HARDWARE USER'S MANUAL

for the

VersaPump 3

SYRINGE DISPENSER MODULE

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Part Number 23454
Revision C for
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1.0 INTRODUCTION

1.1 GENERAL DESCRIPTION

The Kloehn VersaPump 3 (V3) syringe pump shown in Figure 1-1 is a programmable, precision, liquid metering instrument with user-programmable memory and Input / Output (I/O). It offers 6000 or 12,000 step resolution for its 3 cm stroke. Two to six port valves can be mounted, and syringes from 50 uL to 5 mL can be used. The unit can accept individual commands or programs via its serial communications interfaces.

Two-way, serial communications between the V3 and a controlling host is done via an RS485 or RS232 interface. Up to 15 addressable pumps or other devices can share a single, standard, bidirectional RS485 communications bus, controlled from a single PC serial port at baud rates from 1200 to 38,400 baud. Two protocols, DT and OEM, are supported, both of which are fully compatible with the Cavro protocols. The unit may be interrogated for status or operating parameter values at any time. Individual commands or groups of commands may be sent for immediate or later execution by the pump.

Command strings, or programs, can be executed from RAM or may be stored into and executed from the non-volatile memory (NVM). Up to 10 programs may be stored. A program in the NVM can be set to self-start when power is first applied to the pump and immediately after a Reset input. Program retention in the NVM is typically greater than 15 years without batteries. Program looping and if-then program flow control is supported.

Three external logic inputs and three logic outputs permit interfacing to a variety of other devices. One input can be used to halt a dispense in progress. A built-in digital voltmeter (DVM) is included. For applications which require more I/O, an I/O expander card is available to provide 16 more inputs and 16 more outputs.

Many different program test-and-jump instructions allow the pump to respond to external events and conditions as well as internal program conditions. External inputs can be used to set internal programmed operating parameters. The I/O can be used to operate a synchronized, two-pump, continuous flow application. Real-time, remotely-controlled and monitored I/O is supported simultaneously with other pump operations.

The V3 interface is located on a single card edge connector at the rear of the pump. This permits simple wiring connections and the use of modular, plug-in mounting.

1.2 OPTIONS

The VersaPump 3 series can be ordered in 6000 or 12,000 step resolutions, with or without valves. A starter kit with all the things needed to begin using the pump is also available from Kloehn Company. The kit includes cables, power supply, manuals, and software.

There are versions of the VersaPump3 which do not have any motor driver or control electronics. These versions come with an interface board containing the electromechanical interfaces and a convenient card edge connector.

