Product Manual

TRICONTINENT®
An Ingersoll Rand Business

C-Series
Syringe Pump

C3000
C3000MP
C24000
C24000MP

NOTICE

The information presented in this material is based on technical data and test results of nominal units. It is believed to be accurate and reliable and is offered as an aid to help in the use of Tricontinent products. It is the responsibility of the user to determine the suitability of the product for the intended use and the user assumes all risk and liability in connection therewith. Tricontinent does not warrant, guarantee or assume any obligation or liability in connection with this information.

Contents

5 Operating instructions

6 Maintenance

7 Troubleshooting

8 Customer support

9 Reference information

10 Revision history

1   About this manual

Introduction

This comprehensive manual provides the instructions you need to get the C-Series Syringe Pump installed and operating as desired, as well as to keep it properly maintained. Contact information is also included in case you need to reach Tricontinent for assistance. See "Customer support" (page 119).

Audience

This manual is provided primarily for customers who purchase products from Tricontinent. It is expected that the majority of customers are instrument designers and software engineers who are familiar with this type of product and existing software/firmware of similar design. However, this manual is also designed to accommodate those who don't have such familiarity or who simply wish to learn more about the product.

Products covered by this manual

The following products are covered by this manual:

- C3000
- C3000MP
- C24000
- C24000MP

These are described in "Product overview" (page 11).

Operating instructions are updated to support firmware improvements. See "Revision history" (page 173). Firmware versions may be queried with the [&] command (sent without brackets).

Parts of this manual

The following parts are included in this manual:

- About this manual (this chapter)
- Safety and standards, page 9
- Product overview, page 11
- Installation instructions, page 15
- Operating instructions, page 39
- Maintenance, page 107
- Troubleshooting, page 113
- Customer support, page 119
- Reference information, page 121
- Revision history, page 173

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2   Safety and standards

About this chapter

This chapter contains safety notifications that may appear in this manual, cautions about proper use of the equipment, and information about regulatory standards that may affect the C-Series Syringe Pump.

The C-Series pump is designed to meet recognized technical regulations and is built with state-of-the-art components. Nevertheless, risks to users, property, and/or the environment can result when it is used carelessly or improperly. Appropriate warnings are included to notify of possible hazards.

Safety notifications

⚠ **CAUTION**

CAUTION: Alerts you to the possibility of equipment damage and/or improper function if these instructions are not followed.

⚠ **WARNING**

WARNING! Indicates a hazardous situation which, if not avoided, could result in injury and/or property damage.

⚠ **DANGER**

DANGER! Indicates a hazardous situation which, if not avoided, can result in death or serious injury and property damage. This alert is reserved for the most extreme situations.

ESD precaution

⚠ **CAUTION**

CAUTION: ESD-sensitive equipment!

Always use proper ESD practices when handling the C-Series Syringe Pump. Because it is an electronic device, the pump is vulnerable to ESD (electro-static discharge). Electrostatic discharge can come from common objects, fixtures, and flooring materials such as carpets, causing the pump to fail prematurely. Proper ESD practices include the use of static-free work areas, wrist or ankle grounding straps, ESD mats, non-static flooring material or treatment, and similar provisions.

Proper use of equipment

The C-Series pump is designed for pipetting and dispensing operation. Any other use may damage the pump and/or produce unreliable results.

Note: It is the purchaser's responsibility to determine the suitability of an application and material compatibility of the product. For syringe pumps only, a chemical compatibility chart is in the Reference information chapter.

Syringe shipping precaution

⚠CAUTION

CAUTION: Avoid shipping pumps to Tricontinent with syringes installed. During transport, shock and vibration can be transmitted directly to the syringe. This can lead to glass breakage, loosening of syringes from their threaded ports, and potentially other problems. Syringes should always be shipped separately inside their original packaging for the highest level of protection from damage. Using the pumps' original packaging is insufficient.

For example, when shipping pumps to Tricontinent that have been installed in an instrument, syringes should be removed and shipped in their individual packaging.

Regulatory notices

FDA

The C-Series Syringe Pump is a general laboratory component. Because it is not a medical device, it is not subject to FDA approval.

CE

The C-Series Syringe Pump is a modular device intended for incorporation into larger systems, which themselves require independent certification. Therefore, the C-Series Syringe Pump does not have its own CE mark.

RoHS

The C-Series Syringe Pump is RoHS compliant. It is constructed of components that meet the requirements set by the European Union's Restriction of Hazardous Substances Directive.

EMI

The C-Series Syringe Pump can be affected by excessive electromagnetic interference.

EMC

The C-Series Syringe Pump has been designed to CISPR 11 class B standards. Depending on the system configuration, the user may need to take steps to mitigate radio interference.

3   Product overview

About this chapter

This chapter provides a general introduction to the C-Series Syringe Pump, including features, facilities, and key specifications.

The following parts are included:

- About this chapter, page 11
- General description, page 11
- Features and facilities, page 13
- Key specifications, page 14

General description

Figure 3-1.   Typical C-Series pump

The C-Series Syringe Pump is an OEM pump module designed for automated instrumentation.

The module is a self-contained unit that includes the pump, stepper motors, control electronics, drive, and valve. The C-Series pump utilizes a proprietary high-efficiency, direct-drive design instead of belts that can stretch or wear out. The robust drive mechanism has been life tested to several million cycles with no maintenance required during its lifetime.

This pump is an excellent choice for new installations, and for replacement where experienced IVD instrument manufacturers would like to maximize investments they have already made in instrumentation. The C-Series pumps utilize standard communication interfaces and methods for mounting used by other compact syringe pump designs. The pumps are outfitted with the Tricontinent long-life valves available in various configurations and material combinations. All C-Series pumps can be customized for specific liquid handling needs.

The C-Series hardware and firmware automatically detect OEM or DT protocol for RS232/RS485 applications. The pump can be configured to operate at different communication speeds.

There are currently four models of the C-Series Syringe Pump: C3000. C3000MP, C24000, and C24000MP.

C3000. The C3000 provides all normal aspiration and dispensing operations expected from an OEM syringe pump module. The stepper motor-driven syringe will accurately and precisely handle fluid capacities from a few microliters to 12.5 milliliters. The syringe drive arm can be easily back driven, making syringe installation or replacement extremely quick and easy. The C3000 supports valves with 3 or 4 ports.

C3000MP (C3000 Multiport). The C3000MP provides all of the features of the C3000 but is designed to support a 6-way distribution valve.

C24000. The C24000 is a high-resolution version of the C3000 that achieves full syringe resolution to 192,000 increments/full stroke. The C24000 is ideal for achieving low flow rate and meeting low pulsation requirements. The C24000 supports valves with 3 or 4 ports.

C24000MP (C24000 Multiport). This model has all the features of the C24000 but is designed to support a 6-way distribution valve.

Features and facilities

Each pump provides two digital inputs and three outputs (digital I/O) that can be used for synchronization with external devices (see Figure 3-2.) Multi-pump communication is possible over an RS485 or CAN bus. The built-in RS232 interface automatically converts to RS485. With an optional converter, USB communication can also be accommodated.

Other features

- Proprietary high-efficiency and maintenance-free direct drive system
- Long-life rotary shear valves (up to 24 times the life of competing valves)
- Valve drive < 250 ms between neighboring ports
- High resolution options available up to 192,000 increments/full stroke
- Up to 15 pumps on a bus; can be addressed individually
- Syringe sizes from 50 µL to 12.5 mL
- LED indicators to assist in monitoring function and providing notification of specific error conditions.

Figure 3-2. Facilities on C-Series Syringe Pump

Front View

Rear View

LED Indicators

Valve

Syringe

Communication, power, Digital I/O D-sub15 pin Connector

Address Switch

Configuration Jumper

Additional jumper underneath provides communication bus termination.
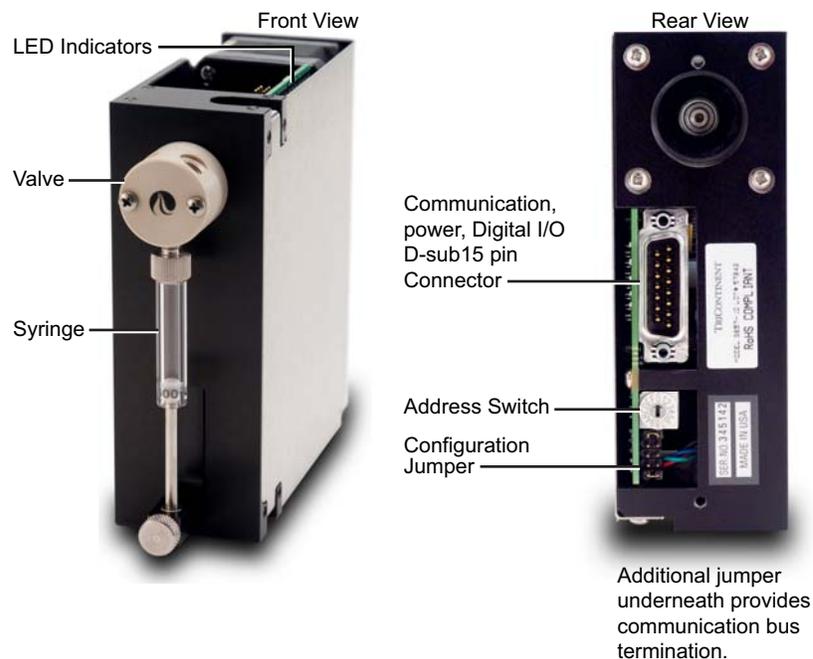
Key specifications

- Interface: RS232, RS485, CAN
- Communication rates: RS232/RS485: 9600 or 38400 baud; CAN: 100K, 125K, 250K, 500K, 1M
- Format (RS232/RS485): Data bits 8, Parity None, Stop Bit 1, half duplex (RS232 is full duplex)
- Operating temperature 15°C to 40°C (59°F to 104°F)
- Humidity 20 to 95% RH at 40°C (104°F)

More detailed specifications can be seen at http://www.tricontinent.com. Product data sheets can be downloaded from this location.

4 Installation instructions

About this chapter

This chapter describes how to install your C-Series Syringe Pump.
The following parts are included:

- About this chapter, page 15
- Unpacking, page 15
- Before starting, page 16
- Place or mount pump, page 20
- Set configuration jumpers and address switch, page 22
- Make electrical connections, page 24
- Confirm communication with pump, page 31
- Initialize pump, page 33
- Check LED indicators, page 35
- Install syringe, page 36
- Connect tubing, page 38

Unpacking

⚠CAUTION

CAUTION: Always use proper ESD practices when handling the C-Series Syringe Pump.

1. Remove items from shipping carton.
2. Check the contents against the packing slip to make sure that all the components are present. If any components are missing or damaged, see instructions in Customer support (page 119).
3. Dispose of packing material in accordance with local environmental regulations.

Before starting

Basic requirements

Basic requirements for installing your C-Series Syringe Pump are listed below. If you have difficulty obtaining any of the items, you can get assistance from Customer Service. See Customer support (page 119).

- **Desired syringe** that is compatible with the C-Series Syringe Pump. See also "Calculating flow rates" (page 158).

> ⚠️ **CAUTION**
>
> **CAUTION:** With larger syringes (>1 mL), there is potential for very high plunger forces depending on the application.

- **Tubing** appropriate to the pump and valve and the nature of fluid to be moved. For guidance on selecting tubing, refer to "Optimizing tubing performance" (page 166).
- **Cabling** as needed. Cabling instructions with diagrams are shown beginning on page 27. For evaluation purposes, also see "Evaluation cables and accessories" (page 153).
- **Computer,** Windows® based, to serve as the host controller.
- **USB-to-RS485 converter and driver.** If you are going to use the USB port of your host computer to connect to the C-Series pump you will need a USB-to-RS485 converter (0960), which can be ordered through Tricontinent Customer Service. You will also need a USB driver, which can be downloaded as described in "Download and install driver for USB/RS485 if needed" (page 18).
- **Optional USB driver for CAN.** For CAN communication through USB, a Tricontinent USB/CAN converter (0963) is available. The USB/CAN converter comes with its own driver and instructions.
- **Software interface** for communicating with the pump or pumps:
  - For the best evaluation and development experience, use TCS Pump Commander. TCS Pump Commander is user-friendly and easy to set up, and contains tools to aid instrument development. It does not require the user to write any protocol software, and is compatible with serial and CAN protocols. Version 2.1.0 and higher is required to fully support the instructions in this manual.
  - Alternatively, terminal emulator programs such as PuTTY and RealTerm may be used to send commands in DT protocol if communicating through RS232/RS4585.
  - For instrument development, only an appropriate communications port on the host controller PC is needed.

Details concerning protocol and communication options are included on page 17.

Protocol and interface options

Communication standards

The C-Series Syringe Pump uses the following communication standards.

- RS232
- RS485
- CAN (Controller Area Network) bus

An integrated RS232-RS485 converter allows RS232 ports to communicate with pumps on the built-in RS485 bus.

Protocols

Three communication protocols are available:

- OEM communications protocol
- Data Terminal (DT) protocol
- CAN (Controller Area Network) protocol

These communication protocols are described in detail in Chapter 9, Reference information (page 121).

The C-Series firmware automatically detects OEM or DT protocol for RS232/RS485 applications.

Table 4-1: Protocol and interface summary

Hardware/electrical interface	Communication protocols/ standards	Comments	Connection
RS232 and RS485	DT or OEM protocol	DT is recommended for use with terminal emulator programs. DT is automatically selected when TCS Pump Commander is used with RS232 or RS485. OEM is recommended for instrument development because of its robust error checking and correction.	Serial or USB computer port Serial connects directly to serial inputs on one pump; RS485 to remaining pumps on bus (daisy-chain). USB goes through an external USB/RS485 converter, which connects directly to the RS485 bus on a pump. Cables are available for these connections. Contact Customer Service (page 119).
CAN	CAN (hardware/electrical interface and communication protocol are included in CAN specification.)	USB port typically connects through optional converter to CAN input on one pump. CAN bus connects to remaining pumps on bus. Direct CAN connection also accepted. If assistance is needed, contact Customer Service (page 119).	

⚠**CAUTION**

CAUTION: Please note that the pump communication buses (RS232/RS485/CAN) use liquid handling industry-developed custom communication protocols (OEM, DT, and CAN). It is possible (but not recommended) for non-pump devices using a different communication protocol to exist on the same RS485 or CAN bus, as long as the non-pump device's protocol does not interfere with the pump bus protocol.

Tricontinent Scientific, Inc. does not encourage or warrant any use of the pump buses with non-pump devices, regardless of information provided by Tricontinent Scientific, Inc. Results may be unsatisfactory.

Download and install driver for USB/RS485 if needed

The USB driver is required only when a Tricontinent USB converter is being used to communicate with the C-Series pump through the RS485 interface.

(This driver is not for the CAN bus interface, which uses a different USB driver supplied with the CAN/USB converter.)

If using other third-party USB converters, follow their instructions for downloading and installing drivers.

Note: When using the TCS Pump Commander, you will need to know which COM port will be used for communicating with the C-Series pump.

1. Go to this link to download the USB driver for your system:

   https://www.silabs.com/developers/usb-to-uart-bridge-vcp-drivers

   This takes you to a web page of Silicon Labs, where the USB drivers for various operating systems are available.

   Note: It is possible for the links referred to in this procedure to change. If this occurs, contact Customer Service for assistance or search elsewhere on the Silicon Labs website for the USB drivers.

2. Click on "Downloads."

3. Select whichever link is appropriate for your operating system. At the date of this writing, the following applicability information was provided. However, please read the accompanying release notes yourself to confirm:

   – CP210x Universal Windows Driver is for Windows 10 version 1803 and later (x64, x86) and Windows 11 (x64). *Follow instructions in the extracted text document to install.*

   – CP210x VCP Windows is for Windows 8/8.1 (64/32), 7 (64/32), Vista (64/32), and XP. *Follow instructions in the extracted Release Notes to install.*

   – CP210x Windows Drivers is for Windows 8.1 (x86 32/64 bit), Windows 8 (x86 32/64), Windows 7 (x86 32/64). *Follow instructions in the extracted Release Notes to install.*

   – Drivers for legacy Windows operating systems may be available on the site. Otherwise, contact Customer Service for assistance. Select whichever link is appropriate for your operating system.

   Note: Do not download files named ". . .Drivers with Serial Enumerator."

4. Connect a USB port on the computer with the USB port on the USB/RS485 converter. Windows® should recognize it and load the correct driver. Once this is done, the USB connection is ready to use.

Power and electrical considerations

The C-Series pump has the following power requirements:

- Input voltage: 24 VDC ± 10%
- Input current; 1.5 A peak current max., 650 mA average (RMS) current max., and 100 mA typical idle current
- It is suggested that an appropriately designed commercial power supply be used.

Power supply requirement for single pump

The power supply for a single C-Series pump should meet the following requirements:

- Output voltage: 24V nominal ±10% with good regulation
- Conformance to required safety and EMI/RFI specifications
- If switching supply, minimum load specification less than pump idle current (above)

Power supply sizing for multiple pumps

When operating more than one C-Series pump, the power supply should be sized to provide the total peak current for all devices. If pumps are not operating simultaneously, a power supply with a reduced rating may be used. The minimum power supply rating should be confirmed by measurement.

Cabling

To reduce voltage drops and increase noise immunity, it is good practice to use one power cable for every two pumps. Power lines to the pump should be 24 AWG or heavier, and as short as possible, based on the total current through the wires. It is good practice to twist together each pair that connects directly from a power supply to a pump.

⚠CAUTION

CAUTION: Mechanical switches should not be located in line with the DC input of the pumps to apply and remove power. This can result in damage to the equipment.

For available evaluation cabling, please refer to "Evaluation cables and accessories" (page 153).

Note: There are limitations on daisy-chaining signals. For more information, see "Install communication/power cabling" (page 26).

Place or mount pump

Before mounting

Termination jumper J9 is located on the bottom of the pump. To avoid later inconvenience during installation, make sure it is set correctly for your situation before securing the pump on a surface. Proper terminations are indicated in "Install communication/power cabling" (page 26).

Mounting

The pumps may be secured at the top, bottom, or either side by four pre-threaded mounting holes. Refer to Figure 4-1 for mounting hole locations and dimensions.

The upright position is used for best priming. For air displacement applications this is not necessary.

Figure 4-1. Mounting holes and dimensions

TOP

* All mounting holes are
  M3 X 0.5 mm X 6.3 mm deep min.

RIGHT SIDE

REAR

BOTTOM

All dimensions, unless otherwise
specified: .XXX ±.008 [0.2 mm]
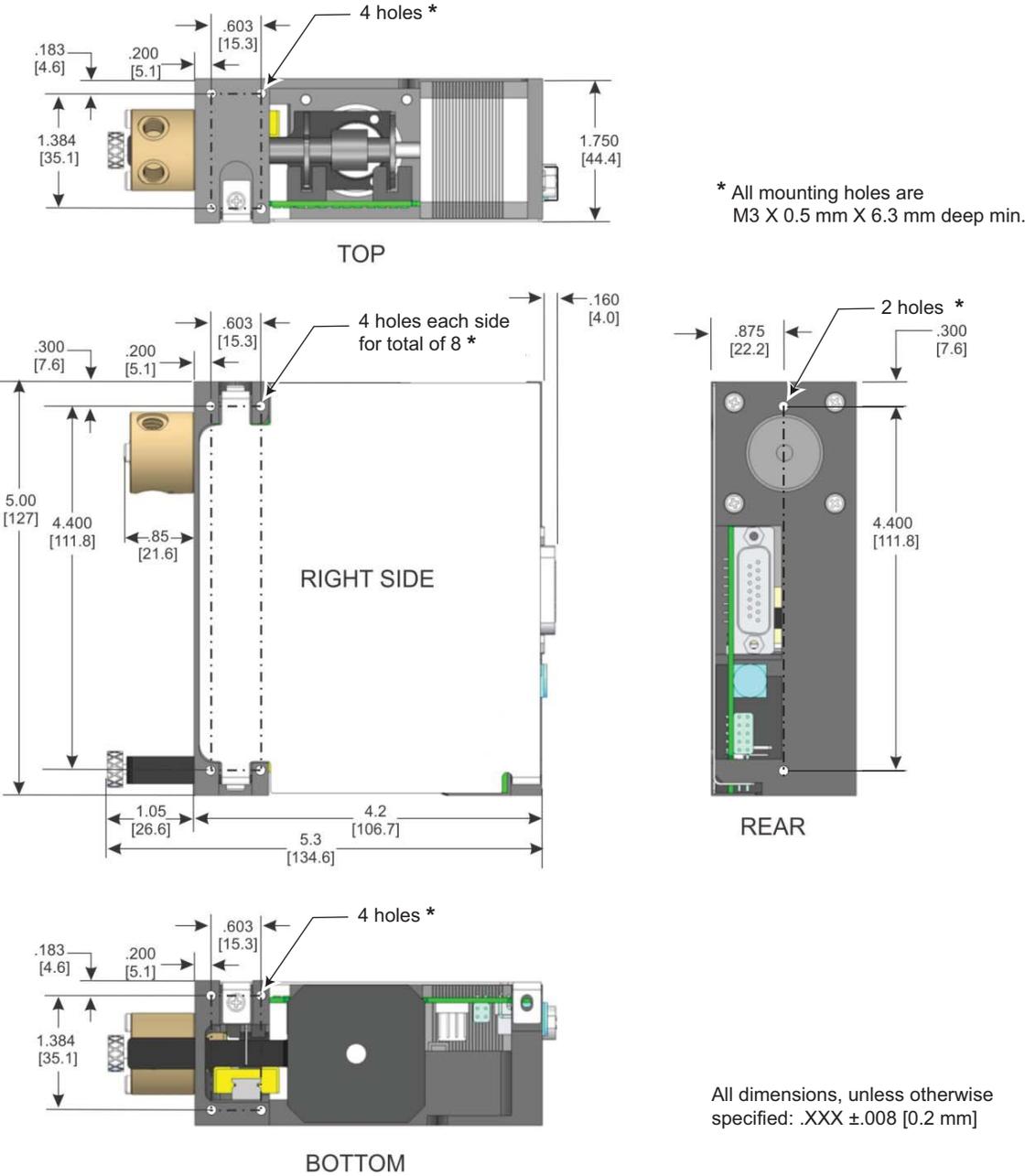
Set configuration jumpers and address switch

Configuration jumpers

Before operating the pump, jumper arrays J2 and J9 must be set for your system. Refer to the following tables and to Figure 4-2.

Table 4-2: J2, various options

Jumper Segment	Function	Action
1	Reserved	None. Spare jumper placed on this segment at the factory.
2	AutoRun	Installed = AutoRun[1] Remove if unused. Recommend removing until operation has been confirmed. AutoRun executes string in EEPROM at power-up.
3	Overload detection	Installed = disabled
4	RS232/485 communication rate	Installed = 38,400 baud Removed = 9600 baud
5	Valve type in use	Installed = 120° 3-port Y valves Removed = all other valve types[2] Doesn't matter = 6-way distribution valve

1. At power-up, if the AutoRun jumper is installed, the pump will execute the string at the memory location pointed to by the address switch setting.
2. All other valve types are EEPROM configurable. This is described in Table 5-1 (page 51).

Table 4-3: J9, RS485 and CAN terminations[1]

Jumper Segment	Function	Action[2]	Application
1	RS485 A termination	Installed = terminated Remove if unused.	Remove all termination jumpers except as shown in cabling diagrams. Cabling diagrams begin on page 28.
2	RS485 B termination	Installed = terminated Remove if unused.	
3	CAN termination	Installed = terminated Remove if unused.	

1. In single-pump installations, the pump is always terminated.
2. Remove, if desired, before mounting pump in a manner in which the termination jumper will be obscured.

Address switch setting

The address switch (Figure 4-2) is normally used to assign the device address. There are 15 possible addresses (0-E hex). For RS485, the device address = address switch setting plus one. If the address switch is set to 1, then, the device address is 2. For CAN, the device address = address switch setting.

Position F is used for the self-test. Use a small flat-bladed screwdriver to rotate the switch.

Note: The address switch function changes if AutoRun jumper J2-2 is installed (see Table 4-2, above). For initial setup and confirmation, make sure the AutoRun jumper is not installed.

CAN COM rate

Default is 100K. For initial installation and operation, this should be left unchanged. Once communication has been established, it may be changed as described in Table 5-4 (page 86).

Figure 4-2. Configuration jumpers and address switch

⚠**CAUTION**

Do not plug or unplug DB-15
connector with power applied
or damage may result.

Address Switch

For RS232/485, device
address = switch setting + 1.
For CAN, device
address = switch setting.
Position F is for
self-test function.

REAR VIEW

J2

Not used — 1
AutoRun — 2 Installed = AutoRun
Overload Detection — 3 Installed = disabled
Baud Rate — 4 Installed = 38,400 baud
Removed = 9600 baud
Valve Type — 5 Installed = 120° 3-port valve
Removed = All other valve types

J9

RS-485A — 1
RS-485B — 2
CAN — 3

Jumper installed =
termination active

BOTTOM VIEW

Make electrical connections

Pin assignments and mating connector information

All electrical connections, including power, communication, and control signal I/O are made through 15-pin D-Sub connector J3. This connector is located on the back of the pump. Mating connector and shield information is provided in the tables below.

Cables are available for these connections. Contact Customer Service for assistance. Also refer to "Evaluation cables and accessories" (page 153).

Figure 4-3. J3 connection
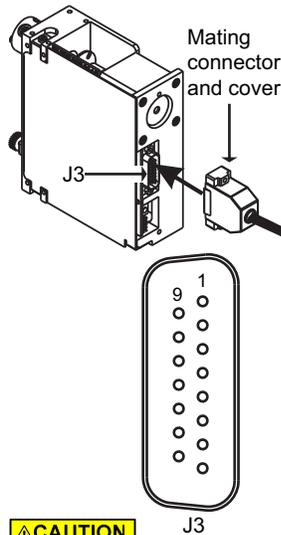
⚠CAUTION

CAUTION: Make sure power is off before making connections to J3. Connecting or disconnecting with power applied may result in damage to equipment, especially when I/O signals are in use.

Table 4-4: Mating connector and cover for J3

Item	Manufacturer	Description	Manufacturer's part number
Mating Connector	TE/TYCO	15-pin female solder cup, receptacle	747909-2
Cover	TE/TYCO	Plastic cover (shield) with male screw retainers	5207908-4

Table 4-5: Pin assignments for J3

Pin	Function	Details
1	24 VDC	24 VDC nominal, ±10%, 1.5A peak
2	RS232 TXD line	Output data
3	RS232 RXD line	Input data
4		Not used
5	CAN HI signal line	
6	CAN LO signal line	
7	AUX Input #1	TTL level (4.7K internal pullup to +5V)
8	AUX Input #2	TTL level (4.7K internal pullup to +5V)
9	Ground	Power and logic
10	Ground	Power and logic
11	RS485 A line	
12	RS485 B line	
13	AUX Output #1	TTL Level (Internal 1K pullup. Max source/sink current = ±20mA)
14	AUX Output #2	TTL Level (Internal 1K pullup. Max source/sink current = ±20mA)
15	AUX Output #3	TTL Level (Internal 1K pullup. Max source/sink current = ±20mA)

⚠CAUTION

CAUTION: Take care when making connections to input and output pins, to avoid electrical damage to equipment. Power must be off. Contact Customer Service with any further questions.

USB/RS485 converter hookup detail

The Tricontinent USB/RS485 converter (0960) is used when it is desired to connect to RS485 from a USB port. The converter is provided with a 4-conductor ribbon cable assembly and IDC-style plug attached. These may be discarded and replaced as needed.

Figure 4-4. USB/RS485 converter wiring detail
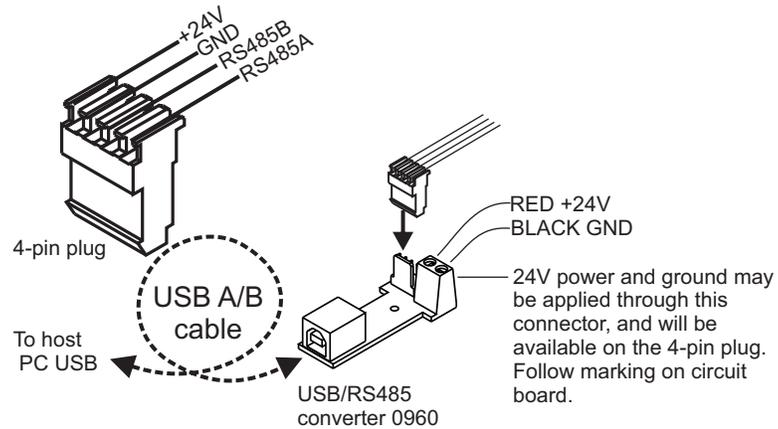
Install communication/power cabling

Cabling multiple pumps

Make connections as shown in the following diagrams. Each bus can support up to 15 devices. The diagrams show connections, address switch settings, and termination jumper positions.

⚠**CAUTION**

CAUTION: Do not use cable for daisy-chaining pumps that will connect all pump signals in parallel. There are several interface signals that cannot be daisy-chained without likely causing damage to the pump electronics. Failure to avoid this type of daisy-chaining may void the warranty. Contact Customer Service if more information is needed.

Cabling a single pump

For single-pump installations, refer to the cabling diagrams and follow the instructions for single-pump installations in the diagrams.

Note: Terminations must remain installed on the pump.

⚠**CAUTION**

CAUTION: Make sure power is off while making connections to DB15 connector J3. Connecting or disconnecting with power applied may cause damage to the equipment, especially when I/O signals are in use.

Install optional control wiring (auxiliary I/O)

The C-Series pump has two auxiliary inputs and three auxiliary outputs at 15-pin connector J3 (pin assignments are listed on page 24).

- The auxiliary *inputs* can be used to externally trigger or condition command sequences.
- The auxiliary *outputs* may be used for any TTL-compatible interfacing.

Note: The specific function of each auxiliary output is determined by programming, as described in "Configuring auxiliary outputs" (page 76).

Cabling diagrams

Cabling for the different protocols is shown in the following diagrams. Please note:

- The diagrams show cabling for RS232, RS485, and CAN buses. Each bus can support up to 15 devices.

- Power, communication, and auxiliary connections are shown.

- Single-pump cabling as well as multi-pump cabling is shown.

- Termination requirements are shown.

RS232 cabling

Cabling for RS232 goes from the host controller serial port to the first pump on the bus. There it is converted by the pump electronics to/from RS485 for the remaining pump connections.

Figure 4-5. RS232 communication and power cabling

Single-pump Installations:
- Make input and power connections as shown for Device 1.
- Leave RS485 termination jumpers installed.

Power Cabling Recommendations
- Cables 24 AWG or heavier, as short as practical.
- Use one power cable for every two pumps as shown.

  However, a single power bus may be used if wire is sized for total current requirements and voltage drops.
- Twist wires together on cable pairs leading from power supply directly to pump.

Host Serial Port		Pump Port (J3)	
Function	DB9 Pin	Function	J3 Pin
RXD	2	TXD	2
TXD	3	RXD	3
GND	5	GND	10

⚠ **CAUTION**

CAUTION: Do not place mechanical switches in line with the DC input of the pumps to apply and remove power. Do not connect or disconnect with power applied; otherwise equipment can be damaged, especially when I/O signals are in use.

Pump Bottom View

RS485 cabling

This would typically go from a PC USB port through the optional USB-to-RS485 converter to the RS485 bus. However, it can also come directly from an RS485 host controller.

