Ready
P <n>	0..3,000 0..24,000 in fine positioning mode	Relative [P]ickup	Busy
p <n>	0..3,000 0..24,000 in fine positioning mode	Relative [p]ickup	Ready
D <n>	0..3,000 0..24,000 in fine positioning mode	Relative [D]ispense	Busy
d <n>	0..3,000 0..24,000 in fine positioning mode	Relative [d]ispense	Ready

G.5 Set Commands

Command	Value of <n>	Description	Default Setting
L <n>	1..20	Slope	(7)
v <n>	50..1000	Start speed (Hz/sec)	(900)
V <n>	5..6000	Peak speed (Hz/sec)	(1400)
S <n>	0..40	Set speed	(11)
c <n>	50..2700	Cutoff speed (Hz/sec)	(900)
C <n>	0..25	Cutoff increments	(0)

G.6 Control Commands

Command	**Value of <n>**	**Description**
R		Executes command or command string
X		Repeats last command string
G <n>	0..30000	Repeats command sequence
g		Marks start of a repeat sequence
M <n>	5..30000	Delay in milliseconds
H <n>	0..2	Halts command string execution
T		Terminate command
J <n>	0..7	Auxiliary outputs

G.7 Non-Volatile Memory (EEPROM) Commands

Command	**Value of <n>**	**Description**
s <n>	0..14	Loads command string in Non-Volatile Memory
e <n>	0..14	Executes Non-Volatile Memory command string

G.8 Non-Functional Commands

Command	**Value of <n>**	**Description**
^ <n>	0..255	Set threshold value for fluid detection.

G.9 Report Commands

Command	Description
Q	Query, Status and Error Bytes
?	Report absolute plunger position
?1	Report start speed
?2	Report top speed
?3	Report cutoff speed
?4	Report actual position of plunger
?6	Report valve position
?10 or F	Report command buffer status
?12	Report number of backlash increments
?13	Report status of input #1 (J4, Pin7)
?14	Report status of input #2 (J4, Pin 8)
?15	Report number of pump initializations
?16	Report number of plunger movements
?17	Report number of valve movements
?18 or %	Report number of valve movements (since last report)
?20 or #	Report firmware checksum
?22 or *	Report current value from valve sensor (always reports 255.)
?23 or &	Report firmware version
?24	Report zero gap increments
?29	Same as Q (query, status and error bytes)
?76	Report pump configuration

G.10 Error Codes

Command	Description	Notes
0	Error free condition	
1 (01h)	Initialization error	Fatal error. Reinitialize pump before resuming normal operation.
2 (02h)	Invalid command	
3 (03h)	Invalid operand	
4 (04h)	Invalid command sequence	
6 (06h)	EEPROM failure	
7 (07h)	Device not initialized	
9 (09h)	Plunger overload	Fatal error. Reinitialize pump before resuming normal operation.
10 (0Ah)	Valve overload	Fatal error. Reinitialize pump before resuming normal operation.
11 (0Bh)	Plunger move not allowed	
15 (0Fh)	Command overflow	

G.11 Error Codes and Status Byte

Status Byte	Hex # if Bit 5 =		Dec # if Bit 5 =		Error Code	
7 6 5 4 3 2 1 0	**0**	**or 1**	**0**	**or 1**	**Number**	**Error**
0 1 X 0 0 0 0 0	40h	60h	64	96	0	No error
0 1 X 0 0 0 0 1	41h	61h	65	97	1	Initialization
0 1 X 0 0 0 1 0	42h	62h	66	98	2	Invalid command
0 1 X 0 0 0 1 1	43h	63h	67	99	3	Invalid operand
0 1 X 0 0 1 0 0	44h	64h	68	100	4	Invalid command seq.
0 1 X 0 0 1 0 1	45h	65h	69	101	5	unused
0 1 X 0 0 1 1 0	46h	66h	70	102	6	EEPROM failure
0 1 X 0 0 1 1 1	47h	67h	71	103	7	Device not initialized

Status Byte	Hex # if Bit 5 =		Dec # if Bit 5 =		Error Code	
0 1 X 0 1 0 0 1	49h	69h	73	105	9	Plunger overload
0 1 X 0 1 0 1 0	4Ah	6Ah	74	106	10	Valve overload
0 1 X 0 1 0 1 1	4Bh	6Bh	75	107	11	Plunger move not allowed
0 1 X 0 1 1 1 1	4Fh	6Fh	79	111	15	Command overflow

G.12 DA-15 Connector Pin Assignments

Pin	Function	Remarks
1	24 V DC	
2	RS-232 TxD line	Output data
3	RS-232 RxD line	Input data
4	Unused	
5	CAN high signal line	
6	CAN low signal line	
7	Auxiliary input #1	TTL level
8	Auxiliary input #2	TTL level
9	Ground	Power and logic
10	Ground	Power and logic
11	RS-485 A line	Data +
12	RS-485 B line	Data -
13	Auxiliary output #1	TTL level
14	Auxiliary output #2	TTL level
15	Auxiliary output #3	TTL level

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