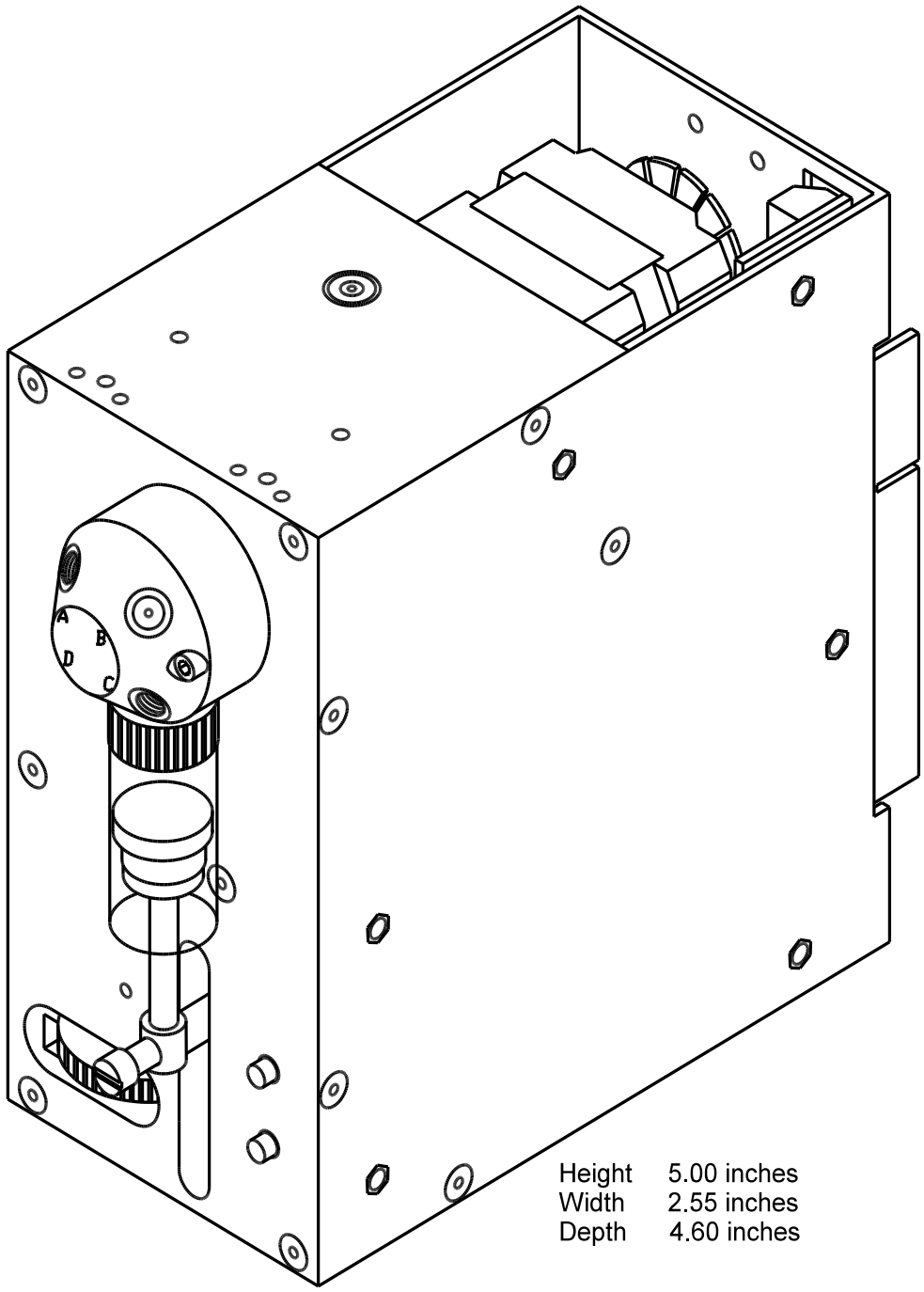


Figure 1-1 VersaPump 3 shown with syringe and valve installed

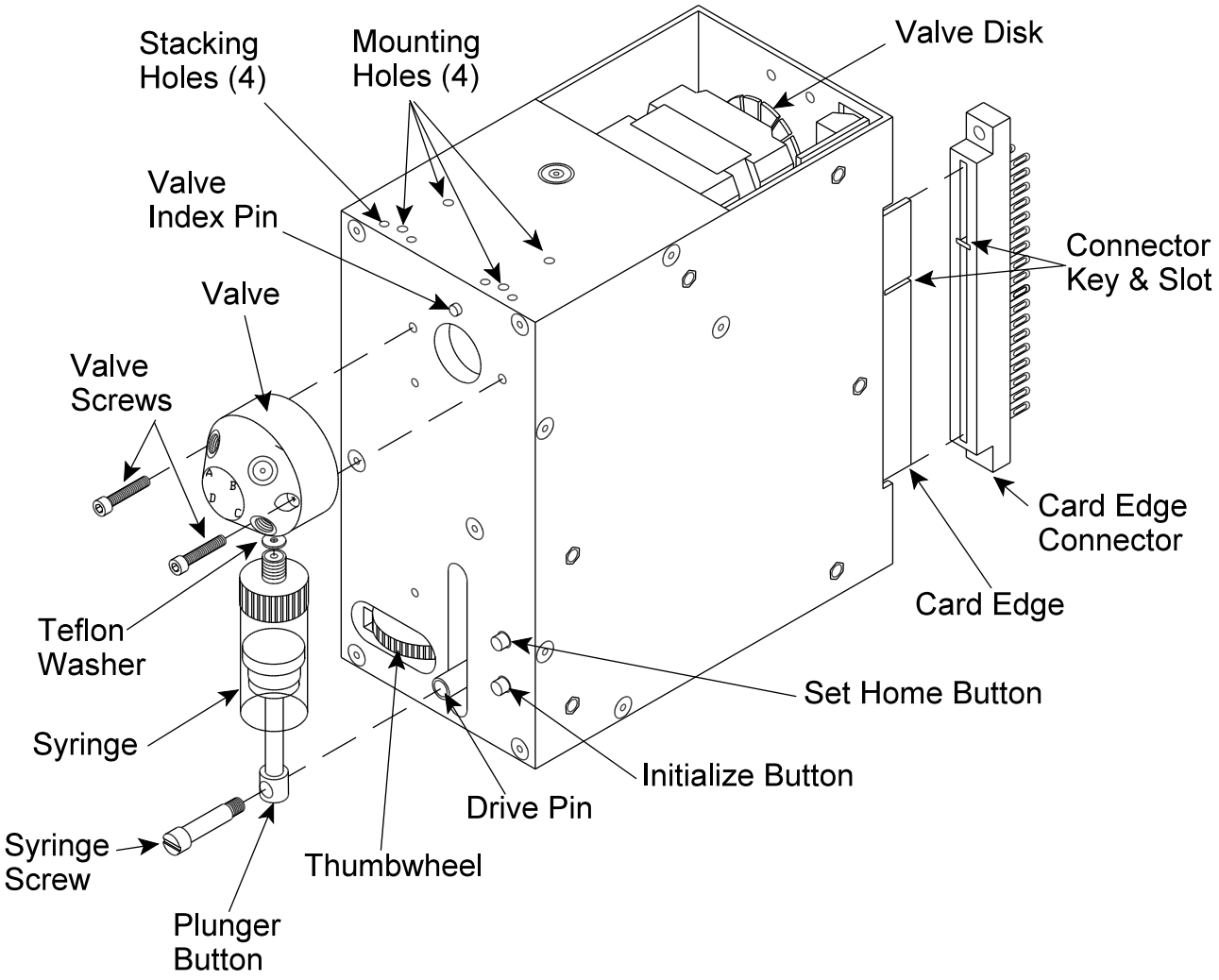


Figure 1-2 Pump Nomenclature

2.0 CARD EDGE INTERFACE

All electrical interfaces are located on the pins of the rear card-edge, P1, shown in Figure 1-1. The mating connector is a dual-row, 18 pins-per-row, card-edge connector on 0.156 inch centers. A connector can be obtained from Digi-Key (800-344-4539, or (www.digikey.com) as part number EDC305360-ND. The P1 pinout is shown in Figure 2-1.

2.1 INPUTS

2.1.1 Power Input

2.1.1.1 Connection

Power for the pump is input on 33 through 36 of the card edge connector. The positive power lead is duplicated on pins 35 and 36. The power ground is duplicated on pins 33 and 34. This permits two solid, straight wires to be passed through the edge connector in-line for a multi-pump system with plug-in pump modules.

2.1.1.2 Low Voltage Warning

When the pump supply voltage drops below an internal reference minimum (20V), a "Low Voltage" error message is generated. This message is generated only once for each drop in voltage. Continued low voltage is not reported in an error message; the voltage should be monitored, if necessary, by repeated queries of the supply voltage. Another low voltage error message will be generated only if the voltage should rise above the reference minimum and then drop below it again. If continuous low voltage error messages occur, the most likely causes are low-frequency noise or ripple on the power supply.

While the voltage remains below the minimum, valve and syringe moves are inhibited. However, unless the supply voltage drops below about 8 Vdc, the internal control electronics and memory are not affected and all other instructions, such as I/O operations and queries, will still operate normally after the low voltage error message has been reported or cleared.

Some power supplies will turn on gradually. If the rise time of the supply is slow enough, the internal computer may report a "Low Voltage" error when the pump is initially queried. This will not cause any operational problems after the message has been reported or cleared.

2.1.1.3 Power Supply Capacity

The power supply capacity should be consistent with the specifications of Section 10.3 of this manual both with regard to dc requirements and ac transient capability. If a Kloehn power supply is used, these specifications will be met.

An output capacity of 25 watts at 24 Vdc is considered a practical value for a one-pump power supply for normal pump operation. The normal idle power consumption is about 9 watts. The 25 watt rating allows for power required during

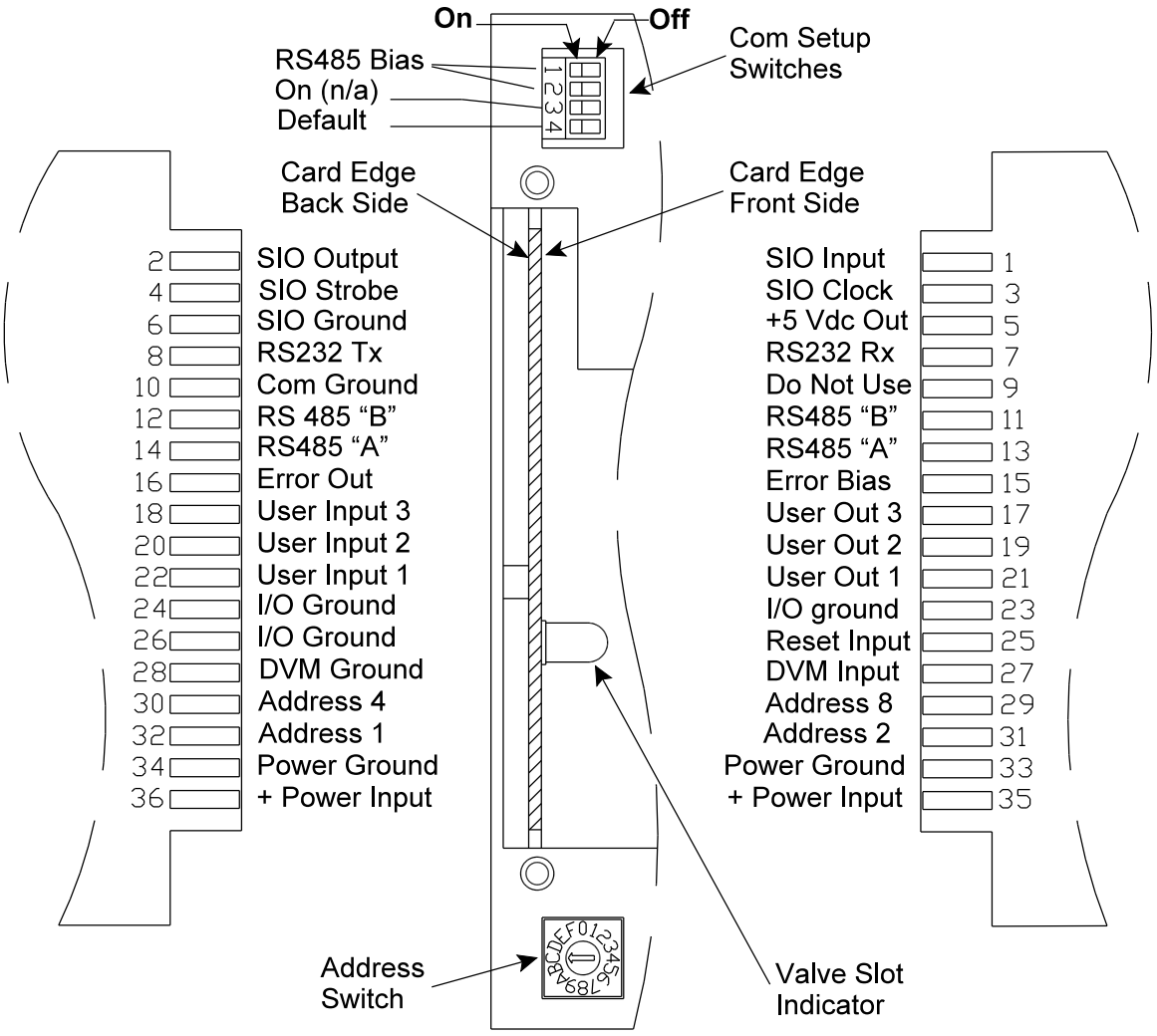


Figure 2-1: Syringe Drive Interfaces

syringe and valve moves, with a derating for reliability. The ac transient currents during syringe moves are negligible. During valve moves, the maximum current waveform has a 1.67 KHz sinusoidal shape with peaks at zero and 1.5 A.