Figure 4-6. RS485 communication and power cabling
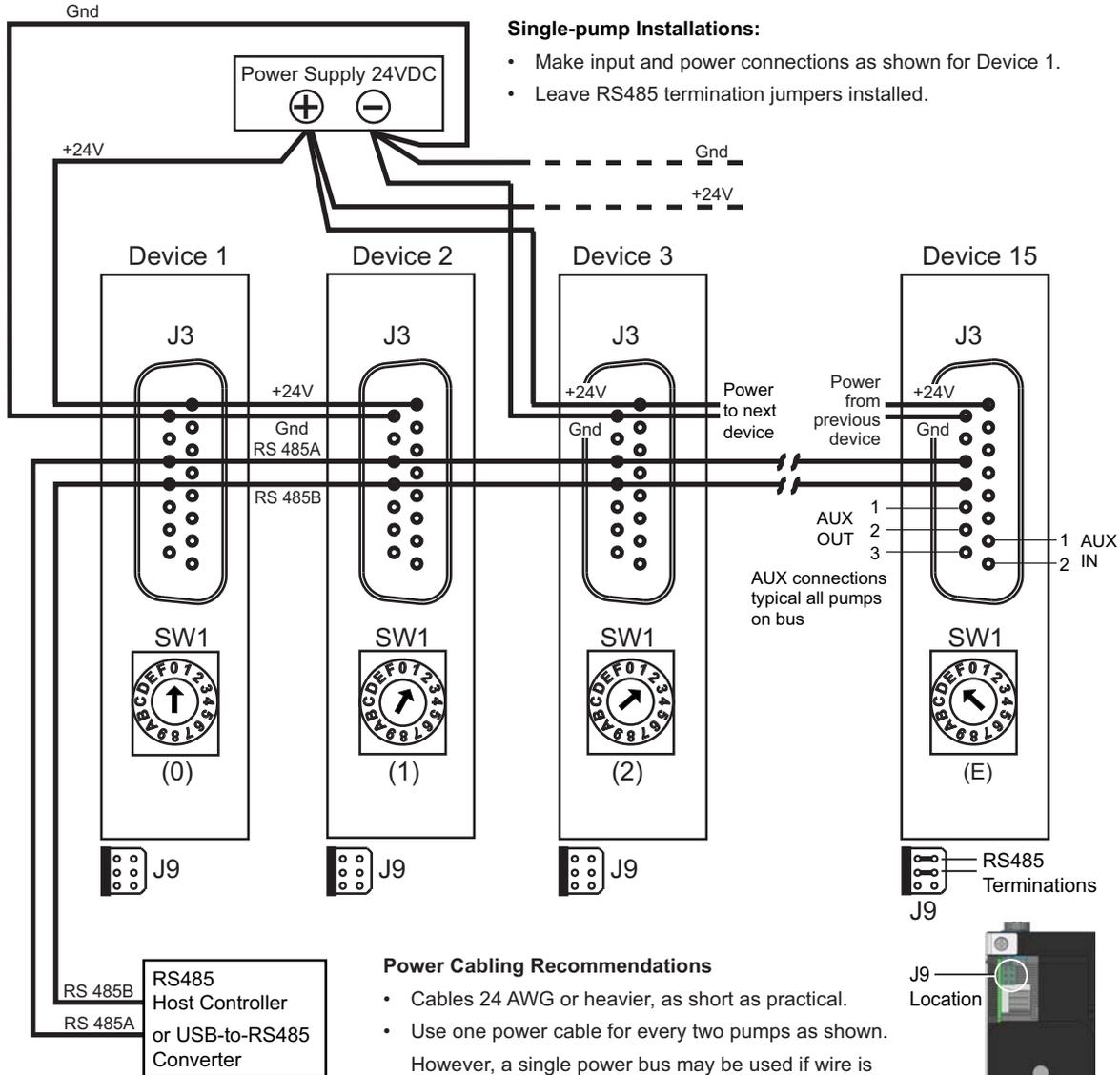
Single-pump Installations:
- Make input and power connections as shown for Device 1.
- Leave RS485 termination jumpers installed.

Power Cabling Recommendations
- Cables 24 AWG or heavier, as short as practical.
- Use one power cable for every two pumps as shown.

  However, a single power bus may be used if wire is sized for total current requirements and voltage drops.
- Twist wires together on cable pairs leading from power supply directly to pump.

⚠**CAUTION**

CAUTION: Do not place mechanical switches in line with the DC input of the pumps to apply and remove power. Do not connect or disconnect with power applied; otherwise equipment can be damaged, especially when I/O signals are in use.

Pump Bottom View

CAN BUS cabling

CAN cabling is direct from a CAN BUS controller to the CAN bus on the J3 connectors.

Figure 4-7. CAN BUS communication and power cabling
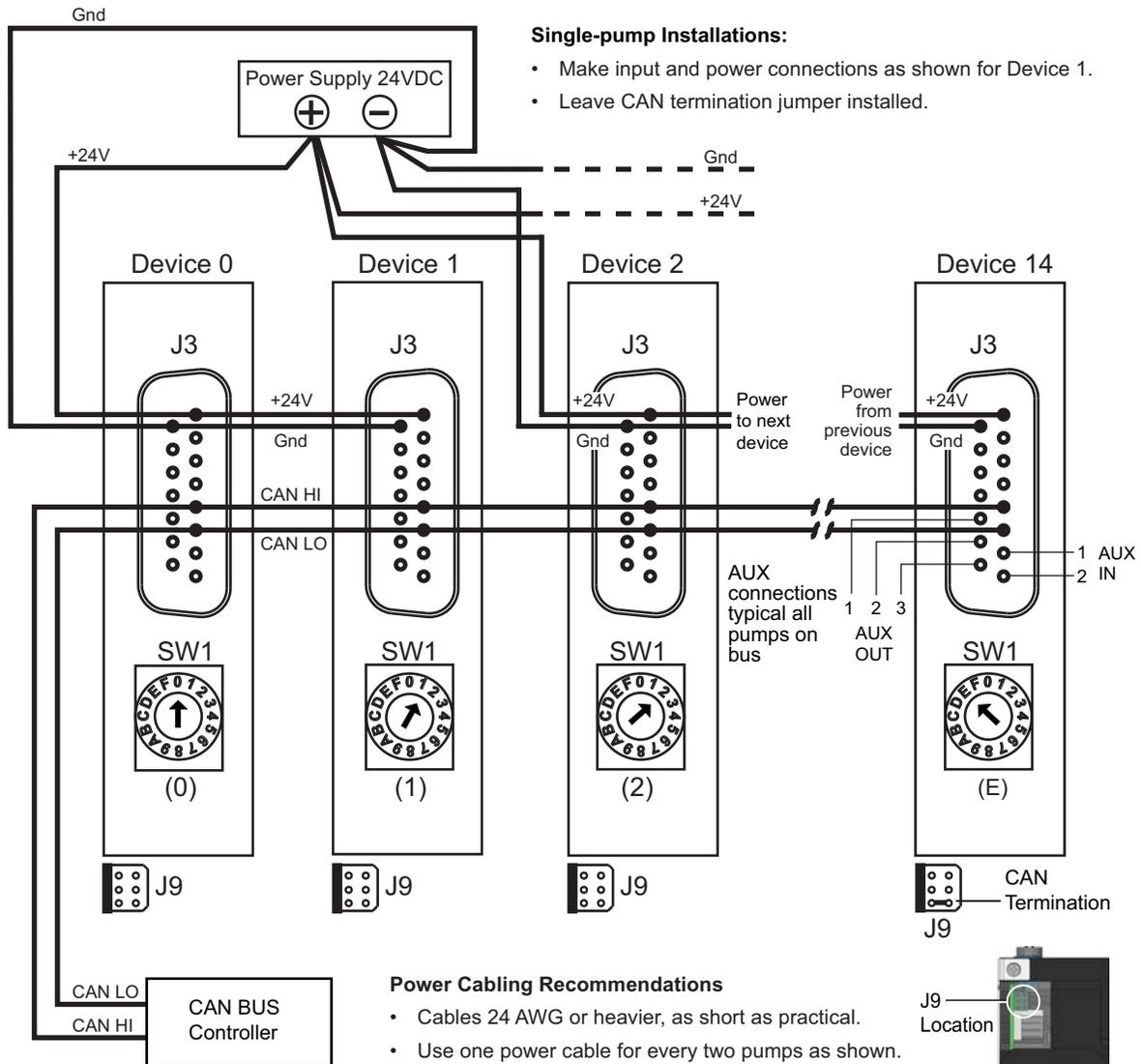
Single-pump Installations:
- Make input and power connections as shown for Device 1.
- Leave CAN termination jumper installed.

Power Cabling Recommendations
- Cables 24 AWG or heavier, as short as practical.
- Use one power cable for every two pumps as shown.
  However, a single power bus may be used if wire is sized for total current requirements and voltage drops.
- Twist wires together on cable pairs leading from power supply directly to pump.

⚠**CAUTION**

CAUTION: Do not place mechanical switches in line with the DC input of the pumps to apply and remove power. Do not connect or disconnect with power applied; otherwise equipment can be damaged, especially when I/O signals are in use.

Pump Bottom View
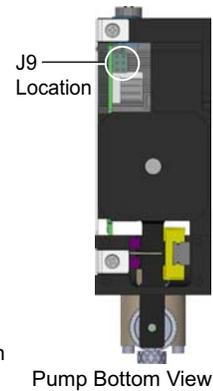
Confirm communication with pump

- Make sure pump is connected, host controller PC is connected, and power is applied.
- Appropriate driver must be installed as described earlier if using USB for communicating.

Confirm with TCS Pump Commander

Note: TCS Pump Commander V2.1.0 or higher is required for the instructions in this manual. Inquire with Customer Service for availability.

1. Start TCS Pump Commander. The Pump Communication Setup window should open.[1] If not, press Setup Communication at the top of the screen:

String area   Setup Communication   Status/Response area
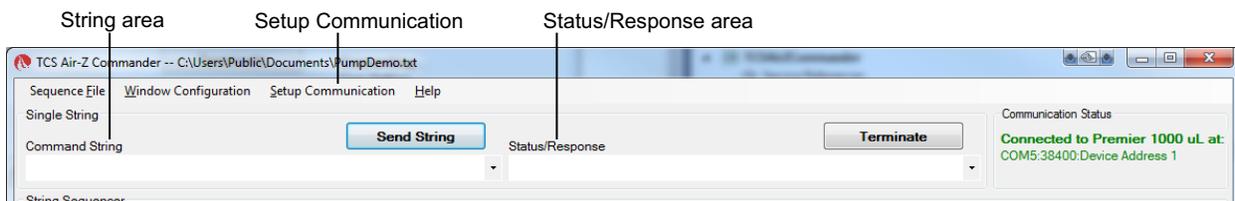
Note: Product name shown in screen capture is for example only.

2. Select COM port.

   With the communication cable and converter, if any, attached to the host PC, the available ports will be shown in the Com Port drop-down window. Select the desired port to connect to the pump.
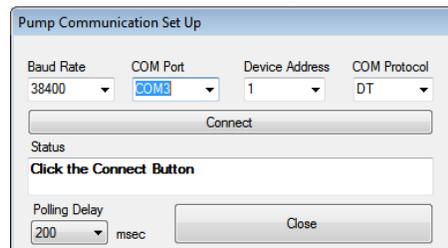
Pump Communication Setup window

3. Select Baud Rate and Device Address:

   – If DT protocol is selected, choose 9600 or 38400, from the Baud Rate drop-down list, as determined by the baud rate jumper on J2. Refer to Figure 4-2 (page 23) if necessary.

   – If CAN protocol is selected, choose 100K from the Baud Rate drop-down list.

   – Device Address: For DT protocol, this is the position of the address switch on the pump plus 1. For CAN, this is the position of the address switch on the pump.

4. Click the Connect button and see the response in the Status area.

   – The response will temporarily display "BUSY." Once communication has been established, "OK" will be displayed.

   – If a "FAILED" response is received, re-check baud rate selection, COM port selection, and device address setting. Check power and wiring also if none of these resolves the problem.

Also see "TCS Pump Commander overview" (page 146) and the help documentation in the program.

---

1. The Communication Setup window will open if TCS Pump Commander cannot connect with the same settings previously used.

Confirm with terminal emulation program

Note: Commands are indicated by [brackets]. The brackets are not to be entered.

1. Open the desired terminal emulation program on the host controller PC.

2. For RS232/RS485, make sure communication settings are as follows:

   – Baud rate: 9600 or 38400, as determined by baud rate jumper on J2. Refer to Figure 4-2 (page 23) if necessary.

     Note: Baud rate setting must be the same as indicated by baud rate jumper on J2.

   – Other settings: data bits 8, parity None, stop bit 1, half duplex if RS485, full duplex if RS232.

3. For CAN bus communication, use default rate of 100K. This can be changed after communication has been established if desired.

4. Issue the command string [/1&],

   where /1 is the address of the pump. If RS232/485, this is the address switch setting plus 1. So if the address switch is set to zero, use /1. If CAN, the pump address equals the address switch setting.

   This command string requests the firmware version of the pump.

   Note: In DT mode, a carriage return (ODh) is required after the command string.

   – The response format is C3000: MMDDYY or C3000MP: MMDDYY where the firmware revision level is indicated by the date (MMDDYY).

     Note: C3000 or 3000MP is the response even if the actual pump configuration is C24000 or C24000MP.

   – This confirms communication with the pump has been established.

   – If instead you receive an error message, re-check your communication settings within the communication interface, the COM port selection, and/or communication and power wiring.

Initialize pump

Initialization verifies correct operation and places the plunger and valve into specific starting positions. Initialization is required before any move commands to the valve or plunger will be accepted.

In this test, default settings specific to the valve provided with your pump are used. In the next chapter, there are instructions for adjusting the settings to your instrument design.

⚠WARNING

WARNING! Keep fingers out of the syringe slot while the pump is running. Failure to do so can result in injury.

Initialize with TCS Pump Commander

Note: This procedure is intended for use only during pump installation, before syringe has been installed and/or fluid has been added. For other situations, see "Initializing pump" (page 44).

1. Issue the [ZR] command, using the Command String area near the top of the screen, and press the Send String button.

Command String area   Setup Communication   Status/Response area
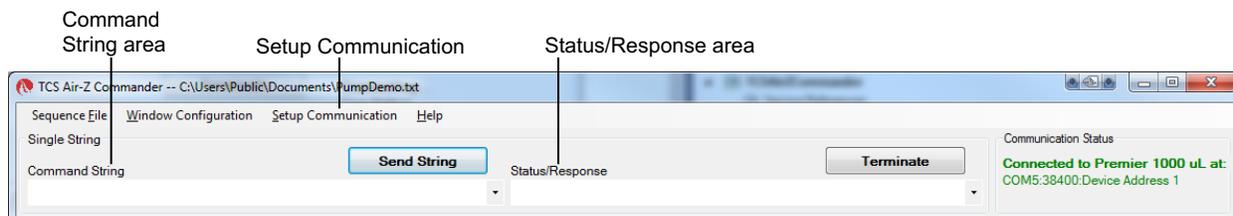
Note: Product name shown in screen capture is for example only.

2. Observe pump:
   – The plunger arm should move, and the valve will turn (movement not visible).
   – An "OK" message should appear in the Status: Response area. Most of the LEDs at the top of the pump should be lit.
   – The ERR LED will be off, and the LIFE LED will be blinking slowly.
   – If a "Failed" message is received, check communication settings and power, or for something blocking the mechanism.
   – Once TCS Pump Commander shows a status of "OK" the pump is ready to accept further commands.

Initialize with terminal emulation program

Note: When in DT mode, a carriage return (ODh) is required after the command string.

⚠**CAUTION**

CAUTION: This procedure is intended for use only during pump installation, before syringe has been installed and/or fluid has been added. For other situations, see "Initializing pump" (page 44).

1. Issue the [Z] command. An example would be [/1ZR], where /1 represents the address of the pump (address switch setting plus 1 if RS232/485; address switch setting if CAN).

2. Observe pump:
   - The plunger arm should move, and the valve will turn (movement not visible).
   - Most of the LEDs at the top of the pump should be lit. The ERR LED will be off, and the LIFE LED will be blinking slowly.

3. Issue a [Q] command to confirm initialization, for example [/1Q].
   - If initialization was successful, the response status byte will indicate so. See "Data Terminal (DT) protocol" (page 130). Possible status byte responses are shown in Table 5-9 (page 96).
   - If an error occurred during the initialization, an initialization failure error will be returned in response to the [Q] command. Check communication settings and power, or for something blocking the mechanism.
   - Once initialization is successful, the pump is ready to accept commands.

Check LED indicators

Diagnostic LEDs are provided to assist in monitoring the functioning of the pump. Please refer to Figure 4-8, below.

Note:

- Valve sensor LEDs indicate either at home or in other designed position.
- The solenoid LED is not functional.
- If the Error LED is blinking, see Table 7-1 (page 115) for instructions.

Figure 4-8. C-Series pump LED indicators
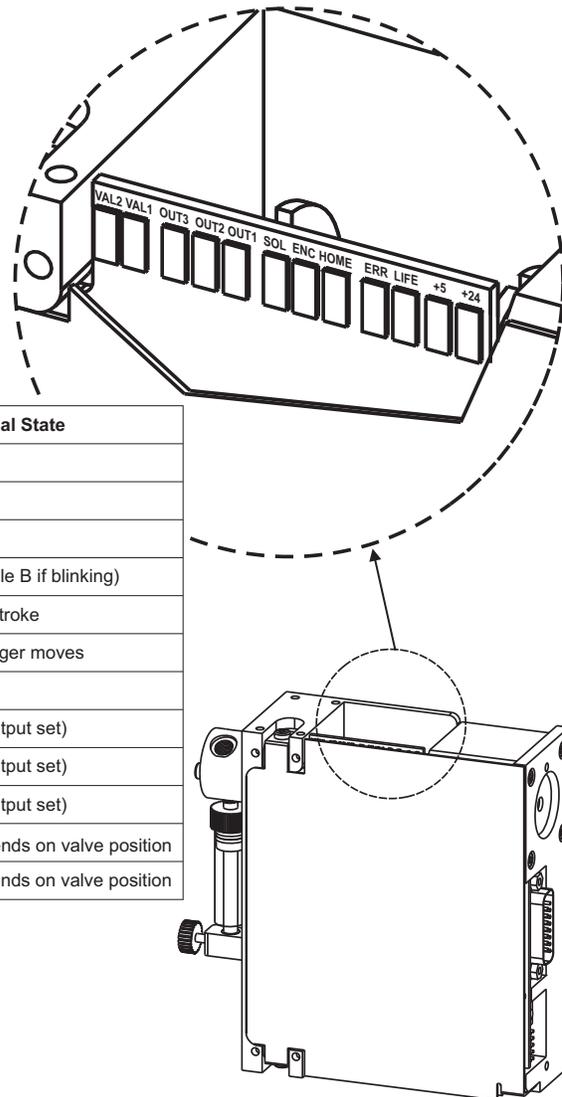
Table A: LED Functions

LED	Function	Normal/Typical State
+24	24 VDC Supply	ON
+5	5 VDC Regulator	ON
LIFE	Processor heartbeat	Blink slowly
ERR	Error	OFF (See Table B if blinking)
HOME	Top of stroke sensor	ON at top of stroke
ENC	Linear encoder sensor	Blinks as plunger moves
SOL	Solenoid output	ON
OUT1	Auxiliary output 1	ON (OFF if output set)
OUT2	Auxiliary output 2	ON (OFF if output set)
OUT3	Auxiliary output 3	ON (OFF if output set)
VAL1	Valve sensor	ON/OFF depends on valve position
VAL2	Valve sensor	ON/OFF depends on valve position

Table B: ERROR Indications

ERR LED	Error
OFF	No error
1 blink	Initialization error
2 blinks	EEPROM failure
3 blinks	Plunger overload
4 blinks	Valve overload

Install syringe

Note: The C24000 pumps must be initialized before the syringe can be installed. This is because these pumps cannot be moved manually. For C24000 pumps, first go to "Initialize pump" (page 33) and return to this procedure after initialization has been performed.

Refer to Figure 4-9 during this procedure.

1. Lower the syringe plunger arm to ensure sufficient room to install the syringe and plunger.
   - C3000 pumps: if the pump is powered off, manually lower the plunger by pushing firmly down on the syringe plunger arm. If the power is on, this can be done by sending the command [A3000R].
   - C24000 pumps: with the power on, send the command [A24000R]. The plunger cannot be manually lowered on the C24000 pump due to the high resolution of the drive system.

2. Make sure the plunger is fully seated in the syringe, to ensure the length is short enough to fit into the available space.

⚠**CAUTION**

CAUTION:
   - Do not overtighten the syringe or fittings. This can cause damage to the syringe and valve, which can lead to leakage and reduced life. Do not exceed 21 oz-in. torque on either the syringe or fittings.
   - Do not use Teflon® tape on syringe or fitting threads. All syringe port seals are face seals (not thread sealing). Use of Teflon® tape can lead to valve damage due to over stress on the valve seat from excessive torque applied to the syringe or fittings.

3. Screw the threaded portion of the syringe clockwise into the valve (hold the syringe by the knurled portion when screwing it into the valve).

4. Tighten the syringe until it bottoms in the valve, then tighten another 1/4 turn (this roughly corresponds to 16 oz-in). If a more secure installation is needed, loosen the syringe and repeat the process approximately 24 hours later. *The maximum torque specification is 21 oz-in.*

⚠**CAUTION**

CAUTION: Do not exceed the maximum torque specification of 21 oz-in. This can cause damage to the syringe and valve, which can lead to leakage and reduced life.

5. Pull the plunger down and fully seat it into the syringe plunger arm.

6. Securely tighten the plunger lock screw by turning clockwise.

Figure 4-9. Installing syringe

Valve

Syringe

Plunger

Plunger Lock Screw
Turn counterclockwise
to loosen

Syringe
Plunger Arm
lowered

Screw syringe
clockwise to seat
in valve body

Pull plunger
down all the
way into syringe
plunger arm

Turn plunger lock screw
clockwise to tighten
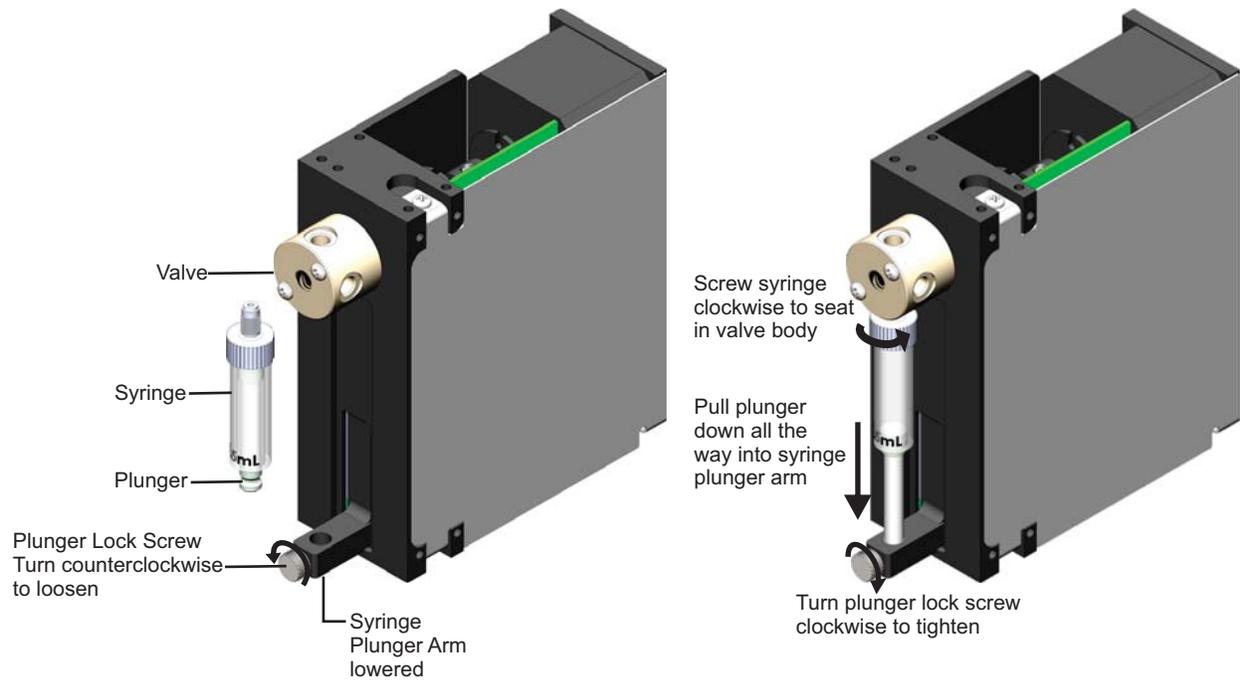
Connect tubing

For fluid connections, the standard C-Series valves are equipped with 1/4-28″ ports for the tubing fittings.

⚠️**CAUTION**

CAUTION: Be sure to check fluid compatibility with the materials in the valve, syringe, and plunger seal. Refer to the Chemical compatibility chart on page 161.

Procedure

Connect tubing to pump and fluid source and outlet according to your instrument design and the tubing supplier's instructions.

⚠️**CAUTION**

CAUTION: Do not exceed the maximum torque specification of 21 oz-in. This can cause damage to the valve, causing leakage and reduced life.

Do not use Teflon® tape on fitting threads. Use of Teflon® tape can lead to valve damage due to over stress from excessive applied torque.

Note: If more information is needed about valve port options, refer to "Valve movements" (page 51) and the associated illustrations.

The following application information may also be helpful:
- "Precision and accuracy" (page 162)
- "Optimizing pump performance" (page 164)
- "Optimizing tubing performance" (page 166)

5   Operating instructions

⚠CAUTION

CAUTION: After connecting fluids, the initialization command will result in fluid movement. Make sure the pump is properly plumbed and there are no leaks. Otherwise the fluid movement can result in spills.

Always run liquid through the syringe and valve when issuing a move command. Failure to do so will eventually wear out the valve and syringe seal.

About this chapter

This chapter describes how to operate the C-Series pump once the following have been done (described in the previous chapter):
*   Physical and electrical installation has been completed.
*   Communication with pump has been confirmed.
*   Tubing has been installed and connections with fluid have been made.

This chapter includes:
*   About this chapter, page 39
*   Operation overview, page 40
*   Interface options review, page 40
*   Command guidelines, page 41
*   Initializing pump, page 44
*   Priming syringe and tubing, page 50
*   Valve movements, page 51
*   Plunger movements, page 64
*   Configuring auxiliary outputs, page 76
*   Execution control commands, page 78
*   Using EEPROM, page 84
*   Standalone operation (AutoRun), page 90
*   Report (query) commands, page 92
*   Status and error codes, page 94
*   Non-functional commands, page 97
*   Command summaries, page 97

Operation overview

Operation consists of:

- Initializing the pump with input/output ports defined for your application
- Priming syringe and tubing
- Programming the moves and making the settings that are described following "Priming syringe and tubing" (page 50)

Interface options review

Interface requirements are described in the preceding chapter, Installation instructions. The following is a summary. For full information, refer to "Protocol and interface options" (page 17).

Communication standards

The C-Series Syringe Pump uses the following communication standards.

- RS232
- RS485
- CAN (Controller Area Network)

An integrated RS232-RS485 converter allows RS232 ports to communicate with pumps on the built-in RS485 bus.

Protocols

Three communication protocols are available

- OEM communications protocol
- Data Terminal (DT) protocol
- CAN (Controller Area Network) protocol

These communication protocols are described in the "Reference information" chapter (page 121)

The C-Series firmware automatically detects OEM or DT protocol for RS232/RS485 applications.

When not using a terminal emulator program for RS232/RS485, the OEM protocol is recommended. It provides robust error checking and recovery.

⚠CAUTION

CAUTION: Please note that the pump communication buses (RS232/RS485/CAN) use liquid handling industry-developed custom communication protocols (OEM, DT, and CAN). It is possible (but not recommended) for non-pump devices using a different communication protocol to exist on the same RS485 or CAN bus, as long as the non-pump device's protocol does not interfere with the pump bus protocol.

Tricontinent Scientific, Inc. does not encourage or warrant any use of the pump buses with non-pump devices, regardless of information provided by Tricontinent Scientific, Inc. Results may be unsatisfactory.

Command guidelines

The C-Series Syringe Pump features a robust command set that permits a wide range of pump actions. Many of the commands have default arguments; these are frequently-used values that, when utilized, can help minimize the length of command strings. Take a moment to familiarize yourself with each command in order to obtain the best performance for your application.

For a quick reference to all commands, see "Command summaries" at the end of this chapter.

Note: All command examples in this section are in DT format.

Command structure

Each command consists of a device address, one or more commands, and (with exceptions) a Run command [R].

Example: [/2A3000R]

Breakdown:

/	Start of command
2	Device address 2 (see "Addressing" below)
A	Move to absolute position.
3000	The magnitude of the move, which in this example is 3000 position increments. The size of an increment is determined by the [N] (increment mode) command.
R	Run. Execute the command string. [R] is not required for certain classes of commands.

Note: In DT mode, a carriage return (ODh) is required after the command string.

Addressing

As part of the communications protocol, every command string must contain an address for the intended pump(s).

Example: [/2A3000R], where 2 is the device address. There are 15 possible addresses on the pump.

- For RS232/485, the device address = address switch setting + 1. So if the address switch(es) are set to 1, the device address is 2. Address numbering starts at 1.

- For CAN communication, the device address = address switch setting. Address numbering for CAN begins at 0, not 1.

- When using RS232/RS485 protocol, multiple-device addressing is available. Two pumps, four pumps, or all 15 pumps may be addressed at once.

For more information about addressing, refer to "Pump addressing scheme" (page 122).

Command syntax

The syntax used in this manual for describing commands in the command set is as shown here:

Convention	Description
[command]	The name of the command; the command itself (or a string). Commands are case-sensitive. Square brackets are used to denote any single command or command string.
<n>	Operand (command argument). For example, [A<n>] represents the A (absolute move) command and operand <argument>. The argument must be a value within the valid operand range.
0...3000	(Example) valid operand range of numerical <argument>
(n)	Default <argument>, if no argument is included in command when issued
{n}	Power-up default <argument>
	Note: If there is no default value provided for an <argument> in a command description, a value must be included with the command for the command to be valid.

The symbols [ ], <>, ( ), and { } are not to be sent as part of a command.

Command execution guidelines

To enter commands properly, keep the following in mind:

- Commands are case-sensitive.

- For DT and OEM protocol, the host must allow adequate time for the pump to process commands. For details, see "OEM and DT timing and polling guidelines" in the Reference information chapter.

- All commands except report commands, the status query command [Q], and some EEPROM configuration commands, must be followed by an [R] (Run) command. If a command is sent without a required [R] (Run) command, it is placed into the buffer without being executed. It can be run at a later time by issuing an [R] command.

- Space characters (ASCII 32) in commands are ignored by the pump. If using the OEM protocol, the checksum must include the space character.

- In DT mode, a carriage return (0Dh) is needed after each command string (following the [R] command).

- Single or multiple commands can be sent to the pump within a string.

  For example:

  - A single command such as [A3000R] moves the plunger to position 3000. Likewise, [ZR] initializes the pump.

  - A multi-command string such as [IA3000OA0R] moves the valve to the Input position [I], moves the plunger to position 3000 [A3000], turns the valve to the output position [O], and finally returns the plunger to position 0 [A0].

- The pump's command buffer holds a maximum of 255 characters.

- Once a command or command string is in the process of being executed, the pump is busy and will not accept new commands until the sequence is completed. If a new command is issued while the pump is busy, a command overflow error code will be issued and the command string will be ignored. Exceptions to this rule include the [T] (terminate), [V] (top velocity), [Q], and most report commands. The busy/idle status is determined by polling the pump with the [Q] command.