For multiple pumps on one supply, the overall system operation should be considered. If there are N pumps, of which only M units will be making a syringe or valve move *at the same time*, then the power capacity of the supply should be at least 25M + 9(N-M) watts. If the syringes do not have to hold position against a back pressure, then the syringe motors can be turned off between moves, reducing the idle power per pump from 9 watts to 3 watts. There is no need to have the valve motor turned on when a valve move is not in progress. The pump automatically turns on the valve motor for moves and then turns it off when not moving.

In-rush current at initial power-up is approximately 1.4 A for about 1.7 milliseconds, then decaying to the idle current value.

2.1.1.4 Power Supply Selection

There are four classes of power supply: unregulated DC, linear regulator types, switching regulator types, and batteries. Each has different selection considerations.

The unregulated supply is the cheapest and simplest. Due to its unregulated nature, it is not recommended.

The linear regulator supply usually has a protective current limiting. This limit value must be set to at least 1.5 A to allow for the start-up in-rush current.

A switching power supply is the preferred choice. It offers higher efficiency, lower heat generation, and a well-filtered output. Note that some switching power supplies have a minimum load current requirement. Since the pump can idle as low as 50 milliamps, the supply should be rated for a minimum load current equal to the minimum total system idle current. A ballast resistor may be added across the supply output to guarantee the minimum load requirement of the supply.

Battery operation from 24 V battery systems is feasible. The wide operating range makes this possible. In most cases, a standby battery voltage of 28 Vdc is seen in automotive and aircraft systems. This is acceptable for normal operation. Mobile systems should provide overvoltage clamping for transients exceeding 34 Vdc.

2.1.1.5 Multiple-Unit Power Distribution

In a system with multiple syringe drive modules, the power distribution wiring can affect the system reliability. The best system wiring practice is to connect each drive module with an individual pair of power leads from the power supply to that individual module. This is called a "star" connection. The power leads for each module should be twisted together along their length to reduce radiated fields. External filter capacitors are not required, as internal filters are included.

2.1.2 Address Inputs

The device address on the communications bus can be hard-wired into the connector so a device can be inserted into an instrument without a need to set the address switch to a particular location. To use this feature, that address switch must be in the “F” position. If the address switch is in any other position, a conflict will result between a hard-wired address and the address indicated on the switch.

The address inputs have built-in pull up resistors and use positive logic. The default Address input level is logic “1". A logic “0" is made by grounding an Address pin. The address is set as a 4-bit binary number by shorting those pins to ground which should have a zero value. The address weighting on the pins is as follows:

Address 8 = 8 **Address 4** = 4 **Address 2** = 2 **Address 1** = 1

The address value is the sum of the pin weights which are not connected to ground. See Table 2-1 for the pin connections corresponding to the equivalent address switch settings.

To wire an address onto the card edge connector, convert the address “1" through

"F" into a binary representation of the hexadecimal number and ground the pins which should have a zero value.

The pin connections are shown below. A "Ground" indicates the pin should be connected to a ground pin. The notation "n/c"signifies there should be no connection to the pin.

Address	Address 8	Address 4	Address 2	Address 1
1	Ground	Ground	Ground	n/c
2	Ground	Ground	n/c	Ground
3	Ground	Ground	n/c	n/c
4	Ground	n/c	Ground	Ground
5	Ground	n/c	Ground	n/c
6	Ground	n/c	n/c	Ground
7	Ground	n/c	n/c	n/c
8	n/c	Ground	Ground	Ground
9	n/c	Ground	Ground	n/c
A	n/c	Ground	n/c	Ground
B	n/c	Ground	n/c	n/c
C	n/c	n/c	Ground	Ground
D	n/c	n/c	Ground	n/c
E	n/c	n/c	n/c	Ground
F	n/c	n/c	n/c	n/c

Table 2-1 Hard-Wired Address Table

To use the hard-wired address, the **Address Switch** MUST be set to "F". If it is not, an address conflict will exist between the wiring and the switch.

The address can be set with either the address switch or with the card edged connector wiring. **Only one** of the two methods may be used.

If the card edge connector wiring method is NOT used to set the pump address, the address must be set with the Address Switch (Figure 2-1).

2.1.3 Digital Voltmeter Input

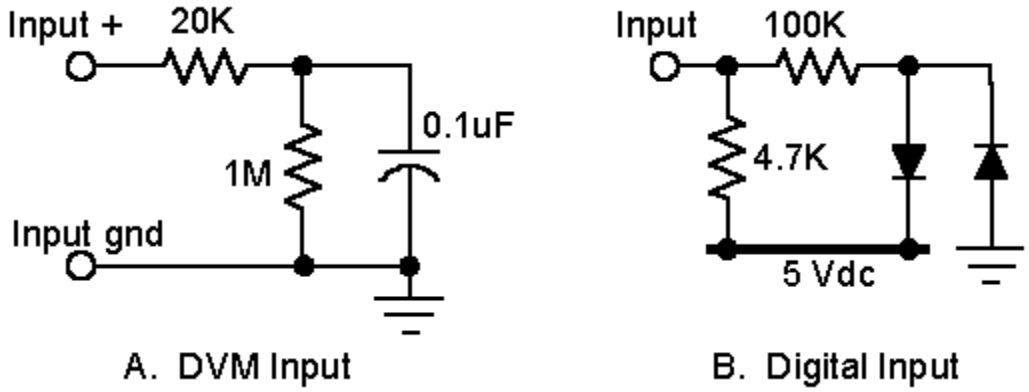
An 8-bit digital voltmeter (DVM) is built into the pump I/O. It is accessible on pins 27 and 28. The analog signal to be read should be placed on pin 27 and the analog signal ground should be connected to pin 28.

The **DVM Input** allows 8-bit measurements of external analog voltages. Analog values may be reported to the host controller, or used within a user program to compare a measured analog value to a user-preset value to make a conditional program jump. Also, the **DVM Input** can be used to set program instruction parameter values, as described in Section 4.5.2.

The input impedance is 1 Mohm for dc inputs, and is 20 Kohm in series with 0.1 uF capacitance to ground for high-frequency signals. This input impedance is due to the anti-aliasing filter. The anti-aliasing filter at the input, shown in Figure 2.2A, has a -3 dB cutoff frequency of 80 Hz, and an attenuation rate of -6 dB/octave above the cutoff frequency. Although the conversion time for an input sample is approximately 18 microseconds, the time constant of the filter is 2 milliseconds. If the input value changes, 5.5 time constants are required, worst-case, for the new value to settle to within the resolution (1/256 of full scale) of the DVM. If an abrupt step change were to occur as a conversion begins, the input filter time constant will insure that the correct valve at the start of conversion will be read to within the DVM accuracy.