- When a command is sent, the pump answers immediately (except in RS232/RS485 multiple-device addressing mode, that is, when the host is addressing multiple pumps). See "Pump addressing scheme" in the Reference information chapter for multiple-device addressing.

- If an invalid command is sent within a command string, the pump reports an error immediately. If there was an invalid parameter, in certain cases the string will execute until the invalid parameter is reached and then stop. In all cases, the [Q] (status query) command may be used to read back errors that have not already been read or returned as part of the command responses.

  The error codes are described in "Status and error codes" (page 94).

Execution controls

Command strings may include command characters that modify command execution. Examples are the [R] command, halt and wait for an external signal [H], and commands that initiate loops (repeat sequences) [g] [G]. For details on these commands, see "Execution control commands" (page 78).

Initializing pump

During installation, an initialization was performed using default settings. Your application is likely to require more specific settings than those the defaults provide.

This section describes the initialization sequence, and the commands and options available for customizing initialization settings for your application. Once the valve is initialized with the input/output ports defined for your application, priming can proceed.

Note:

- For consistency in initialization, it is recommended that initialization always be performed in the normal increment mode (the default mode). For details on increment modes, see "Set plunger resolution/increment mode (N<n>)" (page 65).
- Slower than default initialization speeds may be needed when working with large syringes, viscous fluids, or small I.D. (inner diameter) tubing, due to increased back pressure. Initialization speeds are set by the [Z] and [Y] command arguments, as described on the following pages.
- By default the valve does not initialize on power-up, but this can be enabled by an EEPROM setting.

Initialization sequence

A typical initialization sequence with a non-distribution valve, in response to the [Z] or [Y] command, is as follows:

1. Valve is homed to output right position with the [Z] command, or output left with the [Y] command.

   Output position is assigned to the right or left by the [Z] or [Y] command.

2. Syringe motor speed and stall force are set by [Z] or [Y] arguments.

3. If pump is at top of stroke, valve moves to input and plunger moves down and out of home opto.

4. Valve moves to output; plunger moves up until home opto is tripped.

5. Plunger is then stalled at the top of the syringe.

   Note: Visual confirmation is recommended to make sure the plunger contacts the top of the syringe. If it does not, a slower initialization speed is needed.

6. Valve moves to input; syringe travels downward a fixed number of increments.

7. Valve moves to output; syringe moves up and stops at syringe zero gap [k] increments away from the stall position.

The output position of the valve is assigned to the left or right side, depending upon the Initialization command [Z] or [Y] and all syringe velocity parameters ([V], [v], [c]) and acceleration [L] are reset to default values. Increment mode [N] retains its value.

The complete set of initialization commands is described below.

Initialization commands

Note: For consistency in initialization, it is recommended that initialization always be performed in the normal increment mode (the default mode).

Initialize pump, set valve output to the right (Z<n1,n2,n3>)

The [Z] command initializes the plunger drive and sets a non-distribution type valve output to the right (as viewed from the front of the pump).

For distribution valves, <n2> and <n3> select the input and output ports (ports are numbered clockwise from syringe port). For non-distribution valves, <n2> and <n3> are ignored.

The [Z] command resets the velocity settings ([V], [v], [c]) and acceleration [L] to power-up defaults. The increment mode [N] is preserved after a [Z] command.

Arguments:

<n1>	0...40	Plunger stall force and speed. See table below.
	(0)	Default argument
<n2>	0...X	Set the initialization input port on distribution valves, numbered clockwise from syringe port. X = number of ports on valve; 0 is same as 1. (Ignored for non-distribution valves.) See table page 45.
	(1)	Default argument
<n3>	0...X	Set the initialization output port on distribution valves, numbered clockwise from syringe port. X = number of ports on valve; 0 is same as X. (Ignored for non distribution valves.) See table page 46.
	(X)	Default argument. X = number of ports on valve.

Argument <n1> options:

<n1> options	Description
0	Default argument. Initializes at full plunger stall force at defined speed 11. Recommended for syringes 1.0 mL and larger.
1	Initializes at half plunger stall force at defined speed 11. Recommended for 250 µL and 500 µL syringes.
2	Initializes at one third plunger stall force at defined speed 11. Recommended for 50 µL and 100 µL syringes.
3	Initializes at full plunger stall force at defined speed 16.
4	Initializes at full plunger stall force at defined speed 18.
5...9	Same as <n1> = 0
10...40	Initializes at full plunger force at defined speed 10...40

Note: Defined speeds are explained in the description for the [S] command (page 73). Slower initialization speeds may be needed to avoid excessive back pressure when working with large syringes, viscous fluids, or small I.D. (inner diameter) tubing. Plunger piston must contact the top of the syringe during initialization.

Argument <n2> options:

<n2> options	Description
0	Set the input initialization port to 1 (default).
1...X	Set the input initialization port to a non-default value. X = number of ports on valve.

Argument <n3> options:

<n3> options	Description
0	Set the output initialization port to X (default). X = number of ports on valve.
1...X	Set the output initialization port to a non-default value.

Valve port numbering for distribution valves is illustrated in Figures 5-4 (page 58), 5-5 (page 60), and 5-6 (page 61).

Initialize pump, set valve output to the left (Y<n1,n2,n3>)

The [Y] command initializes the plunger drive and sets a non-distribution valve output to the left (as viewed from the front of the pump).

For distribution valves, <n2> and <n3> select the input and output ports (ports are numbered counterclockwise from the syringe port). For non-distri-bution valves, <n2> and <n3> are ignored.

The [Y] command resets the velocity settings ([V], [v] and [c]) and accelera-tion [L] to power-up defaults. The increment mode [N] is preserved after a [Y] command.

Arguments:

<n1>	0...40	Plunger stall force and speed. **Note:** Argument options for <n1> are the same as for [Z] command. See "Argument <n1> options:" (page 45)
	(0)	Default argument
<n2>	0...X	Set the initialization input port on distribution valves, numbered counterclockwise from syringe port. X = number of ports on valve.) 0 is the same as 1. See "Argument <n2> options" below. (Ignored for non-distribution valves.)
	(1)	Default argument
<n3>	0...X	Set the initialization output port on distribution valves, num-bered counterclockwise from syringe port. X = number of ports on valve. 0 is the same as 1. See "Argument <n3> options" below. (Ignored for non-distribution valves.)
	(X)	Default argument, X = number of ports on valve

Argument <n2> options:

<n2> options	Description
0	Set the input initialization port to X (default).
1...X	Set the input initialization port to a non-default value. X = number of ports on valve.

Argument <n3> options:

<n3> options	Description
0	Set the output initialization port to port 1 (default).
1...X	Set the output initialization port to a non-default value. X = num-ber of ports on valve.

Valve port numbering for distribution valves is illustrated in Figures 5-4 (page 58), 5-5 (page 60), and 5-6 (page 61).

Initialize pump without valve (W<n>)

The [W] command initializes the plunger drive but doesn't initialize the valve drive. The [W] command accepts the same <n1> arguments as the [Z] com-mand.

Initialize valve only (w<n1,n2>)

The [w] command initializes the valve drive only. The valve is initialized as it would be via the [Z] command.

Arguments:

<n1>	0...X	Set the initialization input port on distribution valves, numbered clockwise from syringe port. X = number of ports on valve. 0 is the same as 1. (Ignored for non-distribution valves.) See table below.
	(1)	Default argument
<n2>	0...1	Not used, ignored.

Argument <n1> options:

<n1> options	Description
0	Set the input initialization port to 1. (default)
1...X	Set the input initialization port to non-default value. X = number of ports on valve.

Specify syringe zero gap increments (k<n>)

The [k] command sets a gap between the plunger and syringe seal. During initializations, the plunger moves upward until it contacts the top of the syringe, causing a forced stall initialization. The plunger then moves downward 120 full increments, and then upward 120 increments minus the <n> specified amount, leaving a gap between the syringe seal and the top of the plunger. This small gap was designed so that the seal does not hit the top of the plunger each time the syringe moves to the home or zero position. This maximizes the life of the syringe seal.

Arguments:

<n>	The offset in increments from the zero or stall position	
<n>	0...120	Increments in N0 mode
<n>	0...960	Increments in N1 or N2 mode (micro-increments)
	{24}	Power-up default C3000/C3000MP
	{384}	Power-up default C24000/C24000MP

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

[k10ZR]

Since [k] only takes effect on initialization, the [k] command is usually followed by an initialization command, [Z] or [Y] as shown above.

Note: Each time the unit is powered down, the [k] value returns to the power-up default setting.

Perform simulated plunger initialization (z<n>)

The [z] command simulates an initialization of the pump; however, no mechanical movement of either the plunger or the valve occurs. The position counter is set to <n>, which becomes home for the plunger.

Arguments for C3000/C3000MP:

<n>	0...3000	Increments in N0 mode
<n>	0...24000	Increments in N1 or N2 mode (micro-increments)
<n>	(0)	Default argument

Arguments for C24000/C24000MP:

<n>	0...24000	Increments in N0 mode
<n>	0...192000	Increments in N1 or N2 mode (micro-increments)
<n>	(0)	Default argument

This command can be used to recover from a plunger overload error. Afterwards, the pump must be reinitialized using the [Z], [W], or [Y] command to set the true home position.

Note: Be sure to reinitialize after using the [z] command to ensure correct positioning.

Priming syringe and tubing

Priming prepares the system for operation by removing air from the syringe and tubing.

1. Run the pump with a full stroke and several cycles to prime the system with the working fluid (e.g. water). The following example is in DT protocol.

   Example priming string:

   [ZV6000gIA3000OA0G3R]

   Initialize [Z]; set priming speed [V6000]; set start of looping sequence [g]; move valve to inlet position and fill, with plunger drawing down to maximum position A3000 [IA3000]; move valve to outlet and dispense, with plunger pushing up to minimum position A0 [OA0]; repeat 3 times [G3].

   – The number of cycles depends on the syringe size and internal volumes of the inlet and outlet tubing connected to the pump.
   – Smaller syringes can be harder to prime due to lower fluid velocity, and require more strokes.

2. Observe for bubbles. If any are observed, run the priming sequence again, perhaps specifying more cycles with the [G] command. Check all connections of tubing and syringe for leaks.

   Surfactants can be added to the working fluid to reduce surface tension and help flush bubbles out of the system. The smallest syringes, 50 µL for example, have been primed with alcohol followed by distilled water to help remove air bubbles.

Once priming has been completed, the pump is ready for comprehensive programming.

Note: Slower initialization speeds may be needed when working with large syringes, viscous fluids, or small I.D. (inner diameter) tubing, due to increased back pressure. Plunger piston must contact the top of the syringe/barrel during initialization.

Valve movements

Note: The TCS Pump Commander allows you to view the current and available valve positions as commands are selected, using the Valve Viewer window. The interior of the valve is shown as well, so you can see the fluid path change as valve positions change.

Valve selection information

No valve selection by the user is needed as this is set by the factory, along with the valve jumper on J2. See "Set configuration jumpers and address switch" (page 22) for J2 details.

Note: Valve selection details are provided for *informational purposes only*. Please contact Customer Service if you would like a different valve for your pump evaluation.

Valve characteristics are stored in EEPROM, using variations of the [U] command as shown in Table 5-1, below. In other words, to select a particular valve, one of the [U] command variations shown in the following table are issued.

The pump may be queried via the [?76] command to confirm which valve is selected for your pump.

Table 5-1: Valve selection information

Valve type	?76 query response	Command and operand[1]	Reference figure	Comments
3-port 120° Y valve	3P-Y	[U1]	5-1 (page 53)	Valve jumper[2] installed
4-port 90° valve	4P-90	[U2]	5-2 (page 54)	Valve jumper removed
3-way distribution valve	3WD	[U11]	5-5 (page 60)	Valve jumper removed Uses [I] and [O] commands.
	3WD-IOE	[U4]	5-4 (page 58)	Valve jumper removed Uses [I], [O], [B], and [E] commands.
3-port and 4-port T valves	T-90	[U5]	5-3 (page 56)	Valve jumper removed
6-way distribution valve C3000MP and 24000MP only	6WD	[U7]	5-6 (page 61)	Valve jumper no effect
4-port loop valve	LOOP	[U9]	5-7 (page 63)	Valve jumper removed

1. EEPROM commands require power to be cycled before taking effect. EEPROM commands are non volatile, so they only need to be issued once.
2. See "Set configuration jumpers and address switch" (page 22).

Making valve movements

The following pages describe how to make valve movements with the variety of valves available for the C-Series Syringe Pump.

Descriptions of commands for each type of valve are followed by illustrations which show positions resulting from each command.

Note: The illustrations on the following pages show valve positions as viewed from the front of the pump.

Movements for non-distribution valves (3-port and 4-port)

The following commands apply to the 3-port 120° Y valve and the 4-port 90° valve. Refer also to Figures 5-1 and 5-2.

Move valve to input position (I)

The [I] command moves the valve to the input position. The input position will be either to the left or to the right depending on whether the [Z], [Y], or [w] initialization command was sent first.

For example:

- After [Z] or [w] initialization: sets input to left port.
- After [Y] initialization: sets input to right port.

Move valve to output position (O)

The [O] command moves the valve to the output position. The output position can be either to the right or to the left depending on the [Z], [Y], or [w] initialization commands.

For example:

- After [Z] or [w] initialization: sets output to right port.
- After [Y] initialization: sets output to left port.

Move valve to bypass position (3-port 120° Y valve only) (B)

The [B] command connects the input and output positions, bypassing the syringe. Please see note below.

Connect flush port to inlet port (4-port 90° valve only) (B)

The [B] command sets the flush port to inlet on left or right, bypassing the syringe. See note below.

- After [Z] or [w] initialization: sets the flush port to inlet on left.
- After [Y] initialization: sets the flush port to inlet on right.

Connect flush port to outlet port (4-port 90°valve only) (E)

The [E] command connects the flush port to an outlet port on the left or right, bypassing the syringe.

- After [Z] or [w] initialization: connects the flush port to outlet on right.
- After [Y] initialization: connects the flush port to outlet on left.

Note: When the valve is in the [B] or [E] position, the syringe plunger cannot be moved. Sending a plunger move command causes a plunger move not allowed error.

Figure 5-1. Positions for 3-port 120° Y valve

Syringe port located at bottom of valve

3-port commands using [Z] or [w] initialization

[I] valve command
sets input to the left

[O] valve command
sets output to the right

[B] valve command
bypasses input to output

3-port commands using [Y] initialization

[I] valve command
sets input to the right

[O] valve command
sets output to the left

[B] valve command
bypasses input to output
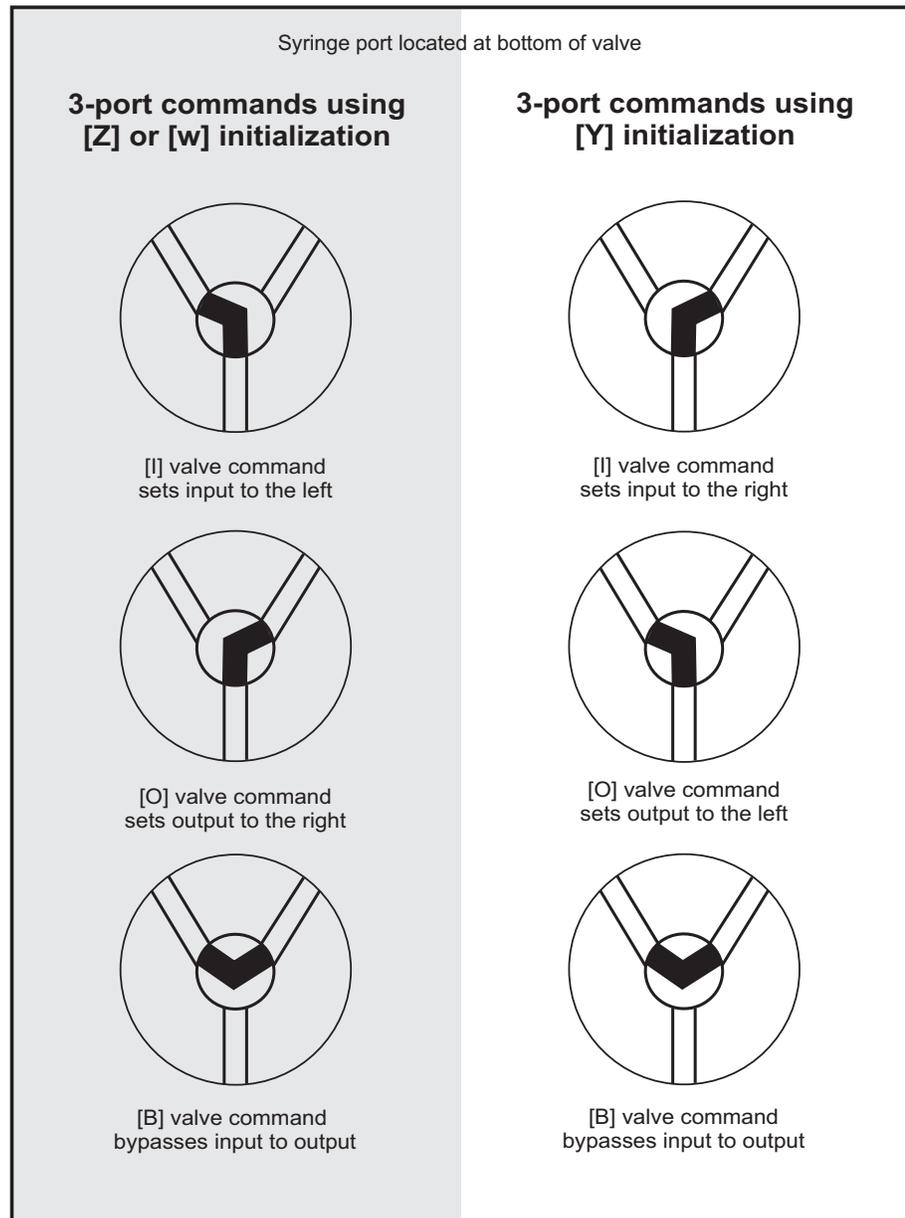
Note: This valve is selected with the [U1] command. Jumper J2 must be installed for this valve.

Figure 5-2. Positions for 4-port 90° valve

Syringe port located at bottom of valve

**4-port commands using
[Z] or [w] initialization**

**4-port commands using
[Y] initialization**

[I] valve command
sets syringe input to the left

[I] valve command
sets syringe input to the right

[O] valve command
sets syringe output to the right

[O] valve command
sets syringe output to the left

[B] valve command
connects flush port to inlet on left

[B] valve command
connects flush port to inlet on right

[E] valve command
connects flush port to output on right

[E] valve command
connects flush port to output on left

Note: This valve is selected with the [U2] command. Jumper J2 is removed for this valve.

Movements for T valves (3-port and 4-port)

The following commands apply to the 90,°3-port T and 90°, 4-port T valves. Refer also to Figure 5-3, which shows valve positions according to valve movement and initialization commands for the 3-port and 4-port T valves.

Move valve to input position (I)

The [I] command moves the valve to the input position. The input position will be either to the left or the right depending on whether the [Z], [Y], or [w] initialization command was sent first.

- After [Z] or [w] initialization: sets input to left port.
- After [Y] initialization: sets input to right port.
- On the 4-Port T valve, the top port is also connected.

Move valve to output position (O)

The [O] command moves the valve to the output position. The output position can be either to the left or to the right depending on the [Z], [Y], or [w] initialization commands.

- After [Z] or [w] initialization: sets output to right port.
- After [Y] initialization: sets output to left port.
- On the 4-Port T valve, the top port is also connected.

Move valve to bypass position (B)

The [B] command connects the input with output and syringe.

Movement is the same regardless of [Z] or [Y] or [w] initialization.

Bypass input to outlet port (E)

The extra [E] command connects the input and output ports, bypassing the syringe. On the 4-port T valve, the top port is also connected.

Movement is the same regardless of [Z], [Y], or [w] initialization.

Note: When the valve is in the extra [E] position, the syringe plunger cannot be moved. Sending a plunger movement command results in a plunger move not allowed error.

Figure 5-3. Positions for 3-port and 4-port T valves

Syringe port located at bottom of valve

**T-port commands
using [Z] or [w] initialization**

4-port valve
top port

[I] valve command sets input to the left
On 4-port valve, top port also connected

[O] valve command sets output to the right
On 4-port valve, top port also connected

[B] valve command connects
Input, output and syringe

[E] valve command connects input to output
On 4-port valve, top port also connected

**T-port commands
using [Y] initialization**

[I] valve command sets input to the right
On 4-port valve, top port also connected

[O] valve command sets output to the left
On 4-port valve, top port also connected

[B] valve command connects
Input, output and syringe

[E] valve command connects input to output
On 4-port valve, top port also connected

Note: These valves are selected with the [U5] command. Jumper J2 is removed for these valves.

Movements for distribution valve (3-way with U4 selection)

The following commands apply to the 3-way distribution valve as it behaves when selected with the U4 command.

In this configuration, the three distribution ports are referred to as left, right, and top. See Figure 5-4 for valve positions vs. commands.

Set syringe to left/right port (I)

The [I] command sets the syringe to either the left port or the right port, depending on [Z], [Y], or [w] initialization. The positioning is opposite that of the [O] command.

- After [Z] or [w] initialization: connects syringe to left port.
- After [Y] initialization: connects syringe to right port.

Set syringe to right/left port (O)

The [O] command sets the syringe to either the right port or the left port, depending on [Z], [Y], or [w] initialization. The positioning is opposite that of the [I] command.

- After [Z] or [w] initialization: connects syringe to right port.
- After [Y] initialization: connects syringe to left port.

Set syringe to top port (E or B)

The [E] and [B] commands both connect the syringe to the top port. Their use is interchangeable.

Movement is the same regardless of [Z], [Y], or [w] initialization.

Figure 5-4. Positions for 3-way distribution valve (U4 select)

Syringe port located at bottom of valve

3-way distribution commands using [Z] or [w] initialization

[I] valve command
connects syringe to the left port

[O] valve command
connects syringe to the right port

[E] valve command
connects syringe to the top port

3-way distribution commands using [Y] initialization

[I] valve command
connects syringe to the right port

[O] valve command
connects syringe to the left port

[E] valve command
connects syringe to the top port

Note: These positions apply if this valve is selected with the [U4] command. Jumper J2 is removed for this valve.

Movements for distribution valves (3-way with U11 selection; and 6-way)

The commands below apply to two distribution valves:

- 3-way distribution valve if optionally selected with the U11 command
- 6-way distribution valve

For these valves, the distribution ports are numbered from the left or right, depending on whether [Z], [Y], or [w] initialization preceded the positioning commands.

- After [Z] or [w] initialization: ports are numbered from left to right (clockwise).
- After [Y] initialization: ports are numbered from right to left (counter-clockwise).

Refer to Figure 5-5 and Figure 5-6 to view valve positions vs. commands.

Move valve to specific distribution port (I<n>)

The [I<n>] command moves the distribution valve to port <n> in a clockwise motion.

<n>	1...X	Assigned port, where X = number of distribution ports on valve, and therefore the highest-numbered port. The syringe port is excluded from the count. For a 3-way valve X=3, and for a 6-way valve X=6, and so on.
	0	Sets valve to port 1.
	(1)	Default argument

Example: [I2R] moves valve clockwise to distribution port 2.

Movement is the same regardless of [Z], [Y], or [w] initialization.

Move valve to specific distribution port (O<n>)

The [O<n>] command moves the distribution valve to the port <n> in a counterclockwise motion.

<n>	1...X	Assigned port, where X = number of distribution ports on valve, and therefore the highest-numbered port. The syringe port is excluded from the count. For a 3-way valve X=3, and for a 6-way valve X=6, and so on.
	0	Sets valve to port X.
	(X)	Default argument

Example: [O3R] moves valve counterclockwise to distribution port 3. Movement is the same regardless of [Z], [Y], or [w] initialization.

⚠CAUTION

Note: The [B] and [E] commands are ignored for these distribution valves.

CAUTION: Due to the smaller internal port diameters of the 6-way distribution valve and the 4-port loop valve, it is recommended that fluid velocity does not exceed 1500 µL/sec when using these valves. Use caution when setting velocity with 2.5 mL and larger syringe sizes, to avoid cavitation and excessive syringe back pressure. Refer also to "Calculating flow rates" (page 158).

Figure 5-5. Positions for 3-way distribution valve (U11 select)

Syringe port located at bottom of valve

3-way distribution commands using [Z] or [w] initialization

2

1   3

[I <1>] or [O <1>] connects
syringe to port 1

2

1   3

[O <2>] or [I <2>] connects
syringe to port 2

2

1   3

[I <3>] or [O <3>] connects
syringe to port 3

3-way distribution commands using [Y] initialization

2

3   1

[I <1>] or [O <1>] connects
syringe to port 1

2

3   1

[O <2>] or [I <2>] connects
syringe to port 2

2

3   1

[O <3>] or [I <3>] connects
syringe to port 3

I= CW rotation
O= CCW rotation
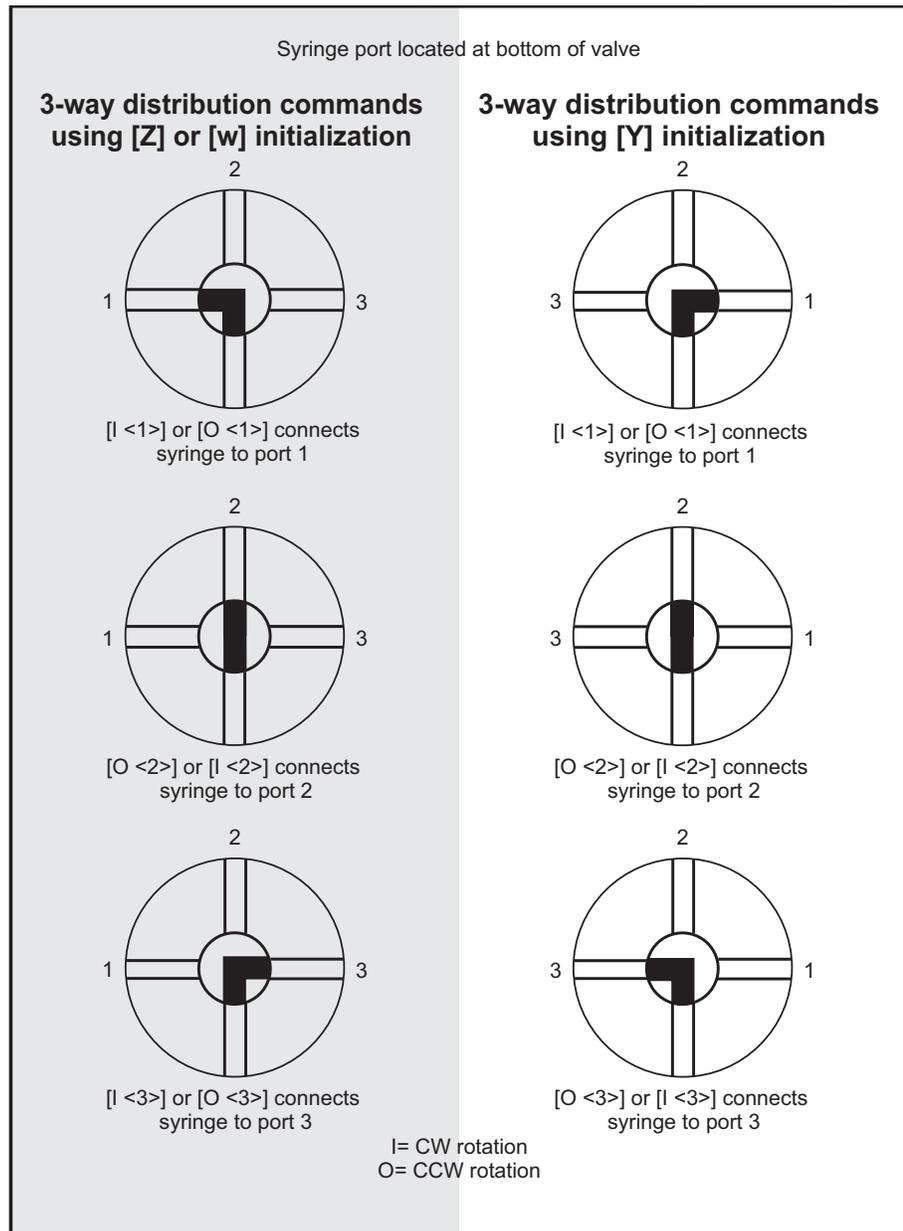
Note: These positions apply if this valve is selected with the [U11] command. Jumper J2 is removed for this valve.

Figure 5-6. Positions for 6-way distribution valve

Syringe port located at bottom of valve

6-way distribution commands using [Z] or [w] initialization

[I <1>] or [O <1>] connects syringe to port 1

[I <2>] or [O <2>] connects syringe to port 2

[I <3>] or [O <3>] connects syringe to port 3

[I <4>] or [O <4>] connects syringe to port 4

[I <5>] or [O <5>] connects syringe to port 5

[I <6>] or [O <6>] connects syringe to port 6

6-way distribution commands using [Y] initialization

[I <1>] or [O <1>] connects syringe to port 1

[I <2>] or [O <2>] connects syringe to port 2

[I <3>] or [O <3>] connects syringe to port 3

[I <4>] or [O <4>] connects syringe to port 4

[I <5>] or [O <5>] connects syringe to port 5

[I <6>] or [O <6>] connects syringe to port 6

I= CW rotation
O= CCW rotation

Note: This valve is selected with the [U7] command. Jumper J2 has no effect on this valve. Used only on the C3000MP and 24000MP pumps.

Movements for 4-port loop valve

The following commands apply to the 4-port loop valve.

In this configuration the four ports are referred to as left, right, top, and syringe. Refer also to Figure 5-7 (page 63), which shows valve positions according to valve movement and initialization commands for the 90° 4-port loop valve.

With [Z] or [w] initialization the valve rotates 90° clockwise when transitioning from [I], to [E], to [O], and to [B]. With [Y] initialization the valve rotates counterclockwise in the same valve position sequence.

Move loop to input position (I)

The [I] command moves the valve to the input position. The input position will be different depending on whether the [Z], [Y], or [w] initialization command was sent first.

- After [Z] or [w] initialization: connects left port to syringe, and top port to right port.
- After [Y] initialization: connects top port to right port, and left port to syringe.

Move loop to extra position (E)

The [E] command moves the valve to the extra position. The extra position is the same for either the [Z], [Y], or [w] initialization command.

- Connects left port to top port, and right port to syringe.

Move loop to output position (O)

The [O] command moves the valve to the output position. The output position can be either to the left or the right depending on the [Z], [Y], or [w] initialization commands.

- After [Z] or [w] initialization: connects top port to right port, and left port to syringe.
- After [Y] initialization: connects left port to syringe, and top port to right port.

Move loop to bypass position (B)

The [B] command moves the valve to the bypass position. The bypass position is the same for either the [Z], [Y], or [w] initialization command.

- Connects right port to syringe, and left port to top port.

Note: Due to the smaller internal port diameters of the 6-way distribution valve and the 4-port loop valve, it is recommended that fluid velocity does not exceed 1500 µL/sec when using these valves. Use caution when setting velocity with 2.5 mL and larger syringe sizes, to avoid cavitation and excessive syringe back pressure. Refer also to "Calculating flow rates" (page 158).