The input voltage range is 0 to 5.1 V, corresponding to an internal conversion integer value from 0 to 255, respectively. It is recommended that the input voltage range be restricted to 5 V or less. Each increment of internal value (an LSB) corresponds to an analog input increment of 20 mV.

Figure 2-2 Equivalent Circuits of the User Inputs



A. DVM Input B. Digital Input

The internal numerical value for a DVM input can be calculated by this relation:

N = 50 x Vin where N = internal integer value
and Vin = analog input voltage

To avoid noise and errors due to ground loops, the ground wire of the voltage source to be measured should be twisted together with the input wire (a "twisted pair") and connected directly to the analog ground pin. If a shielded, twisted pair is used, the shield should be grounded at one end only.

2.1.4 Reset Input

A **Reset Input** is located on pin 25. When this pin is brought low (below 0.8Vdc), the processor resets. The reset condition remains active while the input is low. When the input is returned high, the processor begins a pump initialization cycle after a 0.25 seconds delay. The **Reset Input** is referenced to a ground on one of pins 23 to 26. Reset is also automatically generated internally when power is first applied. A reset causes the following actions:

(1) a checksum is computed on the firmware memory to verify its integrity
(2) the syringe position value is set to zero (position is no longer valid)
(3) the "position snapshot" values are reset to "-1"
(4) any error messages are erased (cleared) and the **Error Out** is turned OFF
(5) the valve moves to the "home", or port A position, if enabled
(6) temporary memory (RAM) is cleared
(7) the communications buffer is cleared
(8) the pump address is read and saved
(9) the Com Setup Switch status is read and saved
(10) syringe speeds are set to the values saved in the non-volatile memory
(11) the User Outputs are reset to OFF

2.1.5 User Digital Inputs

Three **Digital Inputs** are provided on pins 18, 20, and 22. Each of these inputs can be queried at any time, even during pump operation and while an internal program is executing. These inputs may also be used to control operation of the pump.

As shown in the equivalent input circuit in Figure 2-2B, each input has a 4.7K pull-up resistor and is protected for input voltages up to 30 Vdc. Inputs are compatible with CMOS and TTL logic operating from 5V supplies, with other pump's digital outputs, and with external switches. An "on" input is less than 1 V. An "off" input is more than 3.5 V, or an open circuit. The internal resistance provides the bias required for external switches. External switches should make a connection to ground when in the "on" condition.

> Do NOT apply voltages greater than 30 Volts to a User Input.

2.2 OUTPUTS

2.2.1 Digital Outputs

Three digital outputs are provided on pins 17, 19, and 12. These outputs appear directly opposite the digital inputs described in Section 3.5. Each output consists of an “HC” type CMOS output with a signal span of zero to 5 Vdc. The outputs may be controlled under internal user program control or may be set by external commands from a controller.

The **Digital Outputs** are “active low”. An “on” condition outputs a low logic level. An “off” condition outputs a logic high level. This is compatibility with the digital input logic levels. The maximum safe output current is specified in Section 10.7.1.

The **Digital Outputs** are “HC” type CMOS active outputs. Connect ONLY to logic inputs. Do NOT attempt to drive relays or solenoids.

2.2.2 Error Outputs

Pin 16 provides an **Error Out** suitable for driving logic or an LED indicator. The output is active whenever an unreported error condition exists within the pump. When an error condition occurs, the **Error Out** on pin 16 is set to an “on” condition, which acts like a 5 ohm resistance to ground. In the absence of and error or after an error has been reported to a controller via the communications I/O, the **Error Out** is an open-circuit.

The **Error Bias** output on pin 15 consists of a 330 ohm resistor connected internally to the +5 Vdc power. This output provides a current-limited output suitable for direct drive of an LED indicator anode. To drive an external LED error indicator, connect pin 15 to the anode and pin 16 to the cathode.

If an LED is not used, the **Error Out** can be used to drive some other error indicating device. The maximum output voltage in the “off” condition is 40 volts. If an external supply is used, a common ground connection should be taken from the I/O ground to the external supply ground. Since no internal protection is provided for inductive loads, if relays or solenoids are driven, a clamp diode across the load is required. For sending an error indication to a remote electronic equipment, the **Error Out** pin can be used to drive the input of an opto-isolator.

The Error outputs of several devices may be tied together to make a single "wire-OR'ed" system error signal. This signal may be used to drive a LED or an input to a controller.

2.2.3 5Vdc Power Output

To power external I/O circuits, the card edge interface includes a +5 Vdc power output on pin 5. This output is rated for loads up to 100 mAdc. Any of the Ground pins on the card edge may be used in conjunction with this pin.

2.3 SERIAL I/O EXPANSION (SIO)

The serial I/O (SIO) expansion port is independent of the serial communications port and is located on pins 1 through 6 of the edge connector. The SIO uses four signals: **SIO Input**, **SIO Output**, **SIO Clock**, and **SIO Strobe**.

The **SIO Input** receives serial data as 8-bit bytes from an external circuit and the **SIO Output** sends data as 8-bit bytes from the pump. The SIO port acts as a “master” using the **SIO Clock** to synchronize the serial data transfers bit-by-bit. The **SIO Strobe** acts as a synchronous, active-low enable signal for external devices.

Depending on the value of the SIO mode parameter “~S”, SIO operation will perform one-byte or two-byte data transfers.

2.4 COMMUNICATIONS I/O

The pump provides serial communications compatible with PC serial ports and RS485 I/O cards. There are to physical protocols, RS232 and RS485. There are two communications protocols, DT and OEM. See Section 6.4 for the communications physical protocol specifications and Section 6.3 for the communications protocols.

2.4.1 RS485 Communications I/O

The RS485 I/O is available on pins 11 through 14. There are two signals, **RS485 "A"** and **RS485 "B"**. The "A" line is the "positive" line, and the "B" line is the "negative" line under idle bias conditions. To prevent common-mode voltage errors, the communications should also use the **Com Ground** on pin 10 for an RS485 communication ground in addition to the "A" and "B" lines.

The "A" signal is duplicated on pins 13 and 14, while the "B" signal is duplicated on pins 11 and 12. This duplication permits a straight wire to pass straight through each pair of the "A" and "B" lines to interconnect a series of devices.

The RS485 bus requires a proper bias and termination network for reliable operation. The necessary network is included in the pump and is applied via the RS484 Bias toggles "1" and "2" on the **Com Setup Switch** shown in Figure 2-3. The first and last devices on an RS485 bus should have the network switched "on". All other devices between the first and last devices should have the network switched "off". A toggle is "on" when the button is positioned to the center of the switch housing; a toggle is "off" when the button is positioned nearest the edge of the switch housing.

Do NOT have more than two RS485 bias networks switched "on", regardless of the number of devices on the bus. Use ONLY one network "on" at each end of the overall RS485 bus wiring.

The com bus wiring should be a twisted pair for the "A" and "B" signals. The rate of twist should be approximately one to three turns per inch. The ground wire may be a shield or a third wire twisted with the "A" and "B" wires.

An RS485 bus with multiple devices must be wired directly from device-to-device, using "A", "B", and "Com Ground" pins.

2.4.2 RS232 Communications I/O

An RS232 communications option is available on the card edge connector. This provides a communications I/O compatible with the serial ports found on PCs and controllers.

There are two lines: **RS232 Rx** on pin 7 and **RS232 Tx** on pin 8. The Tx pin sends data from the pump to a controller, and the Rx pin receives data from a controller

to the pump. The **Com Ground** connection on pin 10 should be used to connect a communications ground line to the controller.

The RS232 protocol uses no flow control. Therefore, no signals other than RS232 **RxD**, **TxD**, and **Com Ground** are needed for serial communications.

2.5 REAR PANEL SWITCHES

2.5.1 Com Setup Switch

The **Com Setup Switch**, shown in Figure 2-1, is located at the top, left, rear corner of the pump. This switch has four "toggles", or "buttons" numbered "1" through "4". These toggles control whether the RS485 bias network is attached to the RS585 bus and whether the communications defaults for baud rate and protocol are set to the factory default values or to the values set in the configuration variables. The toggles are numbered from "1" at the top to "4" at the bottom of the switch. The toggle assignments are shown in Figure 2-3 below

The **Default** toggle (number 4) must be "**Off**" to enable programs to autostart.

Turn **"On"** BOTH toggles 1 and 2 to connect the RS485 bias network. Whether "On" or "Off", ***both*** toggles must be in the ***same*** position.

The **Default** toggle (number 4) must be in the "**Off**" position to permit the baud rate and protocol to change from the factory default settings.

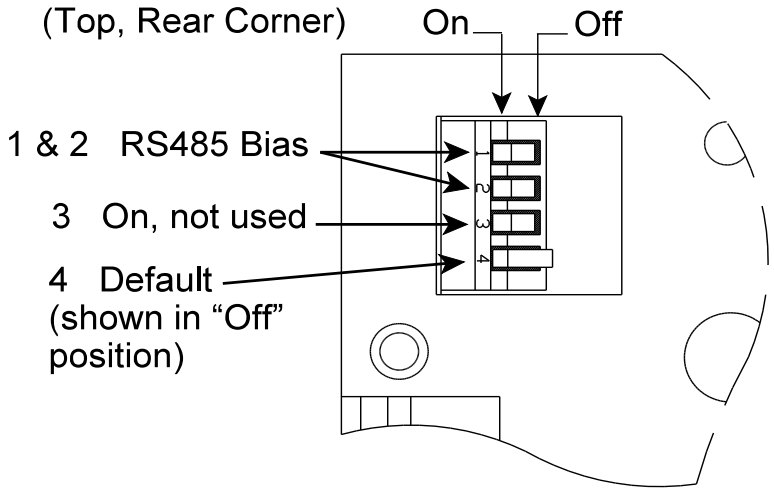


Figure 2-3 Com Setup Switch

2.5.2 Address Switch

The **Address Switch**, shown in Figure 2-1, sets the communications address of the pump on the RS485 bus. There are 15 legal pump addresses on the switch: “1" through “F”. Address “0" is reserved for a controller address and cannot be used for a pump address.

If the **Address Switch** is set to “**F**”, the pump address may be determined by wiring the Address pins on the card edge connector, as explained in Section 2.2. If the switch is in any other position, the wired address will conflict with the switch address.

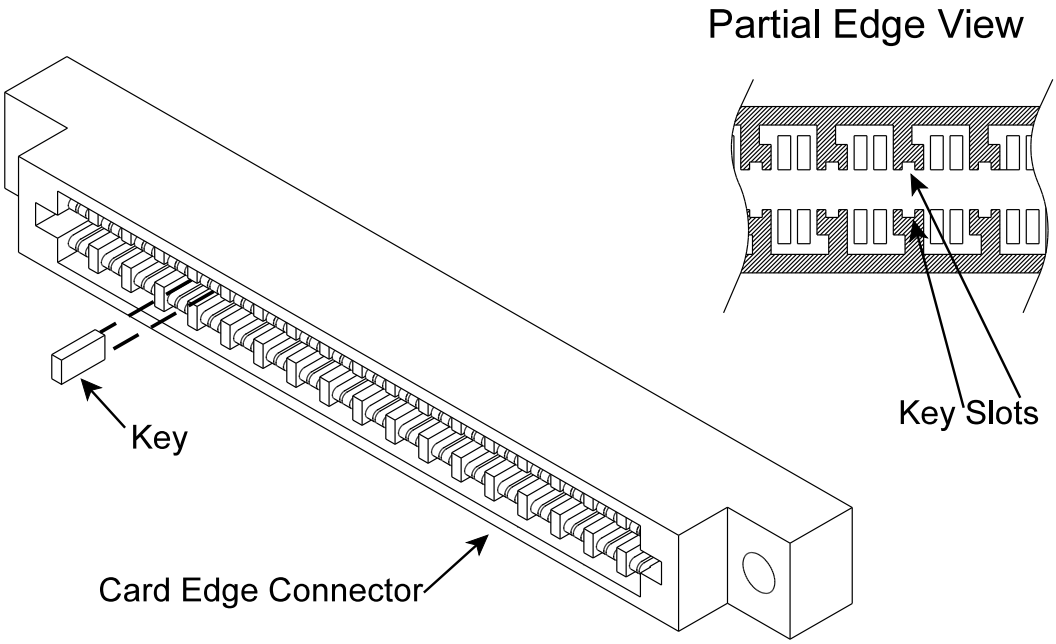


Figure 2-4 Connector Key Slot

2.6 CONNECTOR KEY

As shown in Figure 1-2, the card edge connector is supplied with a “key”. This key is a plastic insert in the connector which corresponds to the slot in the card edge as depicted in Figure 2-4.

Check the key to ensure it is in the proper position in the connector to match the slot in the card edge. The key may be moved by grasping it with a needle-nose plier and pulling it out of the connector. The key may be inserted into the connector by pressing the key into the detents which are located between each opposing pair of connector contacts.

3.0 GETTING STARTED

This section describes the basic setup required to control a single VersaPump 3 from a PC. Refer to Figure 1-2 for the assembly illustration. The following items are required for a basic bump installation:

Quantity	Item
(1)	VersaPump 3 drive module
(1)	Valve
(1)	Syringe
(1+)	Teflon washer (one per port used + syringe)
(1)	Power supply (24 to 30 Vdc, 25 Watts)
(1)	Communications cable, PC-to-pump, Kloehn P/N 17734
(1)	PC communications software
(1)	Card edge adapter board, Kloehn P/N 23352 or card edge connector, Kloehn P/N 23277 or equivalent.

Getting started requires certain basic actions be taken, in order. These actions are:

(1) Install a valve.
(2) Install a syringe.
(3) Set the Com Setup and Address switches.
(4) Connect power and communications.
(5) Configure the pump.

Section 3 leads the first-time user through these steps using either the Kloehn Starter Kit or user-supplied power and wiring. Advanced users can go directly to Section 4 to study the command set.

3.1 INSTALLING a VALVE

(1) Turn on the power to the pump and press the **Initialize Button** on the front panel of the pump. Wait for the initialize move to complete. The slot in the valve drive shaft should be horizontal.

(2) Insert the valve into the faceplate so that the **Valve Index Pin** engages a corresponding hole in the valve and the valve drive motor shaft slot engages the blade in the back of the valve. It may be necessary to rotate the valve slightly to cause full engagement of both the index pin and the motor shaft. The valve should seat flush onto the pump faceplate.

(3) Install the two **Valve Screws** through the valve and into the faceplate. Tighten the screws firmly, but only finger tight. Over-tightening can damage the valve.

Note: The valve should be in the port A position when installing the valve.

Note: If the valve is rotated too far during installation, the valve may be installed with the ports 180 degrees out of position.

3.2 INSTALLING a SYRINGE

(1) Place a Teflon® washer into the syringe port on the valve. This port is located at the bottom of the valve.

(2) Insert the syringe into the syringe port and tighten to a finger-tight tension. Do not over-tighten the syringe, as the hole in the washer will tend to clod flow into a smaller diameter over time.

> Note: The Teflon washer MUST be used to ensure the syringe fully seats. If the washer is not inserted, the syringe will not seat properly and will leak.

3.3 CONNECTING POWER and COMMUNICATIONS

There are two methods for connecting the pump to power and a PC. One method uses the Kloehn Starter Kit and the other method uses a Card edge connector with user-supplied wiring. Section 3.3.1 describes the setup with the Starter Kit. Section 3.3.2 describes the setup with the card edge connector. Use the section which is appropriate for the application.