Figure 5-7. Positions for 4-port loop valve

Syringe port located at bottom of valve

Loop valve commands using [Z] or [w] initialization

[I] valve command
connects left port to syringe,
and right port to top port

[E] valve command
connects left port to top port,
and right port to syringe

[O] valve command
connects top port to right port,
and left port to syringe

[B] valve command
connects right port to syringe,
and left port to top port

Loop valve commands using [Y] initialization

[I] valve command
connects top port to right port,
and left port to syringe

[E] valve command
connects left port to top port,
and right port to syringe

[O] valve command
connects left port to syringe,
and top port to right port

[B] valve command
connects right port to syringe,
and left port to top port

Note: This valve is selected with the [U9] command. Jumper J2 is removed for this valve.

Plunger movements

The following pages describe how to make plunger movements on the C-Series Syringe Pump.

The range of the command arguments can vary depending on the specific pump model, e.g., C3000/C3000MP or C24000/C24000MP.

In addition, arguments vary according to the increment (resolution) mode set by the [N] command (described on page 65). For this reason, the increment mode should be decided upon before programming begins.

Increments and resolution

Increments

The term "increment" is used in the commands for plunger moves and positions, and for setting velocity/acceleration parameters.

An increment is the smallest available plunger movement, and indicates the available positioning resolution. The size of an increment varies with the pump model and with the setting of the [N] command (refer to "Set plunger resolution/increment mode (N<n>)" (page 65). The increments in the higher resolution mode are referred to as "micro-increments" in this manual.

Velocity settings are specified in increments per second. In the higher resolution micro-increments mode, velocity is specified in micro-increments per second.

Set plunger resolution/increment mode (N<n>)

The resolution should be decided upon and set before programming plunger moves. Normal resolution is adequate for most purposes. Higher resolution is useful when greater precision in movement is required, or very low velocity operation is needed.

The [N] command sets the resolution, that is, increments per stroke. It allows you to select a higher resolution for plunger movement, positioning, and/or velocity in order to obtain finer control.

These settings also apply to position and velocity reporting.

Arguments:

<n>	0	N0, normal increment mode. Positioning and velocity are in increments (velocity is in increments per second).
	1	N1, micro-increment mode for plunger positioning only, which is 8X the resolution of normal increment mode. Plunger velocity settings remain in normal increment mode (increments per second).
	2	N2, micro-increment mode for both positioning and velocity. Positioning is in micro-increments, while velocity is in micro-increments per second.
	{0}	Power-up default

Increment mode vs. full plunger stroke:

Increment Mode	Increments/full stroke, C3000/C3000MP	Increments/full stroke, C24000/C24000MP
N0	3,000 increments	24,000 increments
N1	24,000 (8 * 3,000)	192,000 (8 * 24,000)
N2	24,000 (8 * 3,000)	192,000 (8 * 24,000)

Note:
- Changing between N0 or N1 mode and N2 mode does not automatically scale the existing velocity and acceleration settings to maintain the same velocity/acceleration. Thus, going to N2 from N0 or N1 without changing the velocity/acceleration settings will cause the plunger to move 8 times slower. Also, going from N2 mode to N1/N0 mode without changing velocity/acceleration settings can cause inadvisable settings.
- For initialization consistency, always perform initializations in normal (N0) mode.
- These parameters may be changed with the [u] command. However, it is recommended that Customer Service be consulted before utilizing the [u] command. Otherwise unwanted pump behavior can result.

Converting increments to volume resolution

To convert increments to volume resolution, divide the syringe volume by the number of increments as determined by the pump model and the [N] command.

Examples

- 1 mL syringe on C3000 in N0 mode:
  volume = 1000 µL/3,000 = 0.3333 µL/increment

- 1 mL syringe on C24000 in N0 mode:
  volume = 1000 µL/24,000 = 0.0417 µL/increment

- 1 mL syringe on C3000 in N1 or N2 mode:
  volume = 1000 µL/24,000 = 0.0417 µL/micro-increment

- 1 mL syringe on C24000 in N1 or N2 mode:
  volume = 1000 µL/192,000 = 0.0052 µL/micro-increment

Note: See also "Calculating flow rates" (page 158).

Plunger move commands

Move plunger to absolute position (A<n>)

The [A] command moves the plunger to absolute position <n>.

Arguments for C3000/C3000MP:

<n>	0...3000	Increments in N0 mode
<n>	0...24000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

Arguments for C24000/C24000MP:

<n>	0...24000	Increments in N0 mode
<n>	0...192000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

For example:

[A300R] moves the syringe plunger to position 300.

[A600R] moves the syringe plunger to position 600.

Move plunger to absolute position, not busy (a<n>)

The [a] command is the same as the [A] command, except the status bit within the reply string, and any subsequent status query [Q] commands, indicates that the pump is not busy.

Make relative pickup (aspirate) move (P<n>)

The [P] command moves the plunger down the number of increments <n> commanded. The new absolute position is the previous position plus <n>.

Arguments for C3000/C3000MP:

<n>	0...3000	Increments in N0 mode
<n>	0...24000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

Arguments for C24000/C24000MP:

<n>	0...24000	Increments in N0 mode
<n>	0...192000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

For example:

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

The [P] command will return an invalid operand error if the final plunger position is greater than 3000 (24000 in N1 or N2 mode) for the C3000/C3000MP.

Make relative pickup (aspirate) move, not busy (p<n>)

The [p] command is the same as the [P] command, except that the status bit of the reply string, and any subsequent status query [Q] commands, indicate that the pump is not busy.

Make relative dispense (D<n>)

The [D] command moves the plunger upward the number of increments <n> commanded. The new absolute position is the previous position minus <n>.

Arguments for C3000/C3000MP:

<n>	0...3000	Increments in N0 mode
<n>	0...24000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

Arguments for C24000/C24000MP:

<n>	0...24000	Increments in N0 mode
<n>	0...192000	Increments in N1 or N2 mode (micro-increments)
	(0)	Default argument

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 an invalid operand error if the final commanded plunger position would be less than 0.

Make relative dispense, not busy (d<n>)

The [d] command is the same as the [D] command, except that the status bit of the reply string, and any subsequent status query [Q] commands, indicates that the pump is not busy.

Configuring plunger movement

Configuration commands are used to set up pump plunger movement characteristics. These include settings for plunger acceleration/deceleration slope, velocity, acceleration, cutoff, defined speeds, and backlash.

Velocity and acceleration configuration commands

Velocity and acceleration configuration commands are used to control the motion of the plunger. Plunger movement is structured into three phases:

- Ramping up. Plunger movement begins at the start velocity and accelerates with the programmed slope [L] to the constant or top speed.

- Constant or top speed. The plunger moves at the constant or top speed. Plunger speed or velocity can be programmed in increments/sec or in preset speeds [S]. The actual time the plunger travels depends 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 deceleration slope [L]. To enhance fluid break-off, the cutoff command [c] can be used to define the end velocity of the plunger just before it stops.

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.

The top velocity can be changed on the fly (while the plunger is moving) using the [V] command. When the move completes, the speed reverts to its original value.

In the N0 and N1 increment modes, velocity and acceleration settings are configured and reported in increments/sec. In the high resolution mode (N2), they are set up and reported in micro-increments/sec, which provides 8X the resolution as the N0 mode.

Difference between C24000/C24000MP and C3000/C3000MP velocity settings

Since the C24000 and C24000MP have a 4 times finer lead screw pitch than the C3000/C3000MP, the linear velocity is 1/4 as fast for a given velocity setting.

Thus, to aspirate/dispense at the same rate, the top velocity command [V] needs to be multiplied by 4 for the C24000/C24000MP. For example [V1000] in the C3000/C3000MP is equivalent to [V4000] in the C24000/C24000MP.

The same relationship applies to other velocity and acceleration commands.

Using TCS Pump Commander to help configure plunger movement

TCS Pump Commander allows you to view the profile of plunger movements in real time while developing velocity and acceleration commands, using the Trapezoidal Motion Tool window.

Set acceleration/deceleration slopes (L<n>)

During the beginning and end of a move, the plunger speed ramps up and down respectively. The ramp is programmed using the set slope [L] command. It is calculated as <n> x 2,500 increments/sec^2.

Arguments (slope codes):

<n>   1...20   Slope code, N0 or N1 mode (See table below)
<n>   1...160   Slope code, N2 mode (micro-increments/sec^2)
      {14}   Power-up default

Table 5-2 shows slope codes and corresponding acceleration/deceleration values:

Table 5-2: Slope codes

Slope code	N0 or N1 mode Increments/sec^2	N2 mode micro-increments/sec^2
1	2,500	In N2 mode, there are 160 possible codes, from 1 to 160.
2	5,000	
3	7,500	Resolution is 8X the N0 or N1 mode, so each step is 312.5 increments/sec^2.
4	10,000	
5	12,500	A code of 8 is then equivalent to Slope Code 1 in the N0 or N1 mode, or 2500 increments/sec^2. A code of 160 is 50,000 increments/sec^2.
6	15,000	
7	17,500	
8	20,000	
9	22,500	
10	25,000	
11	27,500	
12	30,000	
13	32,500	
14	35,000	
15	37,500	
16	40,000	
17	42,500	
18	45,000	
19	47,500	
20	50,000	

Interaction between velocity settings [v], [V], and [c]

The velocity settings interact according to these rules:

- The top velocity [V] should always be equal to or higher than start velocity [v] and cutoff velocity [c].
- Cutoff velocity [c] may not be made higher than top velocity [V]. If an attempt to set it higher occurs, it will be set equal to [V].
- Startup velocity [v] may be set higher than top velocity. However, the next time [V] is issued, [v] will be lowered to equal [V].

Querying [v] or [c] always reports the value that the pump is currently using. The original user-set values for these commands are retained and restored as described above, until changed by the user. Querying [v] or [c] will report the value that was set, either by the user or by default.

Set start velocity (v<n>)

The [v] command sets the velocity at which the plunger begins its movement.

Arguments:

<n>	1...1000	Increments/sec, N0 or N1 mode
<n>	1...8000	Micro-increments/sec, N2 mode
	{900}	Power-up default

After beginning at the start velocity, the plunger ramps up to the top velocity [V]. The start velocity must be equal to or less than the top velocity [V]. It is normally set to less than the top velocity.

Set top velocity (V<n>)

The [V] command sets the top velocity in increments/sec.

Arguments:

<n>	1...6000	Increments/sec, N0 or N1 mode
<n>	1...48000	Increments/sec, N2 mode (micro-increments)
	{1400}	Power-up default, C3000/C3000MP
	{5600}	Power-up default, C24000/C24000MP

The top velocity can be changed "on the fly," that is, while the plunger is moving, using the [V] command. When the move completes, the speed reverts to its original value. Thus, on-the-fly velocity changes only affect the current move. On-the-fly velocity changes are limited to a maximum of 2000. Any requested changes greater than 2000 will result in an invalid operand error.

The top velocity must be equal to or higher than [v] and/or [c].

For assistance in selecting the most appropriate top velocity, refer to "Calculating flow rates" (page 158).

⚠**CAUTION**

CAUTION: Due to the smaller internal port diameters of the 6-way distribution valve and the 4-port loop valve, it is recommended that fluid velocity does not exceed 1500 µL/sec when using these valves. Use caution when setting velocity with 2.5 mL and larger syringe sizes, to avoid

cavitation and excessive syringe back pressure. See also "Calculating flow rates" (page 158).

Set cutoff velocity in increments/sec (c<n>)

The [c] command sets the cutoff velocity. The cutoff velocity is the velocity at which the plunger ends its movement. The plunger will slope down [L] from the top velocity [V]. The [c] command overwrites the [C] command. Use of the Cutoff command [c] will enhance fluid breakoff.

Arguments:

<n>	1...2700	Increments/sec, N0 or N1 mode
<n>	1...21600	Micro-increments/sec, N2 mode
	{900}	Power-up default

Note: This setting can be affected if it is equal to or higher than the top velocity setting [V]. See "Interaction between velocity settings [v], [V], and [c]" (page 71).

Set cutoff in increments (C<n>)

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

Arguments:

<n>	0...25	Increments, as determined by the N mode
	{0}	Power-up default

For example, [C5] stops the plunger five increments short of the final position. 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.

Set a defined speed (S<n>)

The [S] command sets the top velocity [V] to predefined speeds using the codes shown in the table below.

Arguments:

<n> 0...40   Speed code (see table below)
     (11)   Default
     {11}   Power-up default

These speeds do not cover the full range of speeds the plunger can travel. They are commonly used velocities provided for convenience.

The [S] command sets top velocity [V] without changing start velocity [v], slope [L], or cutoff velocity [c] except under the following condition:

If the cutoff velocity [c] is higher than the desired top velocity [V], the cutoff velocity [c] is changed to equal the top velocity [V]. The [c] cutoff velocity does not revert to its original value when the top velocity [V] is raised.

Note: Speed code is not affected by the [N] command, but increments are, as shown below. The linear speed—and thus the flow rate—is 8 X slower in the micro-increment (N2) mode. The table below uses default ramp settings.

Table 5-3: Defined Speed codes

Speed Code [S<n>]	Increments/sec	Seconds/stroke N0 or N1 mode (increments)	Seconds/stroke N2 mode (micro-increments)
0	6,000	1.25	10.00
1	5,600	1.30	10.40
2	5,000	1.39	11.12
3	4,400	1.52	12.16
4	3,800	1.71	13.68
5	3,200	1.97	15.76
6	2,600	2.37	18.96
7	2,200	2.77	22.16
8	2,000	3.03	24.24
9	1,800	3.36	26.88
10	1,600	3.77	30.16
11	1,400	4.30	34.40
12	1,200	5.00	40.00
13	1,000	6.00	48.00
14	800	7.50	60.00
15	600	10.00	80.00
16	400	15.00	120.00
17	200	30.00	240.00
18	190	31.58	252.64
19	180	33.33	266.64
20	170	35.29	282.32
21	160	37.50	300.00

Table 5-3: Defined Speed codes (continued)

Speed Code [S<n>]	Increments/sec	Seconds/stroke N0 or N1 mode (increments)	Seconds/stroke N2 mode (micro-increments)
22	150	40.00	320.00
23	140	42.86	342.88
24	130	46.15	369.20
25	120	50.00	400.00
26	110	54.55	436.40
27	100	60.00	480.00
28	90	66.67	533.36
29	80	75.00	600.00
30	70	85.71	685.68
31	60	100.00	800.00
32	50	120.00	960.00
33	40	150.00	1200.00
34	30	200.00	1600.00
35	20	300.00	2400.00
36	18	333.33	2666.64
37	16	375.00	3000.00
38	14	428.57	3428.56
39	12	500.00	4000.00
40	10	600.00	4800.00

Set backlash increments (K<n>)

The [K] command sets the number of backlash increments <n>.

Arguments:

<n>	0...100	Increments
	(10)	Default argument, C3000/C3000MP
	(80)	Default argument, C24000/24000MP
	{10}	Power-up default, C3000/C3000MP
	{80}	Power-up default, C24000/24000MP

When the syringe drive motor reverses direction, the plunger arm will not move until the backlash due to mechanical play within the system is compensated. To provide compensation, during aspiration the plunger moves down <n> number of backlash increments, then backs up <n> number of backlash increments. This ensures that the plunger is in the correct position to begin a dispense move.

Note: A small volume of fluid will flow out the input side of the valve during this operation.

Set syringe motor hold current (h<n>)

Note: For factory use only.

The [h] command sets the syringe's motor hold, or non-moving, current to the value <n> specified in percent of maximum. On power-up, this value is overwritten to the factory set default argument.

Arguments:

<n> 0...100   % of maximum current
     {10}   Power-up default set at factory

Set syringe motor run current (m<n>)

Note: For factory use only.

The [m] command sets the syringe motor run, or moving current, to the value <n> specified in percent of maximum. On power-up, this value is overwritten to the factory set default argument.

Arguments:

<n> 0...100   % of maximum current
     {75}   Power-up default set at factory, C3000/C3000MP
     {50}   Power-up default set at factory, C24000/C24000MP

Configuring auxiliary outputs

Set auxiliary outputs (J<n>)

The [J] command sets the three auxiliary TTL outputs high or low.

Arguments:

<n>	0...7	(See table below)
	(0)	Default argument
	{0}	Power-up default

The C-Series pump provides three TTL outputs on connector JP3 (pins 13, 14, and 15), which correspond to outputs 1, 2, and 3 in the table below. The states of the outputs form a binary equivalent to the [J] command argument. They are controlled by the [J] command as follows:

Argument <n> options:

<n> options	Output 3 (pin 15)[1]	Output 2 (pin 14)	Output 1 (pin 13)
0	0	0	0
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

1. (0 = low, Gnd; 1 = high, +5VDC)

Set auxiliary outputs based on plunger position (j<pppp><n>)

The [j] command sets the three auxiliary TTL outputs to the specified state <n> when the actual plunger position is less than or equal to the specified syringe position <ppppn>.

Arguments:

<pppp>	See below	Position value, where auxiliary outputs will be set when the syringe position is less than or equal to this value. The position value is measured from top of stroke, which has a value of zero. Possible argument values are the same as for the [A] command.
<n>	0...7	Sets TTL output state. Argument works the same as in the [J] command.

Arguments for C3000/C3000MP:

<pppp>	0...3000	Position value in N0 mode (increments)
<pppp>	0...24000	Position value in N1 or N2 mode (micro-increments)

Arguments for C24000/C24000MP:

\<n\>	0...24000	Position value in N0 mode (increments)
\<n\>	0...192000	Position value in N1 or N2 mode (micro-increments)

Typically, this command is used during a dispense operation to provide an early trigger to another pump to begin dispensing. This allows for continuous dispense flow using two pumps.

For example, using the following string:

[J0IA3000j5007OA0GR]

Breakdown:

J0	Set all 3 auxiliary outputs low.
I	Move valve to input position.
A3000	Aspirate: move syringe down to bottom of stroke.
j5007	Set all 3 auxiliary outputs high (binary equivalent of the number 7) when syringe position is less than or equal to 500.
O	Move valve to output position.
A0	Dispense: move syringe up to top of stroke (position 0). Auxiliary outputs will change state when syringe position is less than or equal to 500.
G	Repeat continuously until terminated.
R	Execute command string.

For a complete continuous flow example, see "Dual pump continuous flow application" (page 168).

Execution control commands

Execute command or program string (R)

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] command string.

All commands, except report commands and most execution control commands, must be followed by an [R] (Run or Execute) command.

- 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 string in the buffer. Sending another [R] will not repeat the program string that was previously executed.

Execute the last command string (X)

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

Notes:

- An [X] will not run a command in the buffer unless the command includes an [R].
- The [X] command will repeat strings that contain the looping commands [g] and [G]. The [X] command cannot be included within a looped string.

Repeat command sequence, or loop (G<n>)

This command repeats a command or program string the specified number of times. The [G] command can be specified to repeat up to 30,000 times. The [G] command can be used with the [g] command to nest up to 10 loops.

Arguments:

| <n> | 0...30000 | Number of times to repeat loop |
| | (0) | Default argument (repeat forever) |

Note: With a [GR] or a [G0R], the sequence is repeated continuously until a [T] terminate command is issued.

Example:

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

Mark start of a repeat sequence, or loop (g)

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). The [g] command can be used with the [G] command to nest up to 10 loops.

Example of loop nesting:

[A0gP50gP100D100G10G5R]

Breakdown:

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	Go to inner loop start, repeat 10 times.
G5	Go to outer loop start, repeat 5 times.
R	Execute command string.

Delay command execution (M<n>)

The [M] command delays execution of a command for <n> milliseconds. This command is typically used to allow time for liquid in the syringe and tubing to stop oscillating, thereby enhancing precision.

Arguments:

<n>	0...30000	Milliseconds
	(0)	Default argument

Halt command execution (H<n>)

The [H] command is used within a program string to halt execution of the string and wait for a specified condition. To resume execution, an [R] command or TTL signal must be sent. Two TTL inputs are available: Input 1 (JP3 pin 7), and Input 2 (JP3 pin 8).

Arguments:

<n>	0...2	(See table below)
	(0)	Default argument

<n> options	Description
0	Halt and wait for [R] or falling edge on either Input 1 or 2.
1	Halt and wait for [R] or falling edge on Input 1.
2	Halt and wait for [R] or falling edge on Input 2.

Note: Both inputs are pulled up to +5V.

The status of the TTL input lines can be read using [?13] and [?14]. The response of the [H] command to the TTL inputs are set by the EEPROM [u16_x] debounce setting. See details on page 80.

The default configuration is that the inputs are falling-edge sensitive for the [H] command. That is, after the [H] command, if the respective input transitions from high to low, operation will resume.

Example:

[ZgH1IA1000H2OA0G0R]

The pump initializes, halts and waits for the trigger, or low signal on Input 1, then aspirates 1000 increments. It then waits for a low on Input 2 before dispensing.

Breakdown:

Z	Initialize pump.
g	Start loop.
H1	Halt and wait for falling edge on input 1.
I	Move valve to input position (aspirate).
A1000	Move syringe to position 1000.
H2	Wait for falling edge on Input 2.
O	Move valve to output position (dispense).
A0	Move syringe to position 0.
G0	Loop back to [g], run continuously until terminated.
R	Execute command string.

Note: When using [H]<0> and using only one input with the other input left floating: since the unused input is pulled high, this eliminates the requirement for the active input to go high. The firmware will then respond to the low level on the active input. In this case, the inputs will appear to be level sensitive.

Aux input debounce, EEPROM u16_x, where x <=50.

Default value for this parameter is 0. Units are in ms (milliseconds).

Following the [H] command, the respective input must be high continuously for at least X milliseconds before a high-to-low transition can be recognized. Upon transition from high to low (falling edge), the input must remain low continuously for X milliseconds before the string will resume operation.

The auxiliary input debounce only functions if a specific input is selected. That is, it is only valid using [H<1>] or [H<2>]. It has no effect if using [H<0>]. If [H<0>] is used, the inputs are level-sensitive, not falling-edge sensitive.

Note: When debounce is set to zero, the inputs are level sensitive also.

Terminate an executing string (T)

The [T] command immediately terminates any executing command. All plunger movements are terminated immediately. Valve movements in motion are allowed to complete.

The [T] command is issued without inserting an [R].

If the command string that was terminated contains more than one move command, an [R] will resume the string at the command that follows the command that was terminated. The buffer status (via an [F] command) returns 0 after a [T] command is issued.

Note: An [X] command is not recommended following a [T] command, as the results will be unpredictable.

Abort plunger movement on input trigger (t<n>)

The [t] abort command is used before a plunger move command to specify auxiliary input conditions that will abort (stop) plunger movement.

This command can be used for an emergency stop based on external sensor conditions, for example.

Like a [T] terminate, an [R] following a [t] abort will resume plunger motion.

Arguments:

<n>   0...2   (See table below)
      (0)   Default argument

<n> options	Description
0	Abort on falling edge of either input 1 or 2.
1	Abort on falling edge of input 1.
2	Abort on falling edge of input 2.

Examples:

- [IA3000Ot1D3000R] aborts the dispense if input 1 goes low during the dispense.
- [tA3000OD3000R] only aborts the aspirate if input 1 goes low during the aspirate. If aborted, dispense is not executed. If aspirate is not aborted and the input goes low during dispense, the dispense is not aborted.
- [tA3000Ot2D3000R] aborts aspirate if input 1 goes low during aspirate, and aborts dispense if input 2 goes low during dispense.
- [t0A3000R] aborts the aspirate if either input goes low.
- [tD3000R] aborts the dispense if either input goes low.
- [tD3000R] if issued with either input low before the dispense starts, will not execute, but the plunger will require re-initialization.

Execute or skip next command based on aux inputs (x)

The [x] command executes the next command (or skip) based on the auxiliary inputs. If none of the input states specified by operands are met, the next command is skipped.

Arguments:

x<n>   0...3 (see table below)

<n> options	Input 2[1]	Input 1	Action
0	Low	Low	Will execute next command in the string buffer if Input 2 and Input 1 are held low. Otherwise skip.
1	Low	High	Will execute next command in the string buffer if Input 2 and Input 1 are set as indicated. Otherwise skip.
2	High	Low	Will execute next command in the string buffer if input 2 and Input 1 are set as indicated. Otherwise skip.
3	High	High	Will execute next command in the string buffer if Input 2 and Input 1 are both high. Otherwise skip.

1.   Input 1 is located on connector JP3 pin 7, and Input 2 is on JP3 pin 8.

Note: Auxiliary inputs are internally pulled high. Thus, if left floating, they will be high.

The [x] command, in conjunction with the [e] command, can be used as an IF...ELSE, IF...ELSE statement based on the auxiliary TTL inputs. This is especially useful in standalone operation.

Example: switch between strings based on input states

The example below allows a C3000/C3000MP in standalone mode to switch between three modes of operation depending on the states of Input 1 and Input 2. The pump is configured to AutoRun string 0 on power-up. (For more information on storing strings and using AutoRun, see "Standalone operation (AutoRun)" on page 90.)

- If Input 2 is low and Input 1 is high, [e1] will be executed. Thus, the pump will aspirate/dispense cycle 50 increments.
- If Input 2 is high and Input 1 is low, [e2] will be executed. Thus, the pump will aspirate/dispense cycle 1000 increments.
- If none of the above states of Input 2 and Input 1 are realized, [e3] will be executed. The pump will aspirate/dispense cycle a full stroke, 3000 increments.

Note: Using the [e] command in a string will force a jump to the specified string. It will not automatically return to the departure point once the "jumped to" string has completed.

The following four strings are programmed into the EEPROM locations 0, 1, 2, and 3 (the commands s0, s1, s2, and s3 store their strings in locations 0, 1, 2, and 3 respectively):

[s0Zx1e1x2e2e3R]

[s1gIA50OA0G0R]

[s2gIA1000OA0G0R]

[s3gIA3000OA0G0R]

Breakdown:

String 0 [e]:

s0   Store following in EEPROM location 0 (executed on power-up).

Z   Initialize pump.

x1   Execute next instruction if Input 2 is tied low and Input 1 is high (or left open).

e1   Jump to String 1.

x2   Execute next instruction if Input 2 is high (or left open) and Input 1 is tied low.

e2   Jump to String 2.

e3   Else, jump to String 3.

R   Run command string.

String 1 [e1]:

s1   Store following in EEPROM location 1.

g   Start loop.

I   Valve to input position (aspirate).

A50   Move syringe to position 50.

O   Valve to output position (dispense).

A0   Move syringe to position 0.

G0   Loop back to [g], run continuously until terminated.

R   Run command string.

String 2 [e2]:

s2   Store following in EEPROM location 2.

g   Start loop.

I   Valve to input position (aspirate).

A1000   Move syringe to position 1000.

O   Valve to output position (dispense).

A0   Move syringe to position 0.

G0   Loop back to [g], run continuously until terminated.

R   Run command string.

String 3 [e3]:

s3   Store following in EEPROM location 3.

g   Start loop.

I   Valve to input position (aspirate).

A3000   Move syringe full stroke to position 3000.

O   Valve to output position (dispense).

A0   Move syringe to position 0.

G0   Loop back to [g], run continuously until terminated.

R   Run command string.

Using EEPROM

EEPROM (Electrically Erasable Programmable Read-Only Memory) is used to store the following information:

- Up to 15 separate command strings. These strings can be executed under control of the host computer using the [e] command (below), or in standalone (AutoRun) mode (page 90).
- Pump configuration data that determines how the pump functions and communicates.

Note: EEPROM retains its content during power cycles.

Storing and executing command strings

Store program string in EEPROM (s<n>)

The [s] command is placed at the beginning of a program string to store the string in EEPROM.

Argument:

<n>   0...14 EEPROM location 0 through 14

Each stored string can contain up to 128 characters.

Example: [s2IA3000OA0R] loads the string beginning with [I] (valve to input) into memory location 2. To execute this string, issue the command [e2R]. It can also be run on power-up using AutoRun along with the address switch setting. See "Standalone operation (AutoRun)" (page 90).

To read back a programmed string stored in EEPROM, use [?30]-[?44] as shown in Table 5-8 (page 92).

Execute program string stored in EEPROM (e<n>)

The [e] command executes a string stored at EEPROM location <n>.

Argument:

<n>   0...14   EEPROM location of stored string

Example:

[e8R] will run the string stored in EEPROM location 8.

Linking program strings stored in EEPROM

Strings stored in EEPROM can be linked by ending one program string with an [e] command that refers to a second program string stored in another location.

Example program strings:

[sIZgIA3000OA0G5e2R]

[s2gIA3000OgH0D300G10GR]

- The first string loads an initialization and prime sequence into location 1 of EEPROM. It then links to string 2 in EEPROM.
- The second string loads an aspirate and dispense sequence into location 2 of the EEPROM. This string fills the syringe, then performs 10 dispenses of 300 increments each.

Due to the [H0], the dispenses are triggered by the proper auxiliary input, or an [R] command. This sequence is repeated endlessly until the pump is powered down.

If the AutoRun jumper is installed and the address switch is set correctly, on power-up the pump will automatically initialize, prime, and perform the multiple dispenses until it is again powered down.

Note: When linking program strings, a jumped-to string will not automatically return to the calling string. In the example above: [s1] jumps to [e2]. Once [e2] has executed, control will not return to the calling sting [s1]. Thus, [e] commands are normally placed at the end of a string just before the [R].

Executing long program strings using the [e] command

Break up commands

If a program string exceeds 128 characters, it can be broken down into parts stored in separate locations. The [e] command can then be used to run the different parts in the appropriate sequence.

For example, if the first part of a string resides in location 3 (s3) and the second part in location 4 (s4), the command [e4] would be placed at the end of s3. This would run the second part of the string (s4) after the first part was finished.

Virtually embed commands

Another way to limit the length of command strings sent to the pump is to use the [e] command to effectively embed commands in strings. For example, If the command [V2000] is used frequently, it could be stored in EEPROM location 0 by issuing [s0V2000]. Afterwards, this command could be called up and executed using [e0], as in the command string [e0AOR]. This would first execute [V2000], then the remaining commands in the string.

Setting system parameters

Set pump configuration (U<n>)

The [U] command sets pump configuration parameters into EEPROM. A power cycle is required to make these changes effective.

This command does not require an [R] to execute. The [U] command with arguments is shown in Table 5-4.

Table 5-4: Pump configuration set with U<n>

U<n> value	Description
O	Reserved for future use.
U1	3-port 120° Y valve Valve selection jumper on the back of the pump must also be installed.
U2	4-port 90° valve Valve selection jumper on the back of the pump must also be removed.
U3	Reserved for future use.
U4	3-way distribution valve that uses [I], [O], [B] and [E] commands.
U5	3-port and 4-port T valves
U7	6-way distribution valve (C3000MP and C24000MP only)
U8	Reserved for future use.
U9	4-port loop valve
U11	3-way distribution valves that use [I<n>] and [O<n>] commands
U30	Enable AutoRun mode. This setting performs the same function as the AutoRun jumper on the back of the pump. **Note:** If the AutoRun jumper is installed, it will override the EEPROM setting.
U31	Clear AutoRun mode. **Note:** If the AutoRun jumper is installed, it will override the EEPROM setting.
U51	Set CAN COM rate to 100K.
U52	Set CAN COM rate to 250K.
U53	Set CAN COM rate to 500K.
U54	Set CAN COM rate to 1M.
U57	Set CAN COM rate to 125K.

Set pump/system EEPROM configuration parameters (u<n_xxx>)

⚠CAUTION

CAUTION: For factory use only.

The [u] command sets pump configuration in EEPROM. Some of these parameters (AutoRun and CAN COM rate) can also be changed with the [U] command.

This command does not require an [R] to execute. The [u] command EEPROM settings can be reported using the [?27] command.

Table 5-5 shows the full range of settings, and Table 5-6 shows the effect of different settings.

Usage example: [u5_0] = Don't auto initialize valve.

Note: These parameters are read only on power-up. Thus they will only take effect when power is cycled.