3.3.1 With the Starter Kit

The Kloehn Starter Kit, P/N 23427, contains all the accessories needed to power the V3 pump and control it using a PC. The following items are included in the kit:

1. 24 Vdc Power Supply, P/N 17732, with power cables (Figure 3-3)
2. RS232 Communications cable, P/N 17734 (Figure 3-2)
3. Card Edge Adapter Board, P/N 23352 (Figure 3-1)
4. Disk with software and manual, P/N
5. Installation instruction sheet

3.3.1.1 Card Edge Adapter Board

The Card Edge Adapter Board (Adapter P/N 23352), shown in Figure 3-1, converts the card edge connector on the rear of the pump to a set of 0.1-inch connectors compatible with the 50300 series pump accessories, including the power supply cable and the communications cable. Inset the card edge connector on the board onto the card edge of the pump. The .1-inch connectors should be located near the center of the rear of the pump.

When inserting a wiring connector into an Adapter board connector, ensure the **Polarizing Key** is oriented toward the **Locking Tab**, as shown in Figure 3-5, and the pins are properly aligned with the connector.

3.3.1.2 Communications Cable

The Communications Cable (com cable) has a DB-9 connector on one end and a three-pin .1-inch connector on the other end, as shown in Figure 3-2. Plug the 3-pin

connector into the adapter board connector labeled “232". Note the polarization of the locking tab on the 3-pin connector as shown in Figure 3-1. Plug the DB-9 connector into a serial port on the PC.

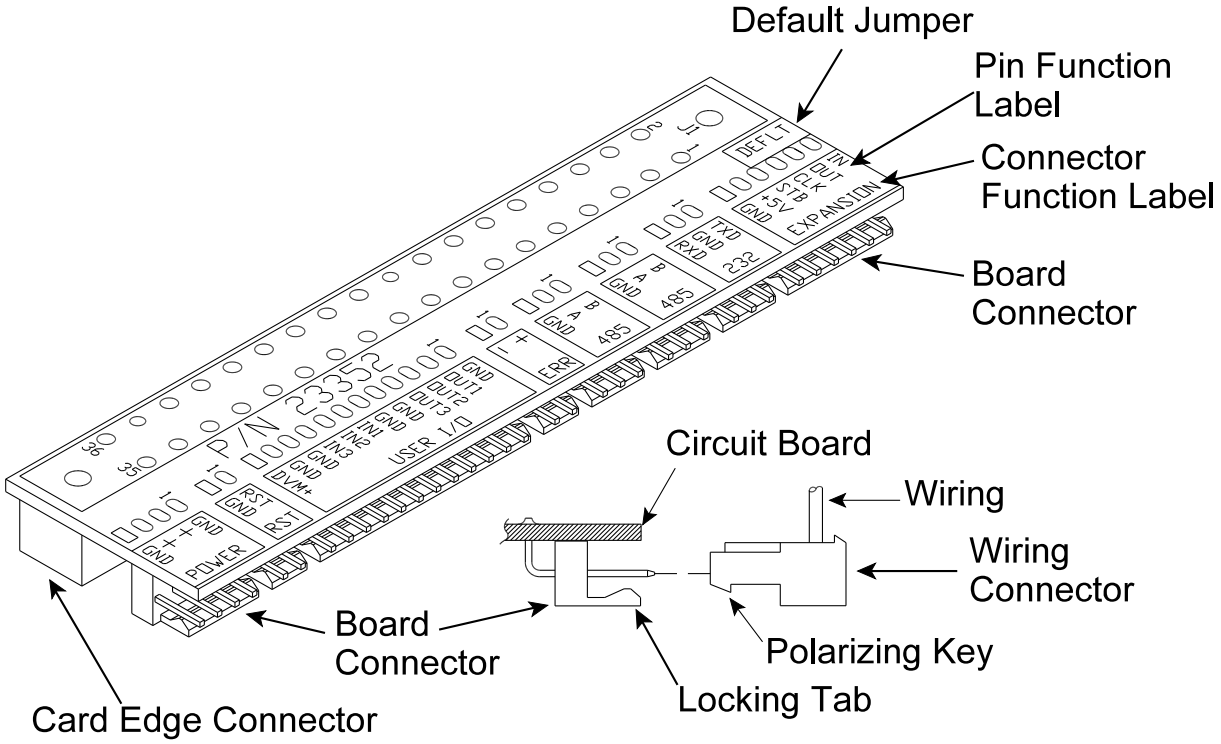


Figure 3-1 Card Edge Adapter Board P/N 23352

3.3.1.3 Power Cables

The 24 Vdc power supply, P/N 17732, is provided with two cables as shown in Figure 3-3. The 24 Vdc cable is integral to the supply and has a 4-pin connector attached. This cable connects to the pump via the Card Edge Adapter. Plug the 4-pin connector into the Adapter board connector labeled “POWER”. Observe the locking tab polarization.

A separate cable is provided to connect the power supply to an AC power source. This cable has a power **Switch**, a 3-prong **Wall Plug**, and a 3-pin **Power Connector**. Plug the 3-pin Power Connector into the mating **Receptacle** in the power supply, as in Figure 3-3. Plug the Wall Plug into a wall power socket.

Note the **Power Indicator Light** on the power supply. If it is not lighted, change the position of the Switch on the AC power cable. There will be a slight delay before the Power Indicator lights. When the indicator is lighted, the power supply is delivering 24 Vdc power to the 4-pin connector.

Note: On the 4-pin **DC Power** connector, the two inner pins are identical +Power Input and the two outer pins are identical Ground pins. The supply has sufficient output to power two VersaPump 3 devices or one VersaPump 6.