Table 5-5: Pump configuration set with u<n_xxx>

Command	Description	C3000/ C3000MP factory default	C24000/ C24000MP factory default
u1_xxx	Motor hold current, 0-100% of maximum	10	10
u2_xxx	Motor run current, 0-100% of maximum	75	50
u3_xxx	Default V max and initialization speed in 100 increments/sec (1...60)	14	56
u4_xxx	Plunger stroke in increments * 100 (1...255)	62	248
u5_x	x = 0, Don't auto initialize valve. x = 1, Automatically initialize valve on power-up. x = 2, No valve circuitry installed on PCB.	0	0
u6_x	CAN COM rate 0 = CAN bus disabled 1 = 100K 2 = 125K 3 = 250K 4 = 500K 5 = 1M	1	1
u7_xx	Power-up default backlash in increments, [K] command (0...100)	20	80
u8_x	Number of increments to jam or stall the plunger into the top of the syringe during plunger initialization. (0...255)	10	10
u9_xxx	Power-up default zero gap in increments, [k] command (0...960)	24	384

u10_IOB	3 way valve position
	I = Input valve position (0-2)
	    Position 0 = 0 deg.
	    Position 1 = 120 deg.
	    Position 2 = 240 deg.
	O = Output valve position (0-2)
	B = Bypass valve position (0-2)
		210/840	210/840

Table 5-5: Pump configuration set with u<n_xxx> (continued)

Command	Description	C3000/ C3000MP factory default	C24000/ C24000MP factory default

u11_ IOBEXYZ	I = Input valve position (0-3)
	  Position 0 = 0 deg.
	  Position 1 = 90 deg.
	  Position 2 = 180 deg.
	  Position 3 = 270 deg.
	O = Output valve position (0-3)
	B = Bypass valve position (0-3)
	E = Extra valve position (0-3)
	X = Allow plunger movement while valve is in bypass position.
	  X = 1, allow movement
	  X = 0, don't allow movement
	Y = Allow plunger movement while valve is in extra position.
	  Y = 1, allow movement
	  Y = 0, don't allow movement
	Z = swap the bypass and extra position on a 4-position valve if a [Y] initialization command is issued.
	  Z = 1, Swap
	  Z = 0, Don't swap
		2130001/ 6390001	2130001/ 6390001

u12_x	x = 1, half-step/increment syringe motor resolution x= 0, full step/increment resolution **Note:** If set to half-step and in normal (N0) increment mode, stroke = 6000 increments (for C3000/C3000MP) If set to half-step and in (N1 and N2) micro-increment mode, stroke = 48000 increments (for C3000/C3000MP)	0	1
u13_x	x = 1, AutoRun mode x= 0, Regular mode This setting performs the same function as the AutoRun jumper on the back of the pump. If the AutoRun jumper is installed, it will override the EEPROM setting.	0	0
u14_x	x = number of ports on a distribution valve x = 0, Non distribution valve (0...7)	0	0
u15_x	x = 0, standard lead screw pitch x = 1, 1 mm lead screw pitch, 4X increment resolution x = 2, Not used x = 3, C3000 emulation mode	0	1
u16_x	De-bounce delay for trigger inputs in ms. After the [H] command, the respective Input must be high for at least x milliseconds before a low transition will be recognized. (0...50) Upon transition from high to low (falling edge), the input must remain low for x milliseconds before the string will resume operation. Only valid for [H]<1> or [H<2>]. Not valid for [H<0>].	0	0
u17_xx	Default init current in percent for full force initialization (1...100)	25	30
u18_xx	Default init current in percent for medium force initialization (1...100)	20	25
u19_xx	Default init current in percent for low force initialization (1...100)	15	20
u20_xx	Run current to hold current delay in 5 millisecond increments (5...255)	5	5
u21_xx	Max velocity allowed, Divided by 100	60	60
u22_xx	CAN common command operations x = 0, work only on addressed pump (default). x = 1, broadcast to all pumps on bus.	0	0

Table 5-6: Example full stroke variations based on [u] command selections

Configuration	Full stroke normal mode (N0)	Full stroke (N1 or N2 mode)
C3000/C3000MP Set to step mode (default settings) (u4_62, u12_0, u15_0)	3,000	24,000
C3000/C3000MP Set to half-step mode (u4_62,u12_1,u15_0)	6,000	48,000
C24000/C24000MP 1 mm lead screw pitch and half-step mode (default settings) (u4_248, u12_1, u15_1)	24,000	192,000

Calibrate encoder levels and store in EEPROM (n<x>)

Note: For factory use only.

Encoder voltage output levels can be calibrated and set into EEPROM.

The [n] command runs the pump through the calibration process, calculates the values, and stores them in EEPROM. These values can be read back using the [?21] report command.

Standalone operation (AutoRun)

In standalone operation, a host computer is not controlling the pump. On power-up, if the AutoRun jumper is installed, the string pointed to by the rotary address switch will be automatically executed. See Table 5-7, below.

Procedure

1. Store strings using the [s] command at the beginning of the string.

   This example stores programs into EEPROM locations 0 and 1, respectively:

   [s0ZIP1000H0OD1000R] stores string in EEPROM location 0.

   [s1ZIP500H0OD500R] stores string in EEPROM location 1.

   Note: An initialization command is required in any stored command string intended to be run at startup in standalone (AutoRun) mode, as shown above.

2. Install the AutoRun jumper on J2, as shown in Figure 4-2 (page 23).

3. Set address switch for string to be run. In the example above, if set to 0, the string in EEPROM location 0 will be run.

4. Power cycle the pump. To return to regular operating mode, remove the AutoRun jumper.

Table 5-7 shows the relationship between the strings stored with [s<n>] and the address switch settings.

Table 5-7: Address switch setting vs. stored strings for AutoRun

Address switch setting with AutoRun jumper installed	Stored string referenced (memory location)
0	s0 (string stored in memory location 0, and so forth)
1	s1
2	s2
3	s3
4	s4
5	s5
6	s6
7	s7
8	s8
9	s9
A	s10
B	s11
C	s12
D	s13
E	s14

Example stored program string for AutoRun:

[s8ZS1gIA3000H0OA0GR]

Breakdown:

s8	Loads following string into location 8 of EEPROM (address switch would be set to position 8).
Z	Initializes pump.
S1	Sets plunger speed.
g	Marks start of loop.
I	Moves valve to input position.
A3000	Moves plunger to position 3000.
H0	Halts operation until either TTL input goes low.
O	Moves valve to output position.
A0	Moves plunger to position 0.
G	Go to [g], repeat continuously until terminated.
R	Run command string.

Report (query) commands

Report commands report various pump parameters. The response is returned immediately and can be used when the pump is busy executing another command string. The report commands are listed in Table 5-8.

Note: Report commands do not require an [R] command.

Table 5-8: Report commands

Report Command	Report description
? or RZ	Reports absolute position of plunger in increments as defined by N mode setting.
?1	Reports start velocity [v] in increments/sec as defined by N mode setting.
?2	Reports top velocity [V] in increments/sec as defined by N mode setting.
?3	Reports cutoff velocity [c] in increments/sec as defined by N mode setting.
?4 or ?5	Reports absolute position of plunger in increments as defined by N mode setting. Same as [?] or [RZ].
?6	For most valves, reports valve position expressed in mnemonics (i = input, o = output, b = bypass and e = extra). For the distribution valve using [I<n>] and [O<n>] or the 6-way distribution valve, [?6] reports the port number 1..X, where X is the number of ports.
?7	Reports acceleration/deceleration slope set using the [L] command, in units of 1,000 increments/sec^2 (increments as defined by N mode setting).
?10 or F	Reports command buffer status. Report values: 0 = buffer empty 1 = commands in buffer If a program string requiring an [R] command is sent to the pump without the [R] command, the string is loaded into the buffer and the buffer status becomes 1. If an [R] command is then sent, the command stored in the buffer will execute. If a command that is executing is terminated the status returned is 0.
?11	Reports plunger resolution/increment mode, as set by the [N] command: 0, 1 or 2.
?12	Reports backlash setting [K] in increments as defined by N mode setting.
?13	Reports status of auxiliary input #1 (JP3, Pin 7). Report values: 0 = low 1 = high
?14	Reports status of auxiliary input #2 (JP3, Pin 8). Report values: 0 = low 1 = high
?15	Reports number of pump initializations since last power cycle
?16	Reports number of plunger movements since last power cycle.
?17	Reports number of valve movements since last power cycle.
?18 or %	Reports number of valve movements since last [?18] or [%] command).

Table 5-8: Report commands (continued)

Report Command	Report description
?19	Reports whether or not pump has been initialized. Report values: 0 = not initialized 1 = initialized
?20 or #	Reports firmware checksum.
?21	Reports calibrate encoder levels.
?22	Non-functional. Always reports 255.
?23, &, or RV	Reports firmware version. Format is "C3000: MMDDYY" or "C3000MP: MMDDYY" where: MM = month DD = day YY = year **Note:** C3000 is the response regardless of whether the actual pump is a C3000/C3000MP or C24000/C24000MP configuration.
?24	Reports zero gap increments set with [k].
?25	Reports syringe motor hold current [h] in % of maximum
?26	Reports syringe motor run current [m] in % of maximum
?27	Reports the EEPROM configuration data set by the [u] command.
?28	Reports state of the 3-port valve jumper (J2, segment 5). 3 = 3-port valve; jumper installed. 4 = other valves, jumper not installed
?29 or Q	Reports system status. Reports error codes and pump status (idle or busy). Also see "Status and error codes"below.
?30	[s0] string. Reports command string stored in EEPROM location 0.
?31	[s1] string. Reports command string stored in EEPROM location 1.
?32	[s2] string. Reports command string stored in EEPROM location 2.
?33	[s3] string. Reports command string stored in EEPROM location 3.
?34	[s4] string. Reports command string stored in EEPROM location 4.
?35	[s5] string. Reports command string stored in EEPROM location 5.
?36	[s6] string. Reports command string stored in EEPROM location 6.
?37	[s7] string. Reports command string stored in EEPROM location 7.
?38	[s8] string. Reports command string stored in EEPROM location 8.
?39	[s9] string. Reports command string stored in EEPROM location 9.
?40	[s10] string. Reports command string stored in EEPROM location 10.
?41	[s11] string. Reports command string stored in EEPROM location 11.
?42	[s12] string. Reports command string stored in EEPROM location 12.
?43	[s13] string. Reports command string stored in EEPROM location 13.
?44	[s14] string. Reports command string stored in EEPROM location 14.
?60	Reports plunger home opto state, 1 is opto closed, 0 is opto open (not for MP pump version).
?76	Reports pump configuration in format "valve type/serial baud/CAN COM rate." For example: 3P-Y/9600/100K **Note:** Valve types are shown in Table 5-1 (page 51).

Status and error codes

The [Q] command reports error codes and pump status (idle 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.

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

> **⚠CAUTION**

CAUTION: All errors reported by the pump should be captured by the user's software and the physical cause corrected before continuing operation. Failure to do so may result in damage to the pump or adversely affect pump performance, and void the warranty.

Pump status bit

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

Bit 5 values:

1   Pump is idle. It is ready to accept new commands.

0   Pump is busy and will only accept report, terminate [T] or velocity [V] 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 Idle. Additionally, commands addressed to multiple pumps at once cannot be used to obtain pump status; each pump 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.

Error codes (bits 0-3)

Error codes describe problem conditions that may be detected when operating the C-Series Syringe Pump. The error codes are listed in Table 5-9 (page 96).

- Error codes are returned in the least significant four bits of the status byte (0-3). If an error occurs, the pump stops executing commands, clears the command buffer, and inserts the error code into the status byte.

- Some errors, such as plunger overloads, continue to appear until they are cleared by an initialization command. On a plunger overload, the device will not execute another plunger move command until it is reinitialized.

- The most recent error has precedence in the status byte. For example, if a command overflow occurs, a command overflow error results. If the next command causes an invalid operand error, the status byte reflects the invalid operand error.

Error types

The pump handles errors differently depending on the error type. There are four error types, described below and listed in Table 5-9 (page 96).

Immediate errors

These include:

- Invalid command
- Invalid operand
- Invalid checksum
- Plunger move not allowed
- Device not initialized

When a command is sent, the answer block immediately returns this type of error. Any subsequent [Q] command will not report the error.

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

Initialization errors

These include:

- initialization failure
- Device not Initialized

To ensure that the pump initialized successfully, send a [Q] command after the initialization [Z], [w], or [Y] command.

- If an error occurs during initialization, an initialization failure error will be returned in response to the [Q] command. The pump must be reinitialized until the [Q} command indicates successful initialization.
- If the response indicates both a successful initialization and that the pump is ready, subsequent move commands can be sent.
- If initialization is not successful, or if any plunger move command is sent prior to an initialization command, a device not initialized error is returned in response to the command.

Overload errors

These include:

- Plunger overload
- Valve overload

If the pump returns either of these errors when queried by a [Q] command, the pump must be reinitialized before continuing.

If another plunger or valve movement command is sent without reinitializing the pump, the initialization failure error will be returned.

Command overflow error

This error occurs when certain commands are sent to the pump while it is busy executing another command string. The pump ignores the new command and issues a command overflow error.

Any move, setting (except [V]), or valve commands that are sent while the pump is busy will cause this error to be issued.

Report, top velocity [V], and terminate [T] commands will not return a command overflow error. These commands are considered valid even when the pump is busy.

The [Q] command is used 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 type of error.

Table 5-9: Error codes, status byte with ASCII and hexadecimal values

Status Byte	Hex if Status Bit 5 =		ASCII if Status Bit 5 =		Error Code Description	
7 6 5 4 3 2 1 0	X= 0 (Busy)	X=1 (Idle)	X= 0 (Busy)	X=1 (Idle)	Number	Error type
0 1 X 0 0 0 0 0	40h	60h	@	`	0	No error
0 1 X 0 0 0 0 1	41h	61h	A	a	1	Initialization failure
0 1 X 0 0 0 1 0	42h	62h	B	b	2	Invalid command
0 1 X 0 0 0 1 1	43h	63h	C	c	3	Invalid operand
0 1 X 0 0 1 0 0	44h	64h	D	d	4	Invalid checksum
0 1 X 0 0 1 0 1	45h	65h	E	e	5	Unused
0 1 X 0 0 1 1 0	46h	66h	F	f	6	EEPROM failure
0 1 X 0 0 1 1 1	47h	67h	G	g	7	Device not initialized
0 1 X 0 1 0 0 0	48h	68h	H	h	8	CAN bus failure
0 1 X 0 1 0 0 1	49h	69h	I	i	9	Plunger overload
0 1 X 0 1 0 1 0	4Ah	6Ah	J	j	10	Valve overload
0 1 X 0 1 0 1 1	4Bh	6Bh	K	k	11	Plunger move not allowed
0 1 X 0 1 1 1 1	4Fh	6Fh	O	o	15	Command overflow

Error reporting examples

[A4000R]	Since <4000> is greater than the stroke of the C-Series pump, this returns an error immediately in the command response. When queried with the [Q] command, does not return error.
[A3000P3500R]	Moves to position 3000 then stops. The [P3500] is past the stroke of the C-Series pump; a [Q] command returns an error.
[e200R]	<14> is the maximum argument for [e]. It returns an invalid command error immediately in the command response. The pump status is Idle.
[BA1000R]	Since valve is in the bypass position, plunger movements are not allowed. This returns an error immediately. When queried with the [Q] command, an error is not returned.

Non-functional commands

The following commands have been included in the C-Series command set to make the pump backward compatible with other pumps. These commands are non-functional.

- Set threshold value for fluid detection (^<n>)
  Always returns 255.
- Clear run from EEPROM (b)

Command summaries

The following tables contain summaries of the commands for RS232/RS485 and CAN Bus communications as a convenient quick reference.

Note: In the following tables,

- "Default argument" is the one supplied if the command is issued without providing an operand.
- If no power-up default is shown, there is none.
- "N/A" means there is no operand for this command. Adding one will result in an invalid operand error.
- "None" means there is no default argument, and one must be supplied or an invalid command error will result.

RS232/RS485 command summary

Table 5-10: RS232/RS485 command summary

Command	Operand \<n\> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
Execution control commands					
R	N/A			Execute command string.	
x\<n\>	0...3	none		Execute next command in buffer based on auxiliary inputs. If input states specified by operand are not met, next command is skipped.	0 = Execute if input 2 is low and Input 1 is low. 1 = Execute if input 2 is low and input 1 is high. 2 = Execute if input 2 is high and input 1 is low. 3 = Execute if input 2 is high and input 1 is high.
X	N/A			Re-execute last executed command string. The [X] command will repeat strings that contain the looping commands [g] and [G]. The [X] command cannot be included in a looped string.	
G\<n\>	0...30000	0		Repeat command sequence (loop).	Number of loops to repeat 0 or no operand = Loop indefinitely
g	N/A			Mark the start of a repeat sequence (loop).	
M\<n\>	0...30000	0		Delay command execution.	Milliseconds
H\<n\>	0...2	0		Halt command execution and wait for [R] command, input state, or negative-going transition.	0 = Wait for [R] or either input 1 or 2 to go low. 1 = Wait for [R] or input 1 to go low. 2 = Wait for [R] or input 2 to go low.
T	N/A			Terminate executing command. Issue without [R]. Immediately terminates any executing command. Plunger movement is terminated immediately. Valve movements will complete. Issuing [R] will resume the string at next command if remaining portion of string contains a move command.	
t	0...2			Abort plunger movement on input trigger. Issuing [R] will resume the string at next command if remaining portion of string contains a move command. Plunger must be reinitialized after abort event.	0 = Abort on falling edge of either input 1 or 2. 1 = Abort on falling edge of input 1. 2 = Abort on falling edge of input 2.

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand \<n> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
Initialization commands					
Z\<n1>	0...40	0		Initialize plunger. Set valve to the right on non-distribution valves.	0 = initialize at full plunger force. 1 = initialize at half plunger force. 2 = initialize at one third plunger force. 3 = initialize at speed 16. 4 = initialize at speed 18. 5-9 = same as 0. 10-40 = initialize at defined plunger speed.
\<n2>	0...X	1		Set input port at initialization on distribution valves.	0 = port 1, counting clockwise X = number of output ports (Ignored on non-distribution valves.)
\<n3>	0...X	X		Set output port at initialization on distribution valves.	0 = port 1, counting clockwise X = number of output ports (Ignored on non-distribution valves.)
Y\<n1,n2, n3>	0...40	Same as Z \<n1, n2,n3>		Initialize plunger. Set valve to the left on non-distribution valves.	\<n1> same as [Z\<n1>] \<n2> same as [Z\<n2>] except counterclockwise \<n3> same as [Z\<n3>] except counterclockwise
W\<n>	0...40	Same as Z\<n1>		Initialize plunger without valve.	Same as [Z\<n1>]
w\<n1,n2>	\<n1> = 0...X \<n2> = 0...1 Not used, ignored	0	N/A	Initialize valve only. Valve is initialized as it would be via the [Z] command.	\<n1> 0...X = set input initialization port on distribution valves, clockwise from syringe port. X = number of ports on valve. 0 is same as 1. Ignored for non-distribution valves. \<n2> Not used, ignored
z\<n>	0...3000 N0 0...24000 N1/N2 (0...24000 N0 0...192000 N1/N2)	0		Set pump's internal position counter to value specified.	
k\<n>	0...120 N0 0...960 N1/N2	24 (384)	24 (384)	Set syringe zero gap increments.	
Plunger move commands					
A\<n>	0...3000 N0 0...24000 N1/N2	0		Move plunger to absolute position.	
a\<n>	(0...24000 N0 0...192000 N1/N2)	0		Move plunger to absolute position, not busy.	
P\<n>		0		Relative pickup	
p\<n>		0		Relative pickup, not busy	
D\<n>		0		Relative dispense	
d\<n>		0		Relative dispense, not busy	

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand <n> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
Valve commands					
I	N/A except as below. For distribution valves (3-way with U11 select and 6-way), <n> = desired distribution port #			• 3 and 4-port non-distribution valves and T valves: move to input position.* • Distribution valve (3-way with U4 selection): move to left/right port.* • Other distribution valves: move clockwise to specified port, • 4-port loop valve: move to input position.* *Direction determined by Z or Y initialization.	
O	N/A except as below. For distribution valves (3-way with U11 select and 6-way), <n> = desired distribution port #			• 3 and 4-port non-distribution valves and T valves: move to output position.* • Distribution valve (3-way with U4 selection): move to right/left port.* • Other distribution valves: move to specified port, numbered counterclockwise. • 4-port loop valve: move to output position.* *Direction determined by Z or Y initialization.	
B	N/A			• 3-port non-distribution valve: move to bypass position. • 4-port non-distribution valve: flush port to inlet port.* • T valve: move to bypass position. • 3-way distribution valve with U4 selection: move to top port. Same as [E] command. • Other distribution valves: N/A • 4-port loop valve: move to bypass position. *Direction determined by [Z], [w], or [Y] initialization.	
E	N/A			• 3-port non-distribution valve: N/A • 4-port non-distribution valve: flush to outlet.* • T valve: bypass input to outlet/bypass syringe. • 3-way distribution valve with U4 selection: move to top port. Same as [B] command. • Other distribution valves: N/A • 4-port loop valve: move to extra position. *Direction determined by [Z], [w], or [Y] initialization.	

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand <n> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
Set commands					
K<n>	0...100	10 (80)	10 (80)	Set backlash increments.	
L<n>	1...20 N0/N1 1...160 N2	none	14	Set acceleration/deceleration slope.	Slope code
v<n>	1...1000 N0/N1 1...8000 N2	none	900	Set start velocity in increments/sec.	
V<n>	1...6000 N0/N1 1...48000 N2	none	1400 (5600)	Set top velocity in increments/sec.	
S<n>	0...40	11	11	Set a defined speed for top velocity.	Speed code
c<n>	1...2700 N0/N1 1...21600 N2	none	900	Set cutoff velocity in increments/sec.	
C<n>	0...25		0	Set cutoff in increments	
N<n>	0...2	0	0	Set resolution/increment mode for positioning and velocity.	0 = Both position and velocity in normal increment mode. 1 = Micro-increment mode for positioning, and normal increment mode for velocity. 2 = Both position and velocity in micro-increment mode (8X normal mode).
J<n>	0...7	0	0	Sets the three TTL auxiliary outputs.	0 = all outputs low 7 = all outputs high <n> operand represents equivalent binary number created from resulting states of the three outputs, 1 through 3.
j<pppp><n>	<pppp> 0...3000 N0 0...24000 N1/N2 (0...24000 N0 0...192000 N1/N2) <n> 0...7	none none		Set auxiliary outputs based on plunger position.	Outputs are set to <n> value when plunger position < = <pppp>. <n> arguments same as for J<n>.
h<n>	0...100	Factory only	10	Set motor hold current in % of maximum	For factory use only.
m<n>	0...100	Factory only	75 (50)	Set motor run current in % of maximum	For factory use only.
^<n>	0...255			Non-functional command; always returns 255.	
b				Non-functional command	

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand <n> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
EEPROM commands					
s<n>	0...14	none		Store program string in specified EEPROM location.	EEPROM memory location
e<n>	0...14	none		Execute program string at specified EEPROM location.	EEPROM memory location
U		none		Set pump configuration parameters.	See "Pump configuration set with U<n>" (page 86)
u	1...16	Factory only		Set pump EEPROM system parameters.	For factory use only.
n<x>		Factory only		Calibrate encoder levels	For factory use only.
Report commands					
Q	N/A			Reports pump system status and error codes.	
?	N/A			Reports absolute plunger position.	
?0	N/A			Same as [?].	
?1	N/A			Reports start velocity in increments/sec.	
?2	N/A			Reports top velocity in increments/sec.	
?3	N/A			Reports cutoff velocity in increments/sec.	
?4	N/A			Reports absolute plunger position; same as [?].	
?5	N/A			Same as [?].	
?6	N/A			Reports valve position (i, o, b and e).	
?7	N/A			Reports acceleration/deceleration slope.	
?10	N/A			Reports command buffer status, same as [F].	
?11	N/A			Reports plunger resolution/ increment mode, as set by the [N] command: 0, 1 or 2.	
?12	N/A			Reports number of backlash increments as set by the [K] command.	
?13	N/A			Reports status of auxiliary 1 input.	
?14	N/A			Reports status of auxiliary 2 input.	
?15	N/A			Reports number of pump initializations since last power cycle.	
?16	N/A			Reports number of plunger movements since last power cycle.	
?17	N/A			Non-functional, will always report 1.	

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand <n> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
?18	N/A			Reports number of valve movements since last [?18]; same as [%].	
?19	N/A			Reports whether pump is initialized.	0 = not initialized 1 = initialized
?20	N/A			Reports firmware checksum; same as [#].	
?21	N/A			Reports calibrate encoder levels.	
?22	N/A			Non-functional; will always return 255.	Non-functional command to maintain backward firmware compatibility.
?23	N/A			Reports firmware version, same as [&].	
?24	N/A			Reports syringe zero gap increments as set by the [k] command.	
?25	N/A			Reports motor hold current in % of maximum	
?26	N/A			Reports motor run current in % of maximum	
?27	N/A			Reports configuration EEPROM data as set using the [u] command	
?28	N/A			Reports 3-port valve jumper installation.	3 = 3-port valve; jumper installed. 4 = Other valve types; jumper not installed
?29	N/A			Reports current status; same as [Q] command.	
?30…?44	N/A			Reports program string stored in specified EEPROM location. ?30 = s0, ?31 = s1, and so on through ?44	
?60				Reports plunger home opto state, 1 is opto closed, 0 is opto open (not for MP pump versions).	
?76	N/A			Reports pump configuration	Format: valve type/serial baud/CAN COM rate Example: 3P-Y/9600/100K
F	N/A			Reports command buffer status; same as [?10].	
&	N/A			Reports firmware version; same as [?23]. Format is "C3000: MMDDYY" or "C3000MP:MMDDYY"	
#	N/A			Reports firmware checksum; same as [?20].	
RZ	N/A			Reports absolute plunger position; same as [?].	

Table 5-10: RS232/RS485 command summary (continued)

Command	Operand \<n\> range	Default argument	Power-up default	Command description	Operand description
	( ) = C24000/C24000MP only				
RV	N/A			Reports firmware version; same as [?23].	
%	N/A			Reports number of valve movements since last report; same as [?18].	

CAN Bus command summary

Table 5-11: CAN Bus command summary

Command	Arguments	Command Description
On-the fly commands frame type = 0		
V	Same as RS232/RS485	Top velocity
T	N/A	Terminate
Action commands frame type = 1		
All RS232/RS485 commands, with the exception of Report commands, are valid action commands in CAN bus mode.		
Common commands frame type = 2		
0	N/A	Reset mode
1	N/A	Start loaded command in buffer.
2	N/A	Clear loaded command in buffer.
3	N/A	Repeat last command; same as [X].
4	N/A	Stop action immediately; same as [T].
Report commands frame type = 6 (same as RS232/485 report commands preceded by "?")		
0	N/A	Reports plunger position; same as [?4]
1	N/A	Reports plunger position; same as [?4].
2	N/A	Same as report command [0].
3	N/A	Reports valve position; same as [?6].
4	N/A	Reports top velocity; same as [?2].
6	N/A	Reports start velocity; same as [?1].
7	N/A	Reports cutoff velocity; same as [?3].
10	N/A	Reports buffer status; same as [F].
12	N/A	Reports backlash increments; same as [?12].
13	N/A	Reports input 1 status; same as [?13].
14	N/A	Reports input 2 status; same as [?14].
15	N/A	Non-functional; will always report 1.
16	N/A	Non-functional; will always report 1.
17	N/A	Non-functional; will always report 1.
18	N/A	Reports number of valve movements since last report; same as [?18].
19	N/A	Reports whether pump is initialized. 1 = initialized, 0 = not initialized. Same as [?19].
20	N/A	Reports firmware checksum; same as [?20].
22	N/A	Non-functional command to maintain backward firmware compatibility. Will always return 255.
23	N/A	Reports firmware version; same as [&].
24	N/A	Reports syringe zero gap increments; same as [?24].
29	N/A	Reports system status; same as [Q].

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6   Maintenance

About this chapter

This chapter provides maintenance information for the C-Series Syringe Pump.

The following parts are included:

- About this chapter, page 107
- Routine maintenance, page 107
- Replacing components, page 108

Routine maintenance

Table 6-1: Maintenance Activities

Frequency	Activity	Comments
Daily	Inspect syringe seals and valves for leaks and proper operation. Look for fluid dripping from the fittings, syringe port, or syringe seal. Also look for air bubbles in the syringe, which would indicate leaking at these interfaces.	Replace as required.
Daily	Inspect tubing fittings for leaks.	Tighten or replace as required.
Daily	Inspect for any fluid or material on outside of pump.	Clean as required.
As needed	Park inactive syringes.	Flush with distilled water at end of use, and place syringe full of system fluid in full down position.

Replacing components

Replacing syringe

Before starting

Prime with air to remove all fluid from the syringe.

Remove syringe

Refer to Figure 6-1 for this procedure.

1. Lower the syringe plunger arm/holder to ensure sufficient room to remove the syringe.
   - C3000 pumps: if the pump is powered off, manually lower the plunger by pushing firmly down on the syringe plunger arm/holder. If the power is on, this can be done by sending the [A3000R] command.
   - C24000 pumps: with the power on, send the [A24000R] command. The plunger cannot be manually lowered on the C24000 pump due to the high resolution of the drive system.

2. Twist the plunger lock screw counterclockwise at least two full turns (do not completely remove the plunger lock screw).

3. Turn the syringe counterclockwise and remove from the valve.

4. Push the syringe down over the plunger.

5. Remove the syringe with plunger from syringe plunger arm/holder.

6. To install the replacement syringe, follow the steps in "Install new syringe" below.

Install new syringe

Note: The C24000 pumps must be initialized before the syringe can be installed. This is because these pumps cannot be moved manually. For C24000 pumps, first go to "Initialize pump" (page 33) and return to this procedure after initialization has been performed.

Refer to Figure 6-1 during this procedure.

1. Lower the syringe plunger arm to ensure sufficient room to install the syringe and plunger.
   - C3000 pumps: if the pump is powered off, manually lower the plunger by pushing firmly down on the syringe plunger arm. If the power is on, this can be done by sending the command [A3000R].
   - C24000 pumps: with the power on, send the command [A24000R]. The plunger cannot be manually lowered on the C24000 pump due to the high resolution of the drive system.