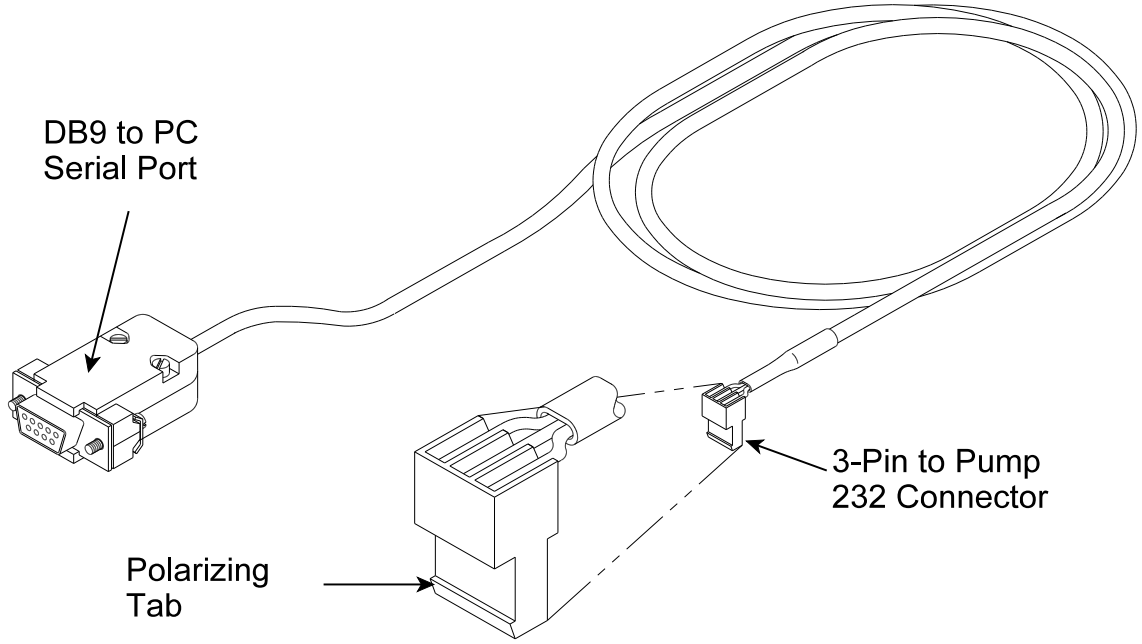


Figure 3-2 PC Serial Communications Cable P/N 17734

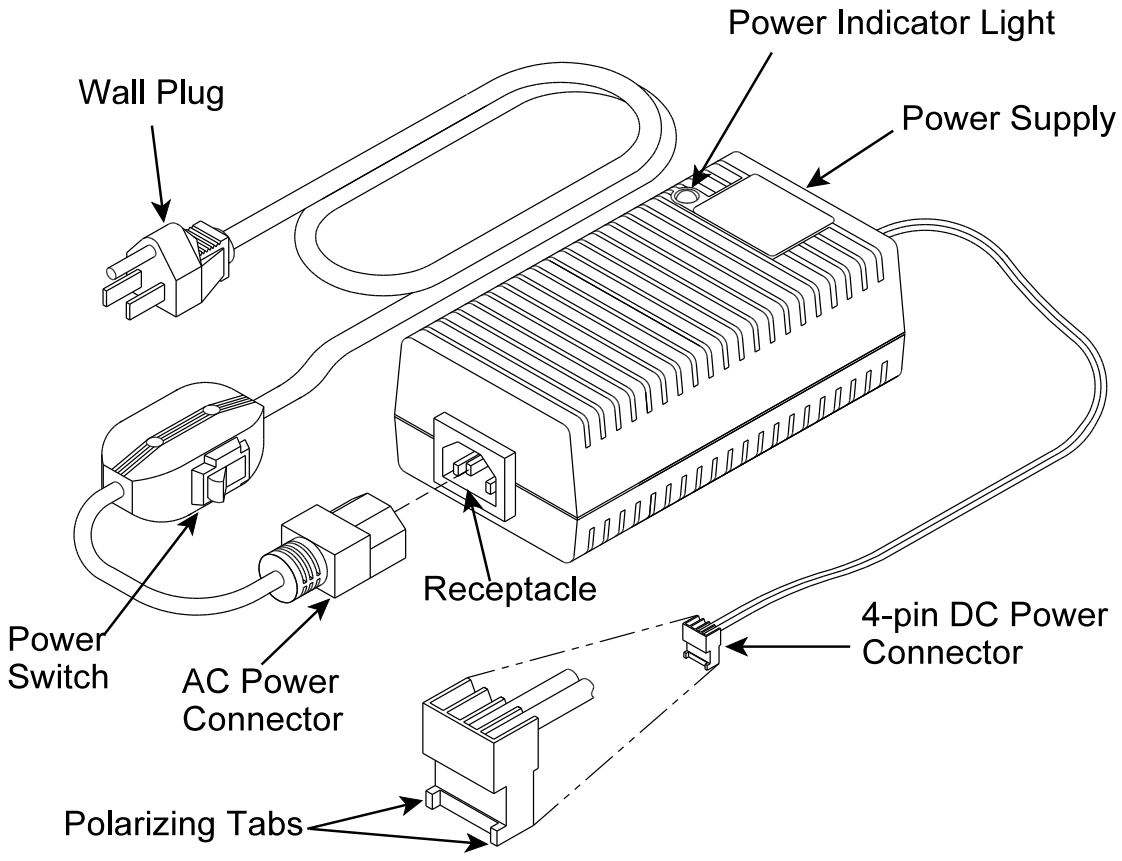


Figure 3-3 24 Vdc Power Supply P/N 17732

3.3.2 Without the Starter Kit

If the Card Edge Adapter Board (Adapter P/N 23352) is not used, the card edge connector, P/N 23277 or its equivalent is required. The connector is a 36-pin card edge connector having 0.156-inch pin centers.

Insert the card edge connector onto the card edge at the rear of the pump. Note the power pins are at the bottom edge of the connector, as indicated in Figures 2-1 and 3-4.

> Be certain the card edge connector is oriented with the power pins at the bottom of the connector as shown in Figures 2-1 and 3-4.

Figure 3-4 shows the connections for DC power and communications with a PC. The PC serial port connects to the “RS232" pins.

The RS232 cable wiring is illustrated in Figure 3-5 for both DB-25 and DB-9 connectors. For connecting more than one pump, see Sections 6.5 for communications wiring and Section 9.2 for power distribution wiring. Section 6.5 also illustrates the wiring for an RS485 bus.

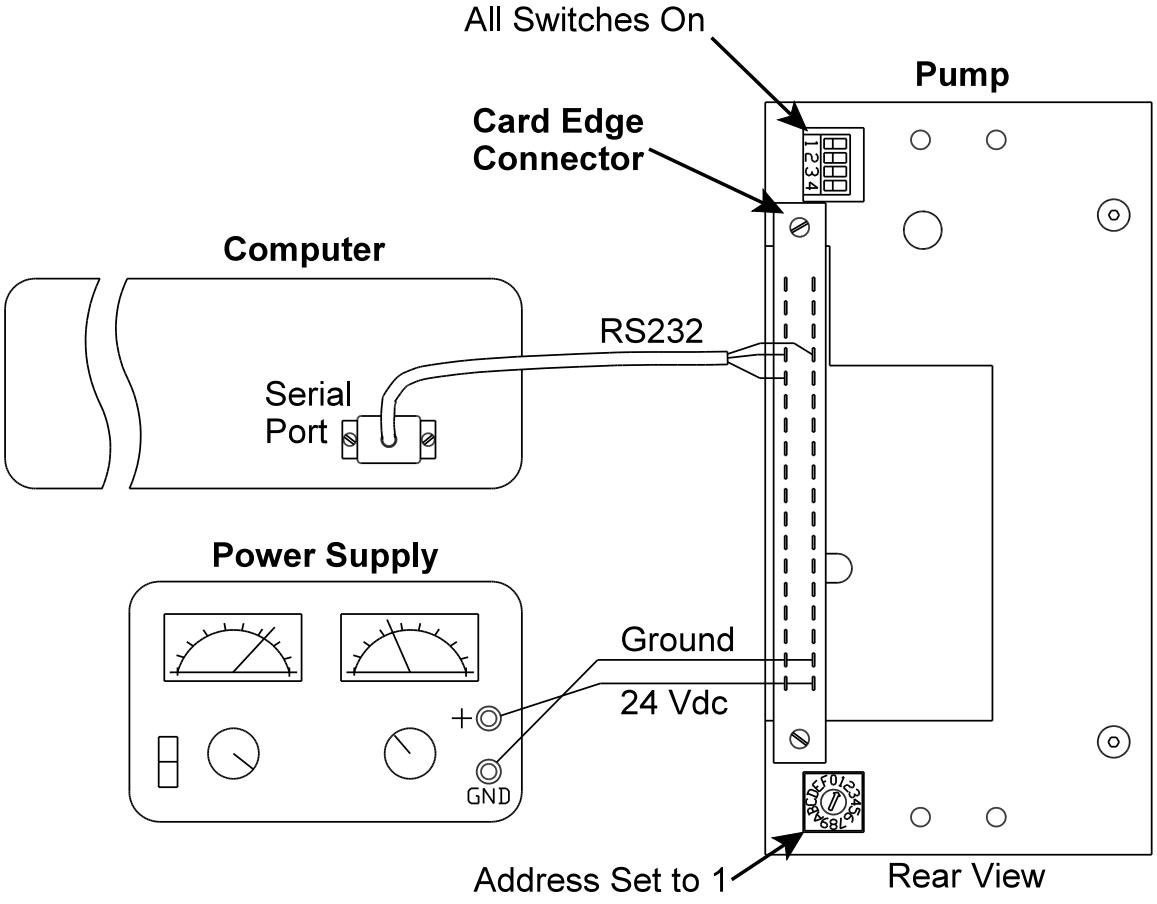


Figure 3-4 Pump Connections With Card Edge Connector

3.4 SETTING the SWITCHES

3.4.1 Com Setup Switch

The four toggles are located on the **Com Setup Switch** shown in Figures 2-3 and 3-4 should all be set to the “On” position.