2. Make sure the plunger is fully seated in the syringe, to ensure the length is short enough to fit into the available space.
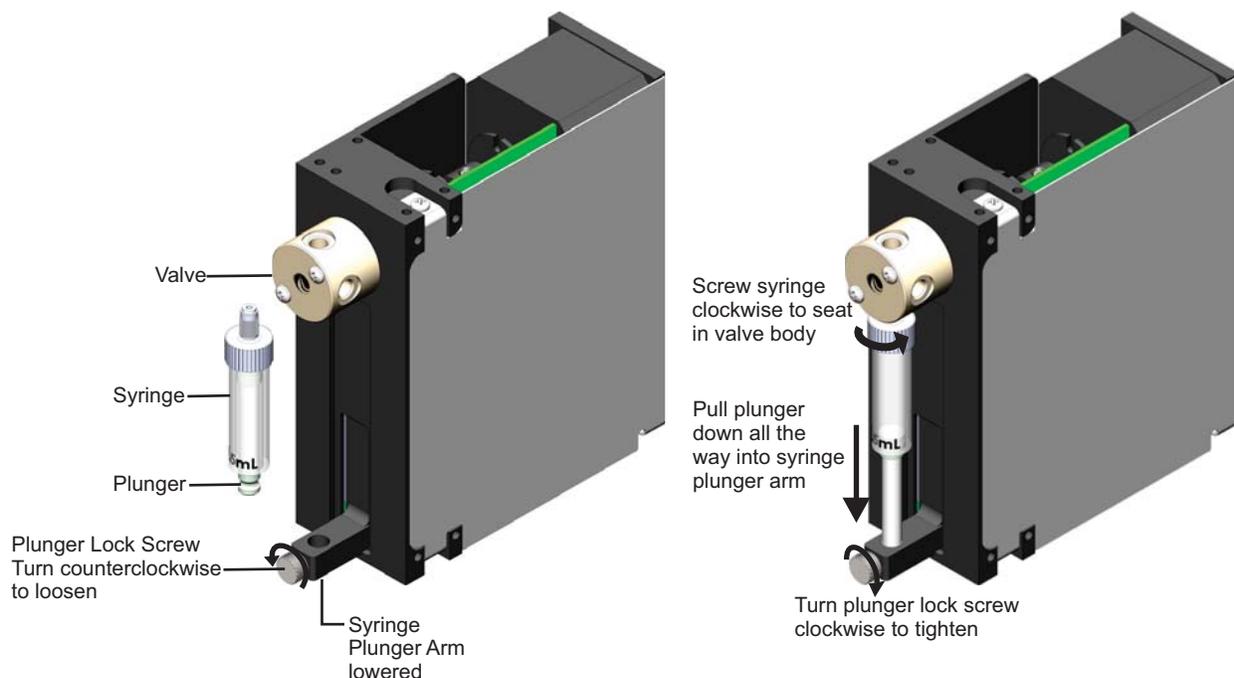
⚠**CAUTION**

CAUTION:

– Do not overtighten the syringe or fittings. This can cause damage to the syringe and valve, which can lead to leakage and reduced life. Do not exceed 21 oz-in. torque on either the syringe or fittings.

– Do not use Teflon® tape on syringe or fitting threads. All syringe port seals are face seals (not thread sealing). Use of Teflon® tape can lead to valve damage due to over stress on the valve seat from excessive torque applied to the syringe or fittings.

3. Screw the threaded portion of the syringe clockwise into the valve (hold the syringe by the knurled portion when screwing it into the valve).

4. Tighten the syringe until it bottoms in the valve, then tighten another 1/4 turn (this roughly corresponds to 16 oz-in). If a more secure installation is needed, loosen the syringe and repeat the process approximately 24 hours later. *The maximum torque specification is 21 oz-in.*

⚠**CAUTION**

CAUTION: Do not exceed the maximum torque specification of 21 oz-in. This can cause damage to the syringe and valve, which can lead to leakage and reduced life.

5. Pull the plunger down and fully seat it into the syringe plunger arm.

6. Securely tighten the plunger lock screw by turning clockwise.

Figure 6-1. Installing syringe

Replacing valve

⚠CAUTION

CAUTION: If you would like to replace your current valve with a valve of a different kind or type, please first contact Customer Service for assistance. There are some important factors to consider in order to avoid damaging the equipment.

Before starting

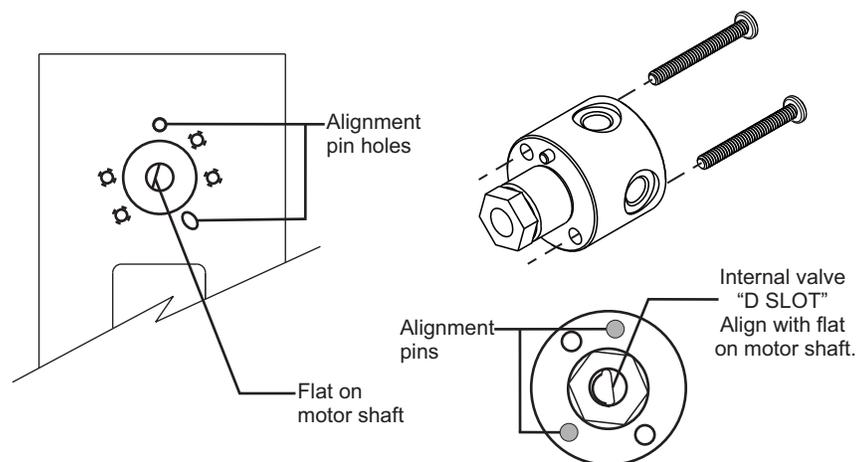Prime with air to remove all fluid from the syringe.

To remove the valve

1. Remove syringe as described on page 108.
2. Disconnect the tubing from the valve.
3. Remove the two screws used to secure the valve to the panel.
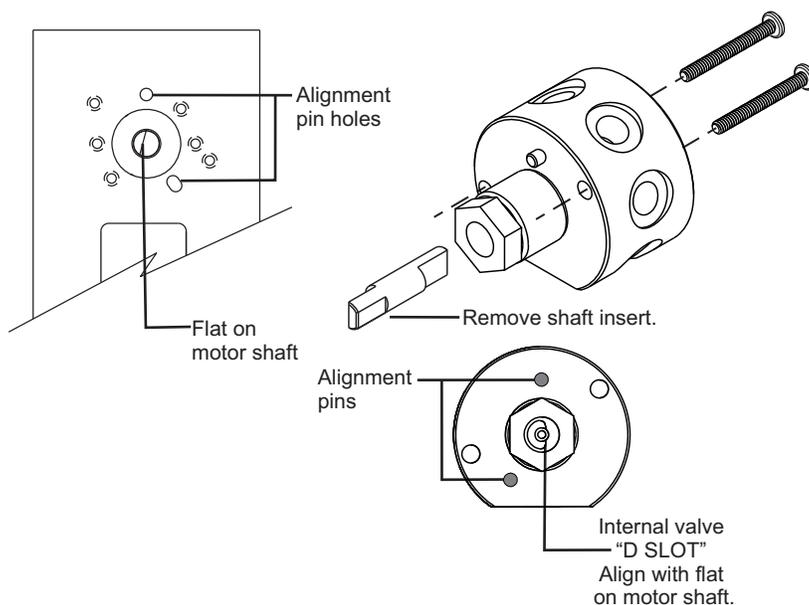4. Remove the valve from the pump by pulling directly away from the pump's front face.

To install the new valve

Refer to Figure 6-2 or 6-3 below.

1. If a 6-way distribution valve (6WD) is being replaced, remove the shaft insert from the valve as shown in Figure 6-3. Discard the shaft insert.
2. Alignthe internal valve "D" slot with the flat on the motor shaft.
3. Gently push and rotate the valve into the correct position to align the pins with the holes in the panel.
4. Replace the two screws that secure the valve to the pump.

Figure 6-2. Common valve interfaces

Figure 6-3. 6WD valve interface (C3000MP and C24000MP only)

Alignment pin holes

Flat on motor shaft

Remove shaft insert.

Alignment pins

Internal valve "D SLOT" Align with flat on motor shaft.

5. Replace tubing fittings and tubing according to your instrument design and the tubing supplier's instructions. Verify fittings are fully seated and finger tight.

> ⚠**CAUTION**
>
> **CAUTION:** When replacing syringe and tubing, do not exceed the maximum torque specification of 21 oz-in for both the tubing fittings and the syringe. Exceeding this maximum torque can cause damage to the syringe and valve, which can lead to leakage and reduced life.

6. Replace syringe as described in "Install new syringe" (page 108).

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7   Troubleshooting

About this chapter

This chapter provides diagnostic and troubleshooting information for the C-Series Syringe Pump.

The following parts are included:

- About this chapter, page 113
- Performing diagnostic self-test, page 114
- Symptoms and solutions, page 115
- Error codes and corrective action, page 117

Performing diagnostic self-test

During the self-test, the pump initializes, then cycles repeatedly through a series of plunger movements. If an error condition occurs, the pump stops moving.

To perform the self-test:

1. Turn power off.

2. Turn the address switch to the F position.

3. Install the AutoRun jumper on J2. For location of the AutoRun jumper, see Figure 4-2 (page 23).

4. Turn power on.

5. If errors are experienced, refer to "Status and error codes" (page 94).

6. Return address switch and AutoRun jumper to their normal position when finished.

Symptoms and solutions

See Table 7-1 for common symptoms and their remedies. Also see Table 7-2 for any error codes that are received.

Table 7-1: Troubleshooting

Symptom	Possible cause(s)	Corrective action
Unit runs automatically	Address switch and jumpers set incorrectly	• Verify proper address switch setting. See "Set configuration jumpers and address switch" (page 22). • Verify AutoRun jumper on J2 is removed. See Figure 4-2 (page 23).
No response to host commands	Pump not receiving power	• Check 24VDC power supply. • Verify LEDs lit on pump. • Check cables (broken or unconnected wires, connectors properly seated, proper connections per pinout diagram). For pinout, refer to "Pin assignments and mating connector information" (page 24).
	No communications to pump	• Verify proper COM port is selected on host computer. • Verify any external RS485 or CAN converter is working properly. • Verify proper pump address is selected. See "Address switch setting" (page 22). • Verify proper baud rate setting is selected. See "Configuration jumpers" (page 22) and "CAN COM rate" (page 22) and Table 5-4 (page 86). • Verify that execute command [R] is being sent at end of move command strings. • If DT mode is in use, verify that carriage return (ODh) is inserted at end of command string following [R] command. • If OEM mode is in use, make sure STX and ETX characters are in the string, and checksum is generated correctly. See "OEM communication protocol" (page 125).
Pump does not complete initialization command. ⚠CAUTION When replacing syringe and tubing, do not exceed the maximum torque specification of 21 oz-in for both the tubing fittings and the syringe. Exceeding this can damage the syringe and valve, causing leakage and reduced life.	Syringe not installed correctly and obstructs motion	• Verify pump initializes without syringe installed. • Reinstall syringe. See "Replacing syringe" (page 108).
	Damaged PCBA (motor connection or sensor issues)	Contact Customer Service.
	Fluid obstruction	Check fittings, look for kinked or obstructed tubing, and probe for other obstructions.

Table 7-1: Troubleshooting (continued)

Symptom	Possible cause(s)	Corrective action
Fluid leaking	Syringe not installed correctly	Reinstall syringe. See "Replacing syringe" (page 108).
	Fittings not installed correctly	Verify fittings are fully seated and finger tight.
	Tubing damaged or broken	Replace tubing.
	Excessive back pressure	Remove/reduce restriction in fluid path (e.g., kinked or blocked tubing). Reduce plunger speed.
	Syringe or valve has exceeded its useful life. (Some valves have a "weep hole" located at bottom of valve behind the syringe port. Fluid coming from this location indicates valve failure.)	Replace syringe or valve. See "Replacing syringe" (page 108) or "Replacing valve" (page 110).

Error codes and corrective action

Table 7-2 lists the error codes and corrective action for each.

Table 7-2: Error codes and corrective action

Error Code	Error LED pattern	Error	Description/possible cause(s)	Corrective action
1	1 blink	initialization failure	Failure occurred during initialization.	See "Pump does not complete initialization command" in Table 7-1.
2	N/A	Invalid command	An unrecognized command was issued.	Correct the command. Refer to "Operating instructions" beginning on page 39.
3	N/A	Invalid operand	An invalid argument (<n>) was included with a command. Command parameters out of valid range.	Correct the argument and pump operation will continue normally. Refer to "Operating instructions" beginning on page 39.
4	N/A	Invalid checksum	Checksum generation is incorrect. In OEM mode, the checksum did not match the received string.	Verify checksum calculation.
			Noise on communication lines	Check communication signals; use repeat and resend command.
			Damaged cable	Check all cables and connections.
6	2 blinks	EEPROM failure	Data is faulty on PCBA, indicating faulty EEPROM.	Contact Customer Service.
7	N/A	Device not initialized	Initialization command not sent before using the pump	Initialize the pump.
			Pump failed previous initialization command	See "Pump does not complete initialization command" in Table 7-1.
8	N/A	CAN bus failure	Cabling issue	Verify cables, and that all connectors are fully seated. See "Cabling" (page 19).
			Incorrect communication rate	Verify communication rate settings match on pump and host computer. See "Setting system parameters" (page 86).
9	3 blinks	Plunger overload	Plunger movement is restricted	Verify syringe is installed properly. See "Replacing syringe" (page 108). Reinitialize pump to allow normal operation to resume.
			Excessive back pressure	Remove/reduce restriction in fluid path (kinked tubing, etc.). Reinitialize pump to allow normal operation to resume.
			Damaged or dirty encoder sensor	Contact Customer Service.
			Damaged PCBA (printed circuit board) or faulty motor connection	Contact Customer Service.
10	4 blinks	Valve overload	Valve drive has lost steps for unknown reason.	Reinitialize pump and send new valve command.
			Excessive torque required to move valve.	Remove valve, re-install, and retry.
			Valve failure	Contact Customer Service.
			Damaged PCBA (motor connection or sensor failure)	Contact Customer Service.
11	N/A	Plunger move not allowed.	Valve is in the bypass position.	Move valve to a position where syringe is not blocked.

Table 7-2: Error codes and corrective action (continued)

Error Code	Error LED pattern	Error	Description/possible cause(s)	Corrective action
15	N/A	Command overflow	Command string is too long. (command buffer limit is 255 characters)	Reduce length of command string. Also see "Executing long program strings using the [e] command" (page 85).
			Host computer sends command before pump is ready. (pump may be busy executing another command)	Before sending, verify pump is ready by polling with the [Q] command.

8 Customer support

About this chapter

This chapter provides the instructions you need to obtain Customer Service assistance, order parts and accessories, and return equipment for warranty service.

Contacting Customer Service

You may obtain assistance with the operation or repair of your product by contacting us at any of the following locations:

Americas	Tricontinent Scientific, Inc. 12740 Earhart Avenue Auburn, CA 95602 USA Tel: +1 800 937 4738 Tel: +1 530 273 8888 liquidhandling.tcs@irco.com
Asia Pacific	Gardner Denver Thomas Pneumatic Systems (Wuxi), Co., Ltd. No. 1 New Dong An Road Shuafang Town Wuxi, Xinwu District Jiangsu 214142 China Tel: +86 510 6878 2258 tricontinent.cn@irco.com
EMEA (Headquarters)	Gardner Denver Thomas GmbH Livry-Gargan-Str. 10 82256 Fürstenfeldbruck Germany Tel: +49 8141 2280 0 thomas.de@irco.com
Website:	http://www.tricontinent.com

Ordering parts and accessories

To view and/or download detailed product and accessory information and literature, please go to the product page for the C-Series Syringe Pump at www.tricontinent.com. Typical Information at this location may include the following:

- Specifications
- Dimensions
- Ordering information
- Models and eDrawings
- Product and accessory ordering information
- Product literature and drawings, data sheets
- Links to associated drivers, etc. as appropriate

To order parts and accessories, contact Tricontinent using any of the methods listed on the preceding page.

Warranty and return information

The C-Series Syringe Pump is warranted against manufacturing defects for a period of one year. For detailed warranty and return instructions, please go to the product page for the C-Series pump at www.tricontinent.com.

Please observe:

DO NOT ship the instrument back for repair until you are advised to do so by Customer Service and have been issued an RMA number.

DO NOT perform any unauthorized repairs.

There is no warranty expressed for syringes and plungers on products that contain these items.

⚠CAUTION

CAUTION: Avoid shipping pumps to Tricontinent with syringes installed. During transport, shock and vibration can be transmitted directly to the syringe.

This can lead to glass breakage, loosening of syringes from their threaded ports, and potentially other problems. Syringes should always be shipped separately inside their original packaging for the highest level of protection from damage. Using the pumps' original packaging is insufficient.

For example, when shipping pumps that have been installed in an instrument, syringes should be removed and shipped in their individual packaging as described above.

9   Reference information

About this chapter

This chapter contains reference information to support use of the C-Series Syringe Pump.

The following subjects are included:

- About this chapter, page 121
- Pump addressing scheme, page 122
- OEM and DT timing and polling guidelines, page 123
- OEM communication protocol, page 125
- Data Terminal (DT) protocol, page 130
- CAN interface communications, page 132
- TCS Pump Commander overview, page 146
- Evaluation cables and accessories, page 153
- PTFE vs. UHMWPE for syringe seals and valve plugs, page 157
- Calculating flow rates, page 158
- Chemical compatibility chart information, page 160
- Precision and accuracy, page 162
- Optimizing pump performance, page 164
- Optimizing tubing performance, page 166
- Dual pump continuous flow application, page 168

Pump addressing scheme

As part of the communications protocol, every command string contains an address for the intended pump(s).

The address corresponds to a device number set by the address switch on the pump. There are 15 possible addresses on the pump. For RS232, RS485, and CAN, the overall hexadecimal addressing scheme is shown in Table 9-1. For RS232 and RS485 only, device settings with corresponding hex and ASCII values are shown in Table 9-2. For RS232 and RS485, the master address is always "0" (0x30). Thus the device addresses start at 1 and the pump address switch settings correspond to addresses 1-15. On a CAN bus, the master has no address. The pumps have addresses 0-14 (pump address is zero indexed).

Note: Information for address switch settings are located at "Address switch setting" (page 22) and Figure 4-2 (page 23). Command structure is described on page 41.

Note: CAN buses have no master address because the master device is predetermined by the CAN message direction bit—not by an address setting.

Table 9-1: Hexadecimal addressing scheme, RS232/485 and CAN

Address (hex)		
RS232/RS485	**CAN**	**Device**
30	N/A	Master address (master controller, host, personal computer, etc)
31...40	0...F	Addresses single device.
41...5F	N/A	Addresses multiple devices. See Table 9-2.

Table 9-2: Device addressing values for RS232/485

Device number[1]	Single Device		Dual Device		Quad Device		All Devices	
	Hex Address	ASCII Address	Hex Address	ASCII Address	Hex Address	ASCII Address	Hex Address	ASCII Address
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							

1. Assigned by switch on pump.

Note: Multiple-device addresses (Dual, Quad, All) cannot be used to query device status or to issue report commands. Each device must be queried separately. Were it not so, all the addressed devices would attempt to respond at once.

Notice that the RS232/485 protocols allow multiple-device addressing. A user can address single pumps, two pumps (Dual Device), four pumps (Quad Device), or all 16 pumps (All Devices). Address 5Fh (All Devices), for example, can be used to perform a simultaneous initialization on all pumps. Afterwards, each pump can be addressed individually using 31h through 3Fh.

OEM and DT timing and polling guidelines

Master/slave relationship

- For OEM and DT protocol, the host controller (host) and pump have a master/slave relationship. The pump never sends a message to the host independently; it is always in response to a host message. Every message "packet" has start and end characters that are protocol-specific. The host must receive and decode the response message from the pump before it can send a new message packet to the pump. See "OEM communication protocol" and "Data Terminal (DT) protocol" in the Reference information chapter for details.

  - Sending additional command packets to the pump while it is in the process of reading a packet from the RS232 or RS485 UART FIFO or in the process of transmitting a packet back to the host will result in communication errors. Observe OEM or DT messaging handshake rules.

  - All signaling, including status polling, fits within the timing framework described in "Signal timing" below. Observe included recommendations.

Signal timing

Following is a representative timing diagram of the master/slave communication process, with best-practice recommendations for associated timing parameters.

Figure 9-1. Master/slave timing
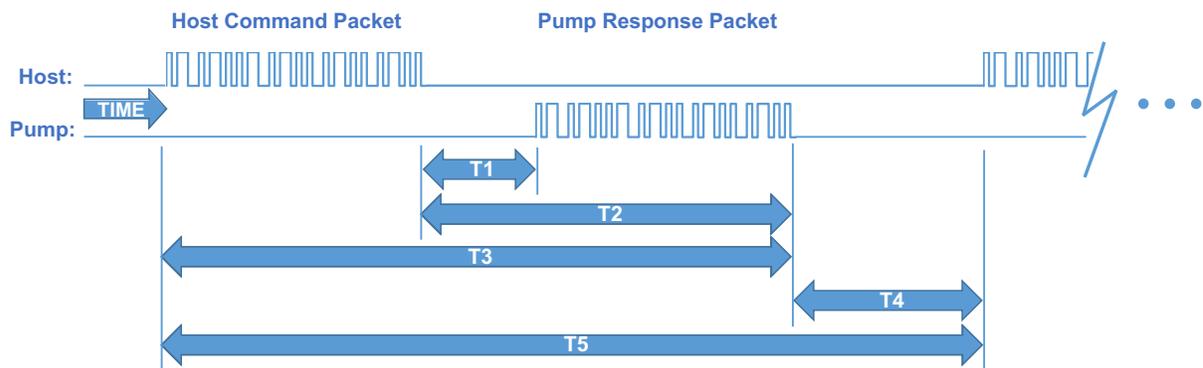
Timing intervals shown in Figure 9-1:

- *T1: time for pump to begin responding.* Can vary due to pump processing load (ongoing fluid operations, calibration commands), but is typically several milliseconds.

- *T2: time for pump to finish responding.* Can vary depending on the length of the response string and baud rate.

- *T3: time for a total round trip master/slave message packet exchange.* Can vary based on command and response string length and baud rate.

- *T4: delay time for the pump to transition from sending a response packet to waiting for the next host command packet.* This period should be at least 10 ms, but 50 ms or greater is recommended so as to avoid over-burdening the pump with polling communications.

- *T5: timeout period after which, if the host has not received a response from the pump, an error code should be generated.* This timeout period should typically be 250 ms or greater. At this point the host should query the pump for an error code and process accordingly.

Polling alternatives

- CAN bus communication is event driven, making polling unnecessary. Also, CAN bus bandwidth is much higher.

OEM communication protocol

OEM communication is a robust protocol that identifies transmission errors. Table 9-3 describes each setting within the OEM communication protocol.

Table 9-3: OEM Protocol communication details

Serial bus configuration

Parameter	Setting
Baud Rate	9600 or 38400
Data Bits	8
Parity	None
Stop Bit	1

Command Block
(see "OEM protocol command block characters" for details)

Byte number	Byte name
1	SYNC (FFh)
2	STX (Ctrl B or 02h)
3	Pump address
4	Sequence Number/Repeat flag
5+n	Data block (length n bytes)
6+n	ETX (Ctrl C or 03h)
7+n	Checksum

Answer Block
(see "OEM protocol answer block characters" for details)

Byte number	Byte name
1	SYNC (FFh)
2	STX (Ctrl B or 02h)
3	Master address (0 or 30h)
4	Status/error code
5+n	Data block (length n bytes)
5+n	ETX (Ctrl C or 03h)
7+n	Checksum

OEM protocol command block characters

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

SYNC (FFh)

Used for backward compatibility with older model pumps.

STX (Ctrl B or 02h)

The STX character indicates the beginning of a command string.

Pump address

The pump address is specific, selected on each individual pump, as described in the instructions for that pump.

Sequence number/repeat flag

The sequence number is a single byte that conveys both a sequence number (legal values: 0 through 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 the error detection 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 number 1 to the pump.
2. The pump receives the command, sends an acknowledgment to the PC, and executes it.
3. Transmission of the acknowledgment message is imperfect; the PC does not receive it.
4. The PC waits 100 ms for the acknowledgment, 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 acknowledgment to the PC, but does not execute the command (since it has already been executed as indicated by the repeat bit).

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

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

Scenario 2

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

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

3. The PC waits 100 ms for the acknowledgment 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 acknowledgment to the PC. It then executes the command.

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

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

Scenario 3

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

2. The pump receives the command and computes the checksum. The checksums do not match.

3. The pump acknowledges the command with a checksum error.

4. The host receives the acknowledgment, increases the sequence number, and repeats the command.

Sequence number/repeat byte structure

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: Value is 0 for non-repeated command, 1 for repeated.

SQ0 - SQ2: Sequence value, as shown below:

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

Data block (length n bytes)

The data block consists of an ASCII string of commands sent to the pump.

ETX (Ctrl C or 03h)

The ETX character indicates the end of the command string.

Command block 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.

For example, if the host were to send the [Q] command to the pump at address 1, in hexadecimal these characters would be 0x02, 0x31, 0x30, 0x51, 0x03. The checksum for these values is 0x51.

OEM protocol answer block characters

The answer block characters in the OEM communication protocol are described below. When developing a parsing algorithm, the programmer should key on the 0xFF as the beginning of the answer block and the check-sum (character after ETX) as the end of the answer block.

Sync (FFh)

Used for backward compatibility with older model pumps.

STX (Ctrl B or 02h)

The STX character indicates the beginning of a response string.

Master address

The master address is the address of the host system. This should always be "0" or 30h.

Status and error codes

The status and error codes define pump status and notify of error conditions. For a complete listing of error codes, see the instructions for the particular pump.

Data block (length n bytes)

This is the response from all report commands except the [Q] command. The [Q] command asks for a status byte only. Therefore the data length is zero.

ETX (Ctrl C or 03h)

The ETX character indicates the end of the response string.

Answer block checksum

The checksum is the last byte of the message string. All bytes (excluding line sync and checksum) 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.

For example, if the host were to send the [Q] command to the device at address 1, in hexidecdimal "pump's "idle" response would be 0x02, 0x30, 0x60, 0x03, 0x51. The checksum for the first four bytes is 0x51.

Data Terminal (DT) protocol

The DT protocol can be used easily from any terminal or terminal emulator capable of generating ASCII characters at 9600 or 38400 baud, 8 bits, and no parity. Table 9-4 lists each setting of the DT protocol.

Table 9-4: DT Protocol communication details

Serial bus configuration

Parameter	Setting
Baud Rate	9600 or 38400
Data Bits	8
Parity	None
Stop Bit	1

Command block
(see "DT protocol command block characters" below, for details)

Byte number	Byte name
1	Start character (ASCII "/" or 2Fh)
2	Pump address
2+n	Data block (length n)
3+n	End character (carriage return, "CR" or 0Dh)

Answer block
(see "DT protocol answer block characters" below, for details)

Byte number	Byte name
1	Start character (ASCII "/" or 2Fh)
2	Master address (ASCII "0" or 30h)
3	Status character
3+n	Data block (if applicable)
4+n	ETX (Ctrl C or 03h)
5+n	Carriage return ("CR" or 0Dh)
6+n	Line feed (0Ah)

DT protocol command block characters

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

Start character

The start character (ASCII "/" or hex 2Fh) indicates the beginning of a message.

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 character

The end character (carriage return, ASCII "CR" or 0Dh) indicates the end of the message.

DT protocol answer block characters

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

Start character

The start character (ASCII "/" or hex 2Fh) indicates the beginning of the response.

Master address

The master address is the address of the host system. This should always be "0" or 30h.

Status character

The status and error codes define pump status and signal error conditions. See the description of the [Q] command in the main part of the product manual.

Data block

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

ETX

The ETX character (Ctrl C or 03h) indicates the end of the response string.

End character(s)

The carriage return ("CR" or 0Dh) and line feed ("LF" or 0Ah) terminate the reply block.

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 host when they have finished the current task.

Note: The pumps use a CAN controller and transceiver chip compatible with Philips Semiconductor CAN bus specification, version 2.0.

Alternative use of pump buses (not recommended)

Please note that the pump communication buses (RS232/RS485/CAN) use liquid handling industry-developed custom communication protocols (OEM, DT, and CAN). It is possible (but not recommended) for non-pump devices using a different communication protocol to exist on the same RS485 or CAN bus, as long as the non-pump device's protocol does not interfere with the pump protocol.

⚠**CAUTION**

CAUTION: Tricontinent Scientific, Inc. does not encourage or warrant any use of the pump buses with non-pump devices, regardless of information provided by Tricontinent Scientific, Inc. Results may be unsatisfactory.

With CAN networks, it is theoretically possible have pump devices which use the liquid handling industry-specific protocol and non-pump devices using a different protocol on the same bus, but the two protocols must not inadvertently address the wrong device. For example, if a non-pump device used the CANOpen NMT protocol, and we compare the syringe pump industry's 11-bit message structure with CANOpen, it is clear that the function code and node ID fields are not in the same locations. Compatibility would require that messages to/from the liquid-handling pump are always distinct from the messages generated to/from any CANOpen device. This is theoretically possible, since the 4-bit CAN Device ID (Device address) of the pump bus protocol overlaps the Node ID field of CANOpen:

CANOpen	Function Code				Node ID							
Syringe Pump Industry	Direction	Group			Device ID				Frame (like function code)			
					<--------------ID Overlap-------------->						

As long as the ID Overlap bits are unique to each device, it appears possible that messages sent to and received from each device could be distinguished. Four bits would allow 16 devices. It is also clear that pump devices do not strictly fit into any of the CANOpen communication models. The closest fit appears to be the NMT master/slave relationship, although the pump will send an unrequested asynchronous command-completion message when a move command completes. Pressure data streaming (Air-Z products) looks more like the consumer/producer push model. Any host implementation of multiple protocols would have to be designed to handle these situations.

CAN messages

Standard CAN messages consist of 18-bit frames. Each frame has a 12-bit *arbitration* field and a 6-bit *control* field. These are all the bits that must be considered at the programming level. On the physical CAN hardware there are additional bits that occur in a message, such as the start bit and CRC Field bits; but these are not discussed here, since they are implemented at the hardware level.

Within the arbitration field, there is an 11-bit message identifier (MID), and within the control field a 4-bit data length identifier.

The eleven MID bits are used to:

- Indicate which device on the bus the message involves.
- Identify the message type.
- Show the direction of the message (either to or from the master device).

The 4-bit data length identifier within the control field (the DLC) specifies 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 data from the separate frames into one message. Setting the DLC bits to values greater than 8 has no effect. The maximum data block is limited to 8 bytes.

CAN message construction

The CAN message formats used to communicate between host and pump are described in this section.

Each message frame begins with the message identifier (MID), followed by three bits that are always zero (RTR, IDE, and r0), the DLC, and finally the data block. The bits are grouped as shown below:

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame					
X	010	XXXX	XXX	0	0	0	XXXX	0-8 Bytes

Direction bit (1)

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame					
X	010	XXXX	XXX	0	0	0	XXXX	0-8 Bytes

The Direction bit determines 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 bits (3)

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame						
X	010	XXXX	XXX	0	0	0	XXXX	0-8 Bytes

The three group bits specify the group number (0-7). Each device on the CAN bus has a group assignment. At power-up, the pump is assigned to group 2 (b010). Group 1 is reserved for the boot request procedure.

Device address bits (4)

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame						
X	010	XXXX	XXX	0	0	0	XXXX	0-8 bytes

The device address bits specify the address of the pump in the indicated group. There can be up to 16 devices in the group, with addresses from 0 to 15. Expressed in binary, these would be b0000 through b1111. In hexadecimal, they would be 0h through 0Fh.

RTR, IDE, r0

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame						
X	010	XXXX	XXX	0	0	0	XXXX	0-8 bytes

The RTR, IDE, and r0 bits are not used in this CAN implementation and should always be set to 0.

Data length code (DLC)

CAN arbitration field					CAN control field				
MID				RTR	IDE	r0	Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame						
X	010	XXXX	XXX	0	0	0	XXXX	0-8 bytes

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

CAN data block

CAN arbitration field					CAN control field				CAN data block
MID				RTR	IDE	r0		Data Length (DLC)	**CAN data block**
Direction	Group	Device	Frame						
X	010	XXXX	XXX	0	0	0		XXXX	0-8 bytes

The data block contains the information to be transmitted (pump commands), up to eight bytes. For command strings that are more than eight bytes in length, multi-frame messages are used. This permits long program strings to be sent, just as when other communications interfaces are used.

Pump commands are sent in ASCII just as in RS-232 or RS-485.

CAN frame bits (3), and frame types

CAN arbitration field					CAN control field			
	MID			RTR	IDE	r0		Data Length (DLC)
Direction	Group	Device	Frame					**CAN data block**
X	010	XXXX	XXX	0	0	0		XXXX
								0-8 bytes

The frame type (specified by the three bits in the Frame portion of the MID) allows a device to determine what type of command it is receiving and process accordingly. 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. Pumps respond to the different frame types as follows:

Type 0: On-the-Fly commands ([V] and [T]). Frame bits = 000

On-the-fly commands are issued with a frame type of 0 (zero).

On-the-fly commands do not generate completion messages, and thus no status code is needed (these commands are simply acknowledged immediately). As their name implies, these commands ([V] and [T]) can be sent while the pump is executing action commands and execute immediately (resulting in either a change in top velocity or termination of the currently executing commands).

Type 1: Action commands. Frame bits = 001

This frame type is used for action commands such as initialization commands [Z], movement commands ([A],[D],[P]), or for setting pump operating parameters. All task-type commands are sent in this type of message frame. When multi-frame messages are required to send an action command, this frame type is used for the last message of the group sent to the pump. Examples are shown later in this section.

Type 2: Common commands. Frame bits = 010

This frame type is used for commands that are common to every device on the bus. The command is a single ASCII character in the data block. The ASCII command characters with hexadecimal equivalents are described here:

Command	Description
0 (0x30 in hex)	Reset. This resets the pump and restarts the boot request procedure.
1 (0x31 in hex)	Start loaded command. The same as sending a run [R] command after a string has been loaded.
2 (0x32 in hex)	Clear loaded command. This clears out the command buffer. This is the same as the [C] command.
3 (0x33 in hex)	Repeat last command. This command is identical to the [X] command (execute last command or string).
4 (0x34 in hex)	Stop action immediately. This is the same as the terminate [T] command.

Type 3: Multi-frame start message. Frame bits = 011

This frame type specifies that the next pump command will be longer than the 8-byte maximum of a single CAN message. Subsequent frames will follow to complete the message. By definition, the frame will contain 8 bytes of data.

Type 4: Multi-frame data. Frame bits = 100

This frame type identifies a frame that is within a multi-frame message. One or more multi-frame data messages can occur between a multi-frame start message and the end of a multi-frame message. By definition, it will contain 8 bytes. If less than 8 bytes of data are required to complete the pump command, a Type 4 frame is unnecessary; the command will start with a Type 3 message and complete with an action or report frame type.

Note: The last frame of a multi-frame message for action commands will be type 1. The last frame of a multi-frame message response from the pump for report commands will be type 6.

Type 5: Event Messages. Frame bits = 101

Type 5 frames are used to send unsolicited messages from the pump. Currently, this frame type is only used to send streaming pressure or capacitance data from a pump, in applicable products.

Type 6: Report/answer commands. Frame bits = 110

This frame type is used to query information from the pump. It is similar in operation to the query commands (e.g. [?]) used in the OEM and DT protocols. The report command is one or two bytes long since the command is sent as ASCII characters in the data block.

When the pump responds to a Type 6 query, the first byte of the data block is the status byte. It is defined like the status byte in the RS485 and RS485 protocols. The next byte is a null character. The remaining six bytes contain the report command 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.

Handling of pump boot requests

When the pump is first powered up or receives a system reset command (frame type 2, command 0 or [!0]), the pump notifies the CAN host of this condition by sending a boot request message at intervals of approximately 1 second until it receives a boot request response from the host. Boot request responses from the host are sent using a MID Group 1, which is reserved for this purpose. The frame type must be 2 when the pump sends a boot request to the host, and the frame type must be 0 when the host replies to the boot request. In the reply, the host has the opportunity to change the pump's address, if desired. In order for a pump to accept the host's boot request reply, the host must specify the pump's group ID and device ID (as set by the address switch or switches) in the Node ID field. This is how a pump on the bus determines that the boot request reply from the host has been sent to it.

When a pump accepts the host's reply, it uses the Slave ID field to set its CAN bus address for all subsequent messages (until a reset or power cycle occurs). The Slave ID may be any value from 0 to 127 (0x00-0x7F). This capability can free up sixteen Group 2 addresses (i.e., the Group ID can be changed), but does not allow more than sixteen Group 2 pumps on the bus. This is because at power-up all pumps belong to Group 2 by default and have only sixteen possible switch-selectable addresses and therefore only sixteen pumps can be addressed from the Node ID field. To further clarify: if two pumps both have their switches set to address 4, both will receive and process the host's boot request reply to Group 2, address 4; and both pumps will set themselves to the same Slave ID, creating a communication conflict.

In the following first two examples, the host sets the pump address (Slave ID) to the same values as the pump's switch-selected address.

Example 1. The pump address DIP switches are set to address 0.

1. Pump sends boot request (Group=1, Frame=2):

Direction	Group	Device	Frame	RTR/IDE/r0	Length
1	001	0000	010	000	0000

2. Host acknowledges:

Direction	Group	Device	Frame	RTR/IDE/r0	Length	Data bytes[1]	
						Node ID[2]	Slave ID[3]
0	001	0000	000	000	0010	0010 0000	0010 0000

1. Node ID = Group ID (2) high nibble, + pump address (0) low nibble = 0010 0000
    Slave ID = Same as Node ID
2. The pump will save the Node ID to use for message filter Group ID.
3. In order for the Slave ID to be accepted, the host must pass the correct Node ID, which is always Group 2 in data byte 0 upper nibble, and the device address as set with the DIP switches in the lower nibble.

Acknowledgment details:

Direction = 0	Host to slave
Group = 1	Boot request response group
Device = 0	Always 0 in boot response
Frame = 0	Boot request response frame
RTR/IDE/r0 = 0	All three always 0
Length = 2	Two data bytes in return message

Note: Boot MID is the same for all nodes.

Example 2. The pump address DIP switches are set to address 6.

1. Pump sends boot request:

Direction	Group	Device	Frame	RTR/IDE/r0	Length
1	001	0110	010	000	0000

2. Host acknowledges:

Direction	Group	Device	Frame	RTR/IDE/r0	Length	Data bytes[1]	
						Node ID[2]	Slave ID
0	001	0000	000	000	0010	0010 0110	0010 0110

1. Node ID = Group ID (2) high nibble, + pump address (6) low nibble = 0010 0110
   Slave ID = Same as Node ID
2. The pump will save the Node ID to use for message filter Group ID.

Acknowledgment details:

Direction = 0	Host to slave
Group = 1	Boot request response group
Device = 0	Always 0 in boot response
Frame = 0	Boot request response frame
RTR/IDE/r0 = 0	All three always 0
Length = 2	Two data bytes in return message

Note: Boot MID is the same for all nodes.

Example 3. The pump address DIP switches are set to address 6, and the pump address is changed to 127.

After the pump receives this message, it will only accept messages (until the next power cycle or reset) from the host that are addressed with a MID using Group 7 and device address 15.

1. Pump sends boot request:

Direction	Group	Device	Frame	RTR/IDE/r0	Length
1	001	0110	010	000	0000

2. Host acknowledges:

Direction	Group	Device	Frame	RTR/IDE/r0	Length	Data bytes	
						Node ID	Slave ID
O	001	0000	000	000	0010	0010 0110	0111 1111

A final note regarding a pump's boot request. The pump's CAN address as set by the pump's DIP switches is one less than the pump's address that the address DIP switches set in the serial DT or OEM communication protocols. In other words, CAN device addresses are zero indexed and DT or OEM device addresses are 1 indexed. This is because in the DT and OEM protocols, index zero is reserved for the host. In the CAN protocol, the direction bit determines the host and a device address is not needed for the host.

CAN host and pump message exchanges

Pump response

When a 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 received. Generally, it will have the following format:

<MID><RTR/IDE/r0><DLC><Answer>

Where:

<MID>	11-bit message identifier. The direction bit is 1. The group number and the frame type are the same as received. Device is the current device address.
<RTR/IDE/r0>	Always zero.
<DLC>	4-bit data length code
<Answer>	Data bytes. The first byte of the data block is always the status byte. It is defined as in the table with this title: "Error codes, status byte with ASCII and hexadecimal values" in the main part of the product manual. 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, multi-frame messages are used.

Note: Only one command of a given frame type can be in progress at any time: e.g., after issuing a command to a 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 a second command of the same type is sent with-

out waiting, a command overload status results. Commands with different frame types can be in progress at the same time (e.g., an action command and a query command).

Example host/pump exchanges

The following are typical exchanges between the host and pump for action commands, multi-frame commands, common commands, and query commands.

Action command example

The host sends a [ZR] command to a pump, where the pump Slave ID is set to Group 2, device address 0.

1. Host sends:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	001	000	0010	0x5A 0x52 ("ZR")

2. Pump acknowledges immediately:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC
1	010	0000	001	000	0000

3. After completing execution of the command, pump reports status:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0000	001	000	0010	0x60 0x00h ("`0")

Note: "`0" decodes as first byte status = idle, followed by a null character (hex zero).

Multi-frame command example

The host sends the command string [Z2S31A3000gHD300G10G5R] to a pump, where the pump Slave ID is set to Group 2, device address 0.

1. Host sends in three consecutive messages:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	011	000	1000	0x5A 0x32 0x53 0x33 0x31 0x41 0x33 0x30 ("Z2S31A30")

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	100	000	1000	0x30 0x30 0x67 0x48 0x44 0x33 0x30 0x30 ("00gHD300")

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	001	000	0110	0x47 0x31 0x30 0x47 0x35 0x52 ("G10G5R")

Note: The last frame type of a multi-message command is the type of command being sent. This example is an action command. Therefore the last frame type is type 1. The first message in a multi-message command is type 3 and messages between the first and last are type 4.

2. Pump acknowledges immediately after receiving the type 1 command:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC
1	010	0000	001	000	0000

3. After completing execution of the command, the pump reports status:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0000	001	000	0010	0x60 0x00h ("`0")

Note: "`0" decodes as first byte status = idle, followed by a null character (hex zero). For multi-frame commands, the pump only sends an acknowledgment for the last frame.

Common command example

After the host has sent command [A1000A0] to the pump, it can send command 0 of frame type 2 to a pump and initiate execution of the buffered command string. The pump in this example has a Slave ID set to Group 2, Device address 0.

1. Host sends:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	010	000	0001	0x31 ("1")

2. Pump acknowledges:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC
1	010	0000	010	000	0000

3. After executing the command, pump reports status:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0000	010	000	0010	0x60 0x00h ("`0")

Query command examples

Example: the host sends report command 29 of frame type 6 to a pump, with the pump Slave ID set to Group 2, device address 1.

1. Host sends:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0001	110	000	0010	0x32 0x39 ("29")

2. Pump reports:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0001	110	000	0010	0x60 0x00h ("`0")

Note: For query commands, no acknowledge frame is needed. The report command response is assembled and returned immediately.

Example: the host sends report command 23 of frame type 6 to a pump, and the pump Slave ID is set to Group 2, device address 1.

1. Host sends:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0001	110	000	0010	0x32 0x33 ("23")

2. Pump reports:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0001	011	000	1000	0x60 0x00h 0x49 0x50 0x5A 0x3A 0x20 0x30 ("`0IPZ: 0")

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0001	110	000	0101	0x38 0x32 0x39 0x31 0x36 ("82916")

Note: For a multi-frame reply, the start frame is type 3, the middle frame is type 4 (if needed), and the last frame is type 6 since type 6 indicates a report command.

Action command example with error

The host sends the [A4000A0R] command to a pump, where the pump Slave ID is set to Group 2, device address 0.

1. Host sends:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
0	010	0000	001	000	1000	0x41 0x34 0x30 0x30 0x30 0x41 0x30 0x52 ("A4000A0R")

2. Pump acknowledges immediately:

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC
1	010	0000	001	000	0000

3. After parsing the command and finding an error (in [N0] mode, an absolute move of 4000 is not supported), the pump reports status of 0x63 (invalid operand):

Direction	Group	Device	Frame Type	RTR/IDE/r0	DLC	Data bytes
1	010	0000	001	000	0010	0x63 0x00h ("**c**0")

TCS Pump Commander overview

TCS Pump Commander (Commander) is a convenient user interface to Tri-continent Air displacement and syringe pumps. It is user-friendly and easy to set up and get running; it requires no programming. TCS Pump Commander contains tools for observing pump behavior and determining best settings for many operations. For some operations, it is essential.

This overview acquaints the user with Commander and its capabilities, introducing the main task windows and their purposes. For actual operating instructions, see the extensive help documentation integrated into the TCS Pump Commander. The help feature also includes links to current copies of the Tricontinent product manuals.

The functionality described here begins with TCS Pump Commander version 2.1.0, which runs on Windows 7 and Windows 10 operating systems.

Features

- This version of TCS Pump Commander supports Tricontinent liquid-handling syringe or air displacement pumps.

- Commander connects with and recognizes the pump it is connected to automatically, and loads the command set and parameters needed to use the Commander tools for that particular pump and, if a syringe pump, the installed valve. For this to occur, the pump must be running a recent version of firmware that supports this communication.

- If the pump cannot be connected automatically, a Communication Setup screen will open, allowing the connection to be made manually. This screen is accessible from any of the other windows.

- The software automatically sets the available windows according to whether an Air-Z or syringe pump is connected. Drop-down menus on most screens allow navigation other windows.
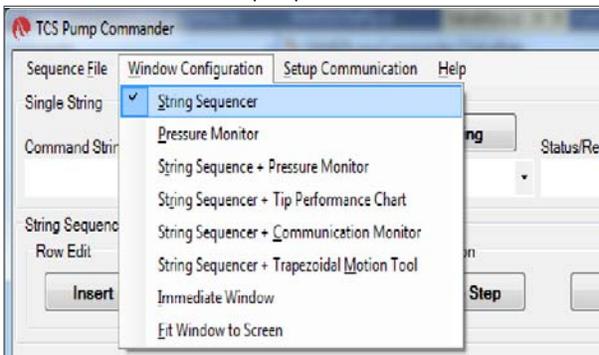
Air-Z pump menu   Syringe pump menu
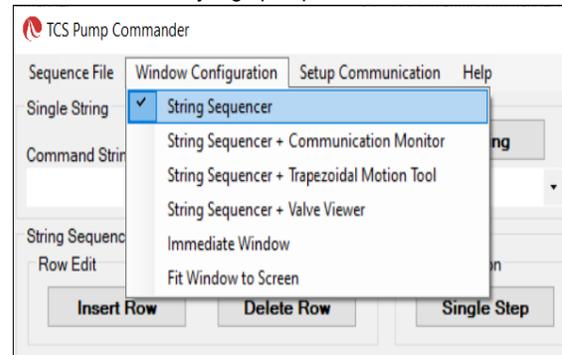
- The user can move directly from any window to any other.

- Commander allows commands to be entered while observing responses in the displayed charts and data.

- Zooming can be done by selecting the zoom area with the mouse.

Windows

String Sequencer Window

The String Sequencer Window allows commands to be entered and sent either singly or in a sequence, to any pump address on the bus. Command strings and sequence can be saved and called up to run whenever needed.

Commands and the pump's response when polled are shown.

By default, TCS Commander opens to this window.

Many of the other window configurations include the String Sequencer, so that real-time charting and data may be observed as commands are issued.
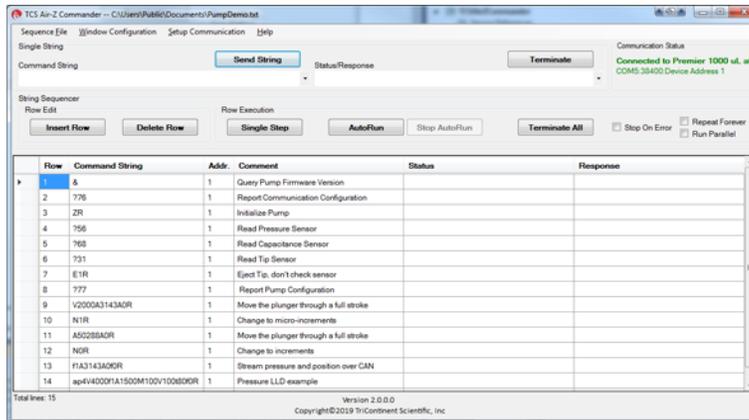
Pressure Monitor Window (Air-Z only)

The Pressure Monitor Window provides three primary tools: the Streaming Data Chart, the Pressure Trace Manager, and the [q] command tool. The Pressure Monitor Window may be opened with or without the String Sequencer attached (Pressure Monitor or String Sequencer + Pressure Monitor).

In all the tools, single command strings may be sent while viewing the effects on the display. If the String Sequencer Window is attached, single or multiple command strings can be sent.
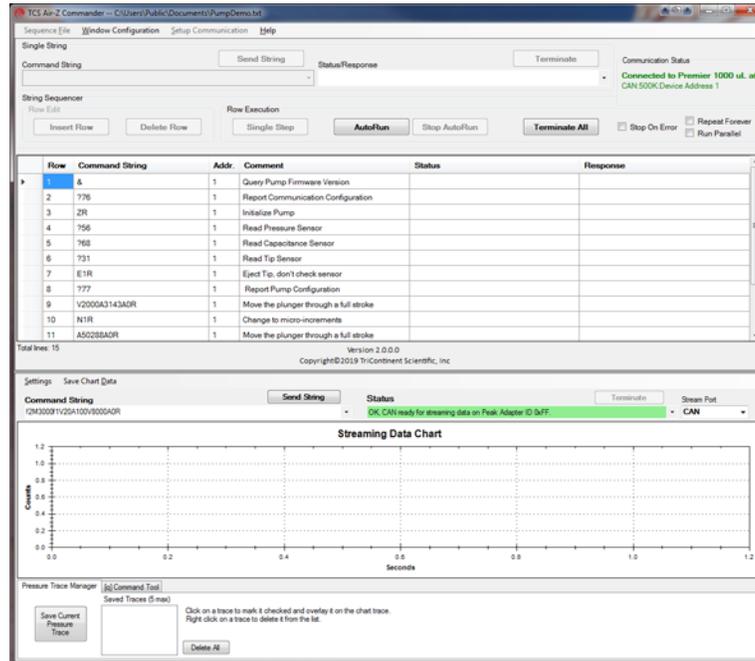
Streaming Data Chart. The Streaming Data Chart shows streaming data from an Air-Z pump in real time. The chart shows moving plunger position, pressure count, and optionally capacitive count (Air-Z Premier only). This information assists in determining optimal settings for liquid level operations. Liquid level operations are described in the product manual.

Pressure traces can be stored and repeated for evaluating consistency.

Pressure Trace Manager. The Pressure Trace Manager is a tool for monitoring consistency in identical, repeated operations. The interface allows you to save and plot up to five pressure traces at one time for comparison. If the pressure traces are different, it is likely that the aspirated/dispensed volumes are different too.
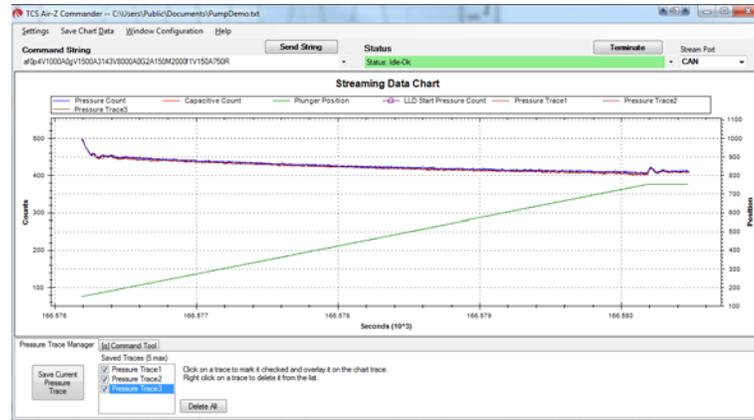
[q] command tool. The [q] command tool helps the user determine the operation validation [q] command arguments, <n1> and <n2>. Operation validation monitors fluid operation and detects tip clogs, aspiration of air or bubbles, and failed dispenses. It also verifies that the expected amount of fluid was handled.

A tab at the bottom of the Pressure Trace Window takes you to this item.

Two forms of the tool are available. Only one of them however, is recommended, as explained in the help documentation. The product manual contains detailed instructions for operation validation.
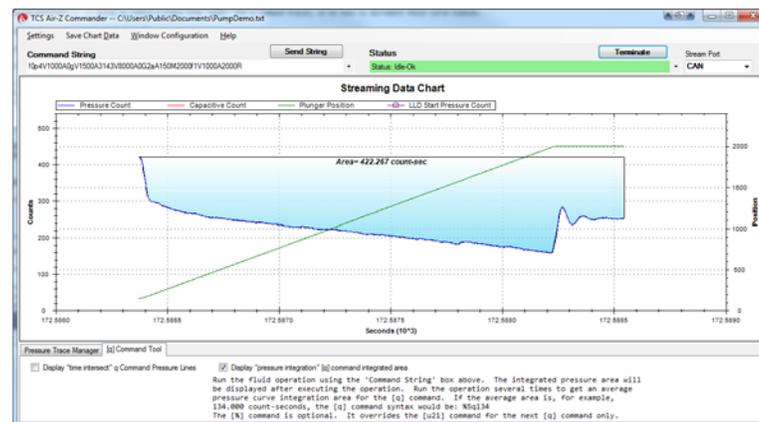
String Sequencer + Tip Performance Chart Window (Air-Z only)

The Tip Performance Chart is a tool that predicts fluid aspiration for a given tip and fluid operation, and gives the user command parameters needed to more accurately use the Air-Z pump's [N2] operating mode (sending commands in uL units). The Tip Performance Chart Window is configured to display with the String Sequencer window.

When a command is sent to move a specific number of microliters (µL), the µL number is converted by firmware to the number of increments the plunger must move in order to displace the specified fluid volume.

There is an inherent non-linearity in the conversion process, and this window provides help in selecting variables that compensate for this non linearity. The selected values can be copied to a command string for evaluation.

The chart displays data showing how far a plunger must move for a given fluid operation for different Axygen tips. Data sets are included for four Axygen tips for forward and reverse pipetting, and the user can create and save additional data sets. The String Sequencer part of the screen can be expanded or reduced, as the arrows below indicate.

Detailed N2 mode operation is described in the product manual.
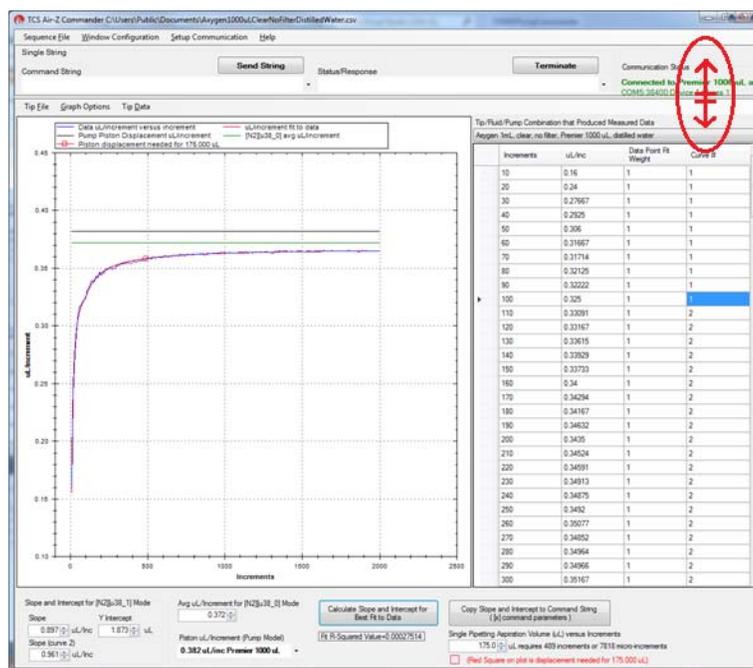
String Sequencer + Communication Monitor Window

The Communication Monitor Window allows the user to observe communication back and forth between pump and host. This window displays all bytes that are transferred between pump and host for a given command sent through the String Sequencer portion of the display.
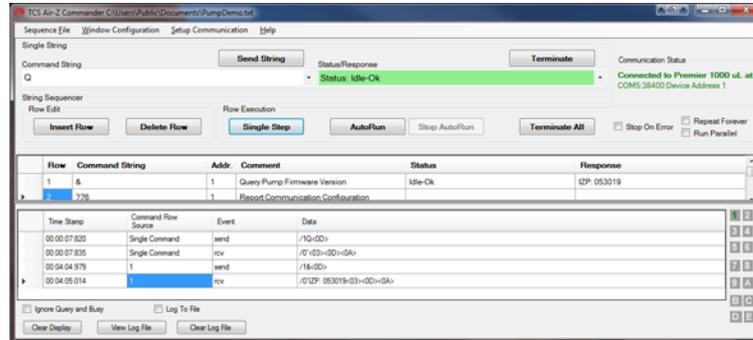

String Sequencer + Trapezoidal Motion Window

The Trapezoidal Motion Tool displays plunger trajectory for different settings. The user can see how movement is affected for different values of velocity, acceleration, and move distance, allowing the user to try different settings and optimize the movement profile for a given move command. The Trapezoidal Motion Window is configured to display with the String Sequencer window. Plunger motion settings are described in the product manual.
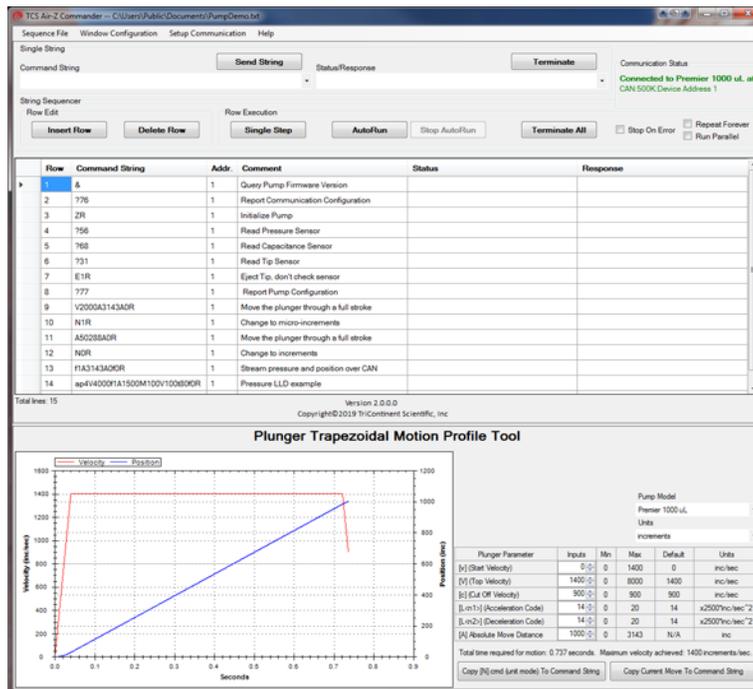
### String Sequencer +Valve Viewer Window (Syringe pumps only)

The Valve Viewer shows the current and available valve positions for the connected pump as commands are selected. The interior of the valve is shown as well, so the user can see the fluid path change as valve positions change. This can be useful as most valves are opaque, with no visual means to know or verify the current valve position.

Valve movements are described in the associated syringe pump manual.
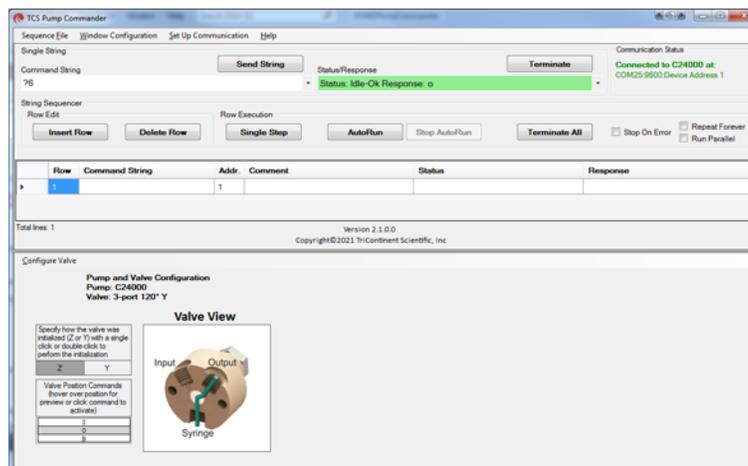
Immediate Command Tool

The Immediate Command Tool allows commands to be sent to a pump without polling for command completion. On-the-fly commands can be sent from this window while the main window is waiting for a move command to complete. Immediate commands include status queries and velocity commands.

An exportable history list in this window records commands sent and pump acknowledgments.
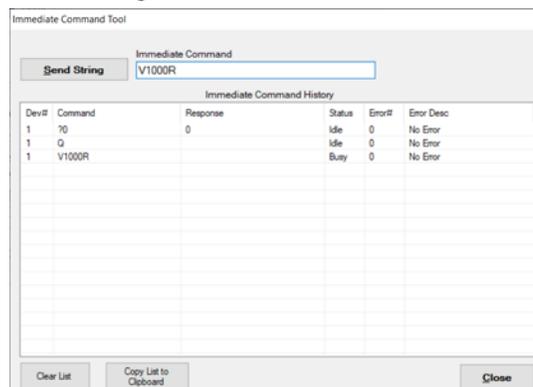
Evaluation cables and accessories

This section identifies the cables and accessories needed for evaluating the Tricontinent pumps/devices that include a DSUB 15-pin connector for power and communication. Several scenarios are described.

Obtaining needed items. Items listed here can be obtained through Customer Service or as otherwise described.

GUI Interface. For the best evaluation experience, use TCS Pump Commander. TCS Pump Commander is user-friendly and easy to set up to get going quickly. It does not require the user to write any protocol software.

Alternatively, terminal emulator programs such as PuTTY and RealTerm may be used to send commands using DT protocol.

USB driver. Some applications use a USB interface. The correct driver may be obtained at

https://www.silabs.com/developers/usb-to-uart-bridge-vcp-drivers

If more detail is needed, refer to "Download and install driver for USB/RS485 if needed" in the installation instructions.

⚠CAUTION

CAUTION: Observe the following to avoid damage to the equipment.

- Always use proper ESD practices when handling these products.
- Keep power OFF while connections are being made.

Evaluation kits. For some products, a kit is available for evaluating a single device. The kit contains all hardware needed for product evaluation: USB to RS485 converter, cables, power supply, and instructions.

In addition, it is necessary to download the USB driver for the kit, and to obtain TCS Pump Commander or a terminal emulator program as described above.

To order a kit or to determine whether there is one available for your product, inquire with Customer Service.

⚠CAUTION

CAUTION: Do not use cable for daisy-chaining pumps that will connect all pump signals in parallel. There are several interface signals that cannot be daisy-chained without likely causing damage to the pump electronics. Failure to avoid this type of daisy-chaining may void the warranty. Contact Customer Service if more information is needed.

RS232 to single or multiple devices evaluation

Items needed

- Evaluation cable 10176, approx. 24" length
- Daisy-chain cable 10179, if multiple devices; one per additional device approx. 6" length
- Bench-top power supply, 24V 3A (user supplied)
- TCS Pump Commander or terminal emulator program (obtain as described at the beginning of this section)

Note: The daisy-chain cables provide about 6" of wire between devices. Ensure devices are mounted close together to accommodate this length.