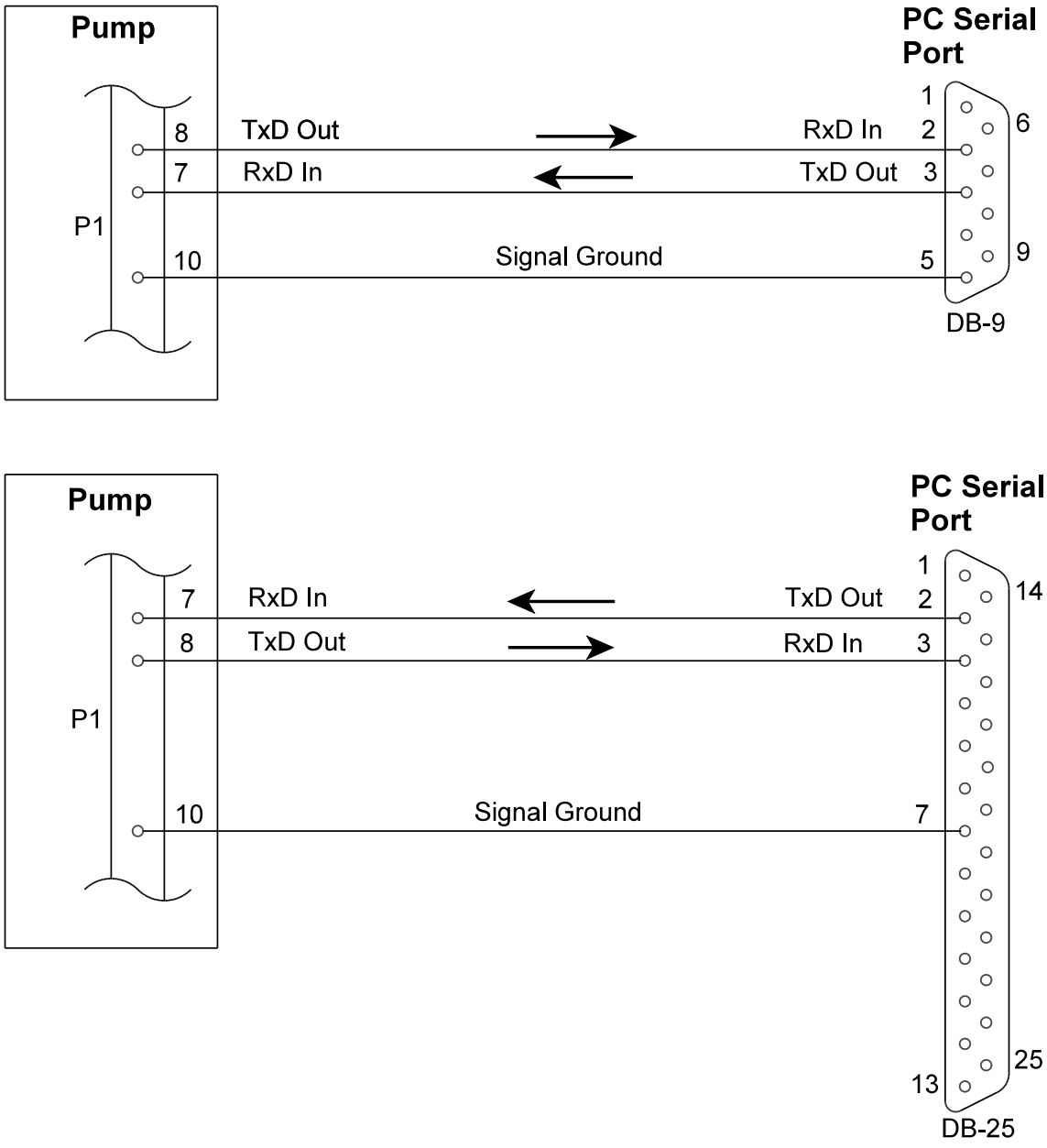


Figure 3-5 RS232 Communications Cable Wiring

Note pins 2 and 3 are reversed between the DB-9 and the DB-25.

3.4.2 Address Switch

The Address Switch, shown in Figure 3-4, set the device address number. Using a small screwdriver, set the switch to “1".

All communications with the pump begin with the address number. The address may be set with the Address Switch or by wiring on the Address pins of the card edge connector. The card edge wiring method permits a wire hamess to set an address when multiple pumps are used in an instrument. See Section 2.2 for the address wiring details.

3.5 SETTING UP COMMUNICATIONS

The HyperTerminal© program supplied with Windows® can be used to verify communications with the pump. If a communications program has been supplied by Kloehn Co., follow the setup directions supplied with the software. Otherwise, use the HyperTerminal program as described in this section.

3.5.1 Setting up HyperTerminal

HyperTerminal allows the monitoring of all pump responses to commands, without the filtering done by the WinPump program. The communications setup described in this section assumes the default communications parameters of "DT" protocol and "9600" baud.

The following procedure will locate and configure the HyperTerminal program.

(1) Click on the **Start** button in the Windows environment screen.

(2) Go to **Program** --> **Accessories** --> **Communication** –>**HyperTerminal** and click on the HyperTerminal folder.

(3) When the HyperTerminal window opens, double-click on the **Hypertrm.exe** icon

(4) At the name prompt, type "Kloehn" and dick on **OK**.

. (5) Go to **Connect Using**, select **Direct to COM1**, and click on **OK**. This will select a serial port. If you are using another serial port, then select the appropriate "Direct to Com...".

(6) In the new window, make these entries:

(a)	Bits Per Second	9600
(b)	Data Bits	8
(c)	Parity	None
(d)	Stop Bits	1
(e)	Flow Control	None

(7) When the preceding entries are made, click on **OK**.

(8) Go to the top line terminal menu and select **File**.

(9) Click on **Properties**.

(10) In the Properties window, click on the **Settings tab**.

(11) Click on the **ASCII Setup** button and place a check mark in the following boxes:
- ✓ Send line ends with line feeds
- ✓ Echo typed characters locally
- ✓ Append line feeds to incoming line ends
- ✓ Wrap lines that exceed terminal width

(12) Click on **OK** and then again on the next **OK**.

(13) Go to the top line terminal menu and select **File**.

(14) Select **Save As**.

(15) Click on **OK**.

Steps 13 through 15 create an icon named "Kloehn" in the *HyperTerminal* Window. This icon can be dragged onto the desktop and used for direct access to a pre-set version of *HyperTerminal*. Each time the terminal program is required in the future, the preceding setup steps need not be performed again. Just double-click on the new "Kloehn" icon.

3.5.2 Checking the Connection

When *HyperTerminal* or some other communications program has been set up for communications with the pump, verify the communications link is operational.

(1) Turn on power to the pump.

(2) After the pump has initialized, send the command: /1 **<Ente**r>

(3) The pump should respond with “/0`”. If this response is seen, proceed to the next section. If not, go to Section 6.6 for troubleshooting tips.

3.6 SENDING COMMANDS

3.6.1 General Command Structure

A ***command*** is an instruction to the pump to do one thing, such as move the syringe or turn the valve. Commands can combined, or ***concatenated***” to form ***command strings***. Command strings, also called ***programs***, can perform complex tasks