Figure 9-2. RS232 evaluation hookup
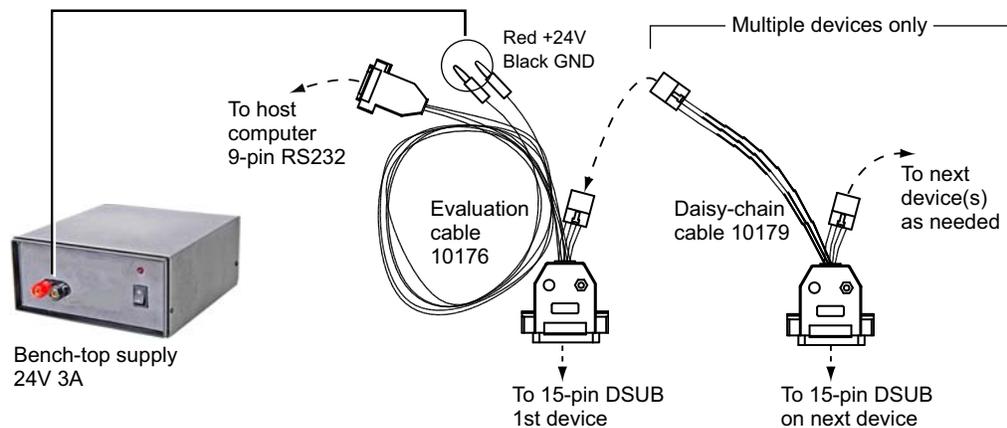
Instructions

1. Start with power OFF to avoid damaging the equipment while connections are being made.

2. Connect evaluation cable 10176 as indicated by dashed lines/arrows in illustration above. Wait to connect power.

3. Multiple devices: Connect daisy-chain cable 10179 as indicated by dashed lines/arrows in illustration above. Repeat for each additional device.

4. Connect power plugs of evaluation cable 10176 to the bench supply. Red is for +24V; black is for ground.

5. Install TCS Pump Commander or terminal emulator on host controller.

6. Apply power, and follow procedures beginning with "Confirm communication with pump" in the Installation instructions.
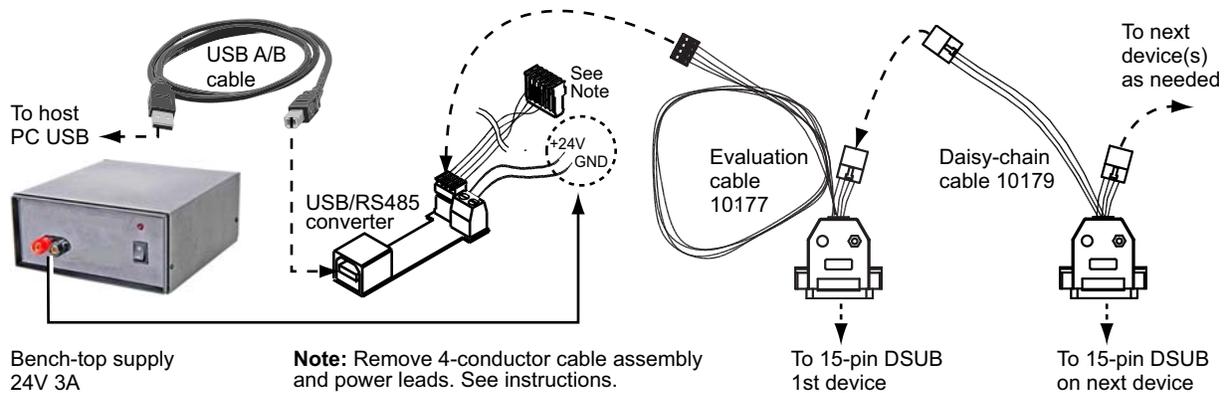
USB to multiple device evaluation

Items needed

- Evaluation cable 10177, approx. 18" length
- Daisy-chain cable 10179, approx. 6" length (one needed for each additional device)
- USB/RS485 converter kit, 0960
- USB A/B cable (order as needed: part number 8698-03, approx. 6' 6" length).
- Bench-top power supply, 24V 3A (user supplied)
- USB driver for host PC (download as described at the beginning of this section)
- TCS Pump Commander or terminal emulator program (obtain as described at the beginning of this section.)

Note: The daisy-chain cables provide about 6" of wire between devices. Ensure devices are mounted close together to accommodate this length.

Figure 9-3. USB to multiple device hookup

USB A/B cable

To host PC USB

USB/RS485 converter

See Note

+24V GND

Evaluation cable 10177

Daisy-chain cable 10179

To next device(s) as needed

Bench-top supply 24V 3A

Note: Remove 4-conductor cable assembly and power leads. See instructions.

To 15-pin DSUB 1st device

To 15-pin DSUB on next device

Instructions

1. Start with power OFF to avoid damaging the equipment while connections are being made.

2. Unplug and discard the 4-conductor ribbon cable assembly from the USB/RS485 converter kit. This uncovers a 4-pin header.

3. Make cable and converter connections as indicated by the dashed lines/arrows above. Evaluation cable 10177 will be plugged into the header on the USB/RS485 converter.

4. Connect power lines from the USB/RS485 converter to the power supply. Observe polarities shown in the illustration.

5. Install the USB driver and TCS Pump Commander or terminal emulator program on the host computer. See instructions at beginning of this section.

6. Apply power, and follow instructions beginning with "Confirm communication with pump" in the Installation instructions.

Single device evaluation with direct USB input

Some products (such as the MC6000) include a direct USB input. The USB input may be used for single-device evaluation if desired. The following items are needed:

- USB A/B cable 8698-03 (if none already available)
- Bench-top power supply, 24V 3A (user supplied)
- USB driver (obtain as described at the beginning of this section)
- TCS Pump Commander or terminal emulator program (obtain as described at the beginning of this section)

Connect the USB A/B cable between the host computer and the device, and provide power as described in the installation instructions in this manual. Then download and install the USB driver. Obtain and install the TCS Pump Commander or terminal emulation program.

Follow instructions beginning with "Confirm communication with pump" in the installation instructions in the product manual.

PTFE vs. UHMWPE for syringe seals and valve plugs

Valve plugs and syringe seals may be PTFE or UHMWPE. Each of these materials has its advantages and disadvantages, as summarized below.

Table 9-5: PTFE vs. UHMWPE

Material	Advantages	Disadvantages
PTFE	• Best chemical resistance. Very inert. • Very soft (good for sealing) • Very low seal drag due to its low friction properties	• Not well suited for crystalline reagents such as buffers. • Easily scored/damaged. • Can shed over time (although we specify the best PTFE available to avoid this potential issue).
UHMWPE	• Very good chemical resistance. • Best abrasion resistance. • Extremely durable material yet fairly soft so well suited for long-lasting seals. • Longest life. • Will not shed over time. • Well suited for crystalline reagents such as buffers.	• Higher seal drag.

Calculating flow rates

In syringe pump applications, flow rate is defined as the amount of fluid being dispensed in a given time frame (total syringe volume divided by dispense speed). Typically, this is in microliters per second (µL/sec). However, depending on the application it could also be stated using a different volume, such as milliliter (mL) or in time (minutes, hours, etc).

While you may or may not ever want to calculate precise flow rates, knowing the ranges of flow rates for each of the C-Series pumps will help guide you in your selection of a C-Series pump and syringe.

Refer to the following table to help determine which syringe/pump will meet your requirements. The table shows flow rate ranges for each of the C-Series pumps, according to the size of the syringe in use.

Table 9-6: C-Series flow rate guide

Syringe size (µL)	C3000/C3000MP		C24000/C24000MP	
	Highest flow rate @ 1.2 sec/full stroke (µL per second)	Lowest flow rate @ 48000 sec/full stroke (µL per second)	Highest flow rate @ 4.2 sec/full stroke (µL per second)	Lowest flow rate @ 192000 sec/full stroke (µL per second)
50	41.67	0.001042	11.90	0.0002604
100	83.33	0.002083	23.81	0.0005208
250	208.33	0.005208	59.52	0.0013021
500	416.67	0.010417	119.05	0.0026042
1000	833.33	0.020833	238.10	0.0052083
2500	2083.33	0.052083	595.24	0.0130208
5000	4166.67	0.104167	1190.48	0.0260417
12500	10416.67	0.260417	2976.19	0.0651042

Note:
• This guide is intended to provide a snapshot of potential flow rates and does not imply specific performance at those rates.
• Higher flow rates may not be achievable due to flow rate restrictions in the fluid path.
• Extremely low flow rates may be accompanied by pulsation.

The flow rate formula is simply total syringe volume divided by dispense time. For example, with a C3000/1000 µL syringe combination at top speed of 1.2 seconds/full stroke, the maximum flow rate is 833.33 µL/ sec. (1000/1.2 = 833.33); and the minimum is 0.0208 µL/sec (1000/ 48000 = 0.0208).

Keep in mind that, as syringe volume goes up and plunger speed decreases, pulsation increases. Running smaller syringes at higher speeds decreases pulsation.

Converting velocity to flow rate

To convert velocity in increments/sec to flow rate in volume/sec: Divide the syringe volume by the position resolution, then multiply by the [V] command setting, as shown by the following examples.

Examples

- 1 mL syringe on C3000 in N0 or N1 mode at velocity [V] of 6000 increments/sec: flow rate = (1000 μL/3000*2) * 6000 = 1000 μL/sec (see note below)
- 1 mL syringe on C3000 in N2 mode at velocity [V] of 6000 increments/sec: flow rate = (1000 μL/24000*2) * 6000 = 125 μL/sec
- 1 mL syringe on C24000 in N0 or N1 mode at velocity [V] of 6000 increments/sec: flow rate = (1000 μL /24000) * 6000 = 250 μL/sec
- 1 mL syringe on C24000 in N2 mode at velocity [V] of 6000 increments/sec: flow rate = (1000 μL/192000) * 6000 = 31.25 μL /sec

Note: Velocity resolution is twice the position resolution for the C3000 pumps.

⚠CAUTION

CAUTION: Due to the smaller internal port diameters of the 6-way distribution valve and the 4-port loop valve, it is recommended that fluid velocity does not exceed 1500 μL/sec when using these valves. Use caution when setting velocity with 2.5 mL and larger syringe sizes. Take these precautions to prevent capitation and excessive syringe back pressure.

Chemical compatibility chart information

Please refer to the chemical compatibility chart on the following page for questions concerning compatibility of the materials in your pump, valves, tubing and interconnections.

Be aware that Tricontinent has obtained this information from reputable sources, and cannot be responsible for the accuracy of its content. Therefore it should only be used as a guideline. Actual testing of the materials should be performed before permanently implementing any application.

For further questions, please contact Customer Service.

This chart is also available for download from the Tricontinent website.

Chemical Compatibility
Fluid Contact Materials

	Acids											Alcohols						Bases			Esters						Ethers			Glycols			Aromatic Hydrocarbons			Halogenated Hydrocarbons					Ketones				Miscellaneous				
	Acetic acid, glacial	Acetic acid 90%	Acetic acid 30%	Acetic acid 10%	Hydrocloric acid, conc. (35%)	Hydrocloric acid. 6N. (20%)	Hydrocloric acid. 1N (3.3%)	Nitric acid, conc. (67%)	Nitric acid, 6N (27%)	Sulfuric acid, conc. (96%)	Sulfuric acid, 6N (16%)	Amyl Alcohol	Benzyl alcohol	Butanol	Ethanol	Isopropanol	Methanol	Ammonium hydroxide, 6N (11.4%)	Potassium hydroxide, 3N (15%)	Sodium hydroxide, 6N (22%)	Amyl acetate	Butyl acetate	Cellosolve acetate	Ethyl acetate	Isopropyle acetate	Methyl acetate	Ethyl ether	Tetrahydrofuran	Tetrahydrofuran/water (50/50,v/v)	Ethylene glycol	Glycerol	Propylene glycol	Benzene	Toluene	Xylene	Carbon Tetrachloride	Chloroform	Ethylene dichloride	Methylene chloride	Tetrachloroethylene	Acetone	Cyclohexanone	Methy ethyl ketone	Methyl isobutyl Ketone (MEK)	Acetonitrile	Dimethyl formamide (DMF)	Dimethyl sulfoxide (DMSO)	Formaldehyde, 37%	Formaldehyde, 4%
Acetal Copolymer	N	N	L	L	L	L	-	N	N	-	N	R	R	R	R	R	R	L	R	R	R	R	R	R	N	R	R	R	L	R	R	R	R	L	R	R	R	R	R	R	R	R	L	R	R	N	-	R	R
Borosilicate Glass	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Buna -N	N	N	L	L	L	L	L	N	N	N	N	L	N	R	L	L	R	N	R	R	N	N	N	N	N	N	N	N	N	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	R	R
Ceramic (Al203)	R	R	R	R	L	L	L	R	R	R	R	R	R	R	R	R	R	R	R	N	R	-	-	R	-	-	-	R	R	R	R	R	R	R	R	R	R	R	-	-	R	-	R	-	-	-	-	-	-
Nylon	R	R	R	R	N	N	-	N	N	N	N	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
PCTFE	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R	R	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-	-	R	R	R
PEEK	R	R	R	R	R	R	R	N	R	N	N	R	R	R	R	R	R	R	R	R	R	R	-	R	R	-	-	R	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R	-	-	R	L	-	-
Platinum Iridium	R	-	R	R	R	R	R	R	R	L	R	-	-	-	R	R	R	R	L	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polycarbonate	L	L	R	R	N	R	R	N	N	N	R	R	N	R	R	R	N	N	N	R	N	N	-	N	N	N	-	N	N	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Polypropylene	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	L	-	R	R	R	L	L	L	L	L	N	L	R	R	R	R	R	R	R	R	R	R
PPS	R	R	R	R	N	N	-	L	L	R	R	R	-	R	R	R	R	R	R	R	R	-	-	R	-	-	R	R	-	R	-	-	R	R	R	R	R	R	R	-	R	R	R	-	-	R	-	R	R
PTFE	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
PVC	N	N	N	N	L	R	R	L	R	N	R	R	N	R	L	R	R	R	R	R	N	N	N	N	N	N	N	N	-	R	R	R	N	N	N	N	N	N	N	N	L	L	L	L	L	R	L	L	-
Santoprene®	N	L	R	R	R	R	R	N	N	L	R	R	N	L	R	-	R	-	L	R	N	-	-	R	-	-	-	N	N	R	N	-	L	N	N	-	N	N	N	-	R	-	N	N	-	R	-	R	R
Silicone Lubricant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silicon-Nitride Ceramic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stainless Steel 304 Series	N	N	L	L	N	N	N	R	R	N	N	R	L	R	R	L	R	R	L	L	R	L	L	L	N	R	L	R	R	L	-	L	L	R	L	L	R	L	R	-	R	R	R	L	R	R	-	R	R
Stainless Steel 316 Series	R	L	L	R	N	N	N	R	R	N	N	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R	R	R	R	L	R	L	R	R	R	R	R	R	R	R	R	R	R
UHMWPE	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R	-	-	-	R	R	R	R	L	L	L	L	L	L	R	R	R	R	-	-	-	-	R	R
Viton®	N	N	L	L	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	N	N	N	N	N	N	N	N	N	R	R	R	R	R	R	R	R	R	L	R	N	N	N	N	R	L	N	R	R

R = Resistant________________1 Completely or alomost comletely inert
L = Limited Resistance_________2 Partially attacked
N = Not Resistant_____________3 Severely attacked
- = Insufficient Data

Precision and accuracy

Overview

Precision is defined as shot-to-shot repeatability. This is typically quantified as "imprecision" and expressed as *Coefficient of Variation (C.V.)*.

The precision of the pump is mechanically controlled through a consistent interface between the stepper motor/leadscrew. A correctly manufactured syringe has little impact on precision.

Tricontinent assures precision by measuring the repeated movements of the pump mechanism with a custom designed fixture.

Accuracy is defined as the agreement of desired volume with actual volume. The difference between the two is quantified as "inaccuracy" and expressed as a percentage.

The accuracy of the pump is mechanically controlled through proper lead-screw pitch and motor step angle. Correct syringe barrel I.D. also assures accuracy. Consistency of I.D. over the entire barrel length is necessary.

Tricontinent assures accuracy by mechanically measuring syringe barrels for proper I.D. using air bore gauges. The pump mechanism is verified by the use of manufacturing test fixtures.

When precision and accuracy data is based on results from gravimetric testing with fluids, the test setups and environmental conditions have been optimized. Tubing sizes, probe configurations, protocols and speeds have been selected to provide optimum results. The fluid measured is distilled water. Whenever any of these factors are changed, you can expect deviations from published performance data.

You can use your pump's specifications as a benchmark to determine how close to optimum your instrument's fluid path is.

Performance of a liquid handling system will depend on many factors. As a rule, empirical testing will be required to resolve all pertinent issues.

Important variables

Below are some typical variables to be considered when developing an application-specific fluid handling system. All these items must reach a balance before optimization is achieved.

- **Syringe size**, while important, is not as critical as you might imagine. A significant shift of volume (either up or down) must be made before any measurable difference in precision and accuracy will be noted in most applications.
- **Pump speed** needs to be adjusted to deliver fluids at rates agreeable with desired throughput but not so fast as to stall the motor when pumping through restrictive tubing. It is used for "fine tuning."
- **Tubing selection** can have a major impact on fluid handling performance. Keep tubes as stiff and as short as possible. Inside diameters should be as large as possible without causing the smallest sample/air gap to break up. See "Optimizing tubing performance" for more details.
- **Orifices** of all valves, connectors, fittings, etc. must be of appropriate size (see tubing). Transitions must be smooth and free from unswept volume.

- **Priming and preloading** to remove air and charge fluid paths is critical to fluid handling system performance. See "Optimizing pump performance" for more detail.

- **Probes** for aspirating and dispensing are often the most critical components in a fluid handling system. Good probe design should follow the same general guidelines as tubing and orifices (see above). Additional probe-specific criteria include:

  - Contour: make all transitions in I.D. smooth and step-free.
  - Surface area: the en d of the probe should have as little surface area as possible. Keep probe end perpendicular to probe and wall thickness minimized to help prevent drops from clinging.
  - Finish: both inside and outside surfaces should be free from burrs.

Optimizing pump performance

There are two types of movements in a syringe pump, *measured* and *preliminary*. Both are equally important in achieving optimum performance.

- **Measured** movements provide accurate and precise fluid volumes to a specified location.
- **Preliminary** movements prepare the fluid path for measured movements.

While most pump users are only concerned with the results of their measured movements, it is imperative to understand and fully utilize preliminary movements if optimum pump performance is to be achieved. One way to visualize the effect of preliminary movement in the fluid path is to imagine trying to push or pull two bricks with an inflated toy balloon between them. In order to get equal movement between the bricks, you must either expand or compress the balloon to its fullest point through preliminary movements. Once you have accomplished this, you have a charged fluid path and measured movements will be optimized.

Air gaps are useful in minimizing mixing of aspirated and primed fluids but must be handled carefully. Their introduction into a positive displacement system can severely degrade precision and accuracy unless countered with appropriate preliminary movements. Air gaps must be kept as small as possible.

Even with air gaps between sample and priming fluids, some mixing will take place in probes and tubes. In one-step sample dilutions, this has no effect; but in multiple aliquoting and sample transfers, some dilution of the measured sample closest to the air gap will occur. Make preliminary allowances for some waste if absolute sample integrity is required. Aspirate an additional amount of the sample to act as a buffer.

Discard this amount as part of the probe cleaning process. Typically 10% can be used as a guideline, but variables such as speed, type of fluids, volumes, and allowable error will determine final adjustments. Optimum waste allowances can only be determined through testing.

Repetitive functions, such as multiple dispenses and aliquoting, are best done when all measured movements are done in a like manner and speed. Preliminary movements to ensure a charged fluid path are critical to achieving optimum precision. The best method for accomplishing this task is to make a preliminary dispense, roughly equal to the desired measured movement, of the aspirated fluid into a waste cup or even into the same receptacle aspirated from, if possible.

Backstepping or anti-backlash routines built into most commercial syringe drive software typically eliminate only the inherent looseness of the drive mechanism. They do not charge the fluid path.

Priming, the most common preliminary movement, is important. All air should be expelled from the syringe, valves, tubes, and other wetted surfaces to achieve optimum performance.

Bubbles and air pockets may cause inconsistencies. Small bubbles located directly on the surface of the syringe seal often do not cause problems. However, should they break free and enter the fluid path, a measured movement could be affected. It is best to try and remove these through adequate priming. Surfactants in priming fluids make priming easier and more effective. If the priming fluid is outgassing during fill, evidenced by recurring bubbles in the syringe, either slow down the fill stroke or increase the diameter of the tubing.

The guidelines and tips offered here are generally effective in optimizing performance of syringe pumps. They are not, by any means, an all-inclusive list of methods and procedures. Every application requires specific techniques, tailored to that application, to achieve optimum performance.

Optimizing tubing performance

There are two types of liquid transfer lines in a typical system: *suction* and *delivery*.

- **Suction** lines transfer liquid from a vessel to the input port of the pump.
- **Delivery** lines transfer liquid from the output port of the pump to another location (i.e., cuvette or test tube).

When selecting liquid lines, the parameters to pay attention to are tubing I.D, length, material, secure port connection, and smooth ID transitions.

Tubing I.D.

- Suction line I.D.
    - Too small will restrict flow causing the pump to cavitate.
    - Too large will generate additional priming requirements.
- Delivery line I.D.
    - Too small will cause additional back pressure and excessive liquid velocity.
    - Too large may slow liquid velocity excessively and generate additional priming requirements.

Tubing length

- Suction line: excessive length may prevent the pump from priming and introduce pressure drop that will restrict flow to the pump.
- Delivery line: excessive length will introduce back pressure, increasing pressure at the pump.

Tubing material

- Suction line: soft tubing will collapse and pulse causing flow restriction, blockage, and pump cavitation.
- Delivery line: soft tubing will expand and pulse causing flow fluctuations, undermining the system's C.V.

    Semi-rigid tubing such as Teflon® or L.D.P.E. is preferred for consistent performance of the liquid transfer system.

Port connection

- Suction line: should be bubble tight to prevent introduction of micro air bubbles into the pump input port.
- Delivery line: should be bubble tight to prevent leakage of liquid from the pump output port.

Smooth ID transitions (contour)

Configurations should be used to prevent particle entrapment and minimize flow turbulence. Particle entrapment may cause material carry-over contamination. Flow turbulence may introduce additional back pressure, affecting system performance.

Typical tubing configurations

Flare connection   Luer connection

Flare connection   Nut & ferrule connection

Dispense nozzle

Flare connection
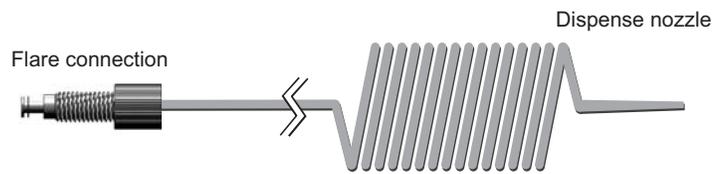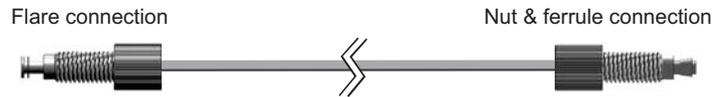
Dual pump continuous flow application

Introduction

This section describes how two C-Series pumps can be used to provide continuous flow in a standalone application.

The [j] command is a unique feature of the C-Series pumps that allows a change in state of auxiliary outputs based on the position of a syringe. This enables one pump to trigger the other before it is finished dispensing, causing the other in turn to begin dispensing. Consequently there is no gap in the flow.

The fluid outputs of the pumps are combined, an auxiliary output of each pump is wired to the input of the other, and program strings utilizing the [j] command are written to the pumps. To achieve standalone operation, these strings are pre-written to the EEPROMs of the pumps.

Sequence of operation

The two pumps are named A and B, respectively.

1. At power-up, Pump A and B are both initialized, and they both aspirate a full syringe.

2. Pump A starts dispensing, while Pump B remains idle.

3. As Pump A nears the end of its stroke, Pump A triggers Pump B to start dispensing.

4. Pump B is now dispensing. When Pump A has finished dispensing its syringe, it aspirates a full stroke.

5. When Pump B nears the end of its stroke, it triggers Pump A to start dispensing.

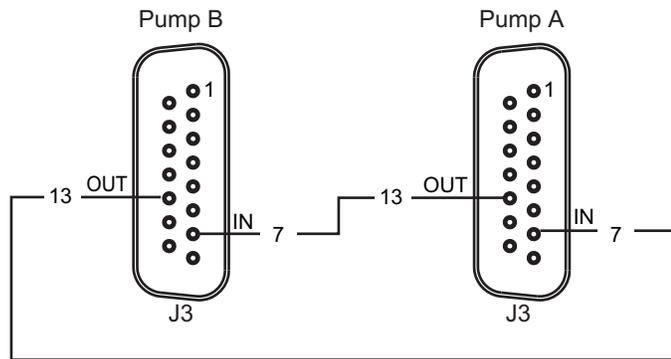6. The sequence returns to step 3 and repeats continuously.

Tubing hookup

The fluid outputs of the two pumps are connected together with a "Y" fitting. The inputs are independent.
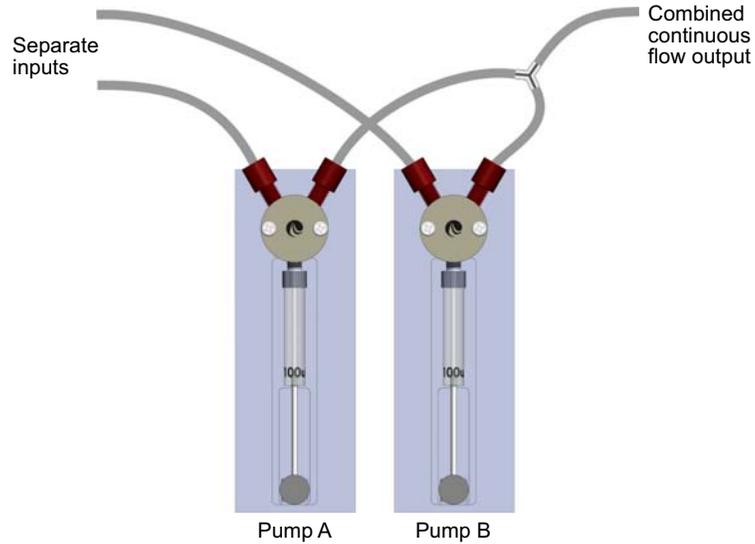
Wiring

Special cable is required (TCS 8246-73). As shown below, this cable connects an auxiliary output of each pump to an auxiliary input of the other pump.

Power and communication cabling not shown

⚠**CAUTION**

CAUTION: Make sure power is off while making connections to DB15 connector J3. Connecting or disconnecting with power applied may cause damage to the equipment, especially when I/O signals are in use.

Jumper and address switch settings

Pump A is set to address 1, and Pump B is set to address 2 using the address switches on the back of the two pumps (address 1 = switch position 0, address 2 = switch position 1).

After programming has been completed, the AutoRun jumper is installed on J2. This causes strings to run automatically from EEPROM on power-up. It also changes the function of the address switch. Its position now indicates which EEPROM location contains the string to be run at power-up.

Note: These are in addition to any other settings that may be required. See "Set configuration jumpers and address switch" (page 22) for details.

Programming

Overview

The following example provides full stroke continuous flow, in standalone (AutoRun) mode.

- Special command strings are issued to each pump. Because this is a standalone application, the program strings are loaded into the pumps' EEPROMs using the [s] command. Strings run automatically at power-up when the AutoRun jumper is installed on the pumps after programming. The address switch indicates which string (memory location) will be run.
- Aspirate velocity must be faster than dispense velocity to provide time for the pump to be ready for triggering after aspiration.
- The [j] command trigger position parameters may require adjustment based on pump dispense velocity and syringe size.

C3000 example program strings

C3000 Pump A (sent to address 1):

s0J7ZV2000IA3000OV1000j100A0IV2000A3000J7OV1000j100g
H0A0IV2000A3000J7OV1000j100GR

C3000 Pump B (sent to address 2):
s1J7ZV2000IA3000OV1000j100gH0A0IV2000A3000J7OV1000
j100GR

C24000 example program strings

Note: Velocity may need to be scaled to account for the fact that the C24000 plunger moves 1/4 as fast as the C3000 at the same velocity [V] setting.

Pump A (sent to address 1):
s0J7ZV2000IA24000OV1000j100A0IV2000A24000J7OV1000
j100gH0A0IV2000A24000J7OV1000j100GR
Pump B (sent to address 2):
s1J7ZV2000IA24000OV1000j100gH0A0IV2000A24000J7OV1000
j100G

Command string breakdown for Pump A

s0	Store following string in EEPROM location 0 [s0].
J7ZV2000IA3000	Initial setup: set outputs high [J7], initialize pump [Z], set velocity to 2000 increments/sec [V2000], move valve to input position [I], aspirate a full syringe [A3000] at set velocity. **Note:** for C24000 pumps, A3000 would be A24000 instead. This applies below also.
OV1000	Prepare for dispense: move valve to outlet [O], set dispense velocity to 1000 increments/sec [V1000].
j100	When syringe position during dispense gets close to top of stroke (10 in this case) [j10], set outputs low [0]. This will trigger Pump B to begin its dispense.
A0	Dispense full stroke (trigger is sent to Pump B when position is at 10, as stated above).
IV2000A3000J7O V1000j100	When finished dispensing, move valve to input position [I], refill [V2000A3000], and reset for next dispense [J7OV1000j100].
g	Start of continuous loop.
H0	Wait for trigger from Pump B.
A0	Dispense full stroke (trigger is sent to Pump B when position is at 10, as stated above).
IV2000A3000J7O V1000j100	When finished dispensing, move valve to input position [I], refill [V2000A3000], and reset for next dispense [J7OV1000j100].
G	Repeat forever (back to [g]).
R	Run command string.

Command string breakdown for Pump B

s1	Store following string in EEPROM location 1 [s1].
J7ZV2000IA3000	Initial setup: set outputs high [J7], initialize pump [Z], set velocity to 2000 increments/sec [V2000], move valve to input position [I], aspirate a full syringe [A3000] at set velocity. **Note:** for C24000 pumps, A3000 would be A24000 instead. This applies below also.)
OV1000	Prepare for dispense: move valve to outlet [O], set dispense velocity to 1000 increments/sec [V1000].
j100	When syringe position during dispense gets close to top of stroke (10 in this case) [j10], set outputs low [0]. This will trigger Pump A to begin its dispense.
g	Start of continuous loop.
H0	Wait for trigger from Pump A.
A0	Dispense full stroke (trigger is sent to Pump A when position is at 10, as stated above).
IV2000A3000J7O V1000j100	When finished dispensing, move valve to input position [I], refill [V2000A3000], and reset for next dispense [J7OV1000j100].
G	Repeat forever (back to [g]).
R	Run command string.

10   Revision history

Revision history table

Revision information for this manual is shown in Table 10-1.

Table 10-1: Revision History

Date	Revision Level	Description
6/22/2017	C	Thorough revision and expansion to create comprehensive product manual.
10/25/2017	D	Updated company logo, made minor corrections and edited to maintain consistency with other product manuals and improve clarity. Added cautions about shipping with syringes installed, and about the capture of errors received during operation.
12/14/17	E	Corrections to RS232 pin assignments, affecting RS232 cabling diagram on page 26 and J3 pin assignment table on page 24. Other minor text changes.
9/17/2019	F	General update and upgrade. Minor corrections and changes to conform with current content standards. Changed syringe installation pictures and cabling diagrams.
1/27/2022	G	Brought instructions up to date with firmware versions V11 for the C3000 and C24000, and V10 for the C3000MP and C24000MP. Changes were also made to improve consistency among manuals.
2/14/2024	H	Brought instructions up to date with V12 firmware (date 032222), for C3000 and C3000MP. Corrected flow rate information and added cross-reference to flow rate information from "Converting increments to volume resolution." Changes were also made to maintain and/or improve consistency among manuals.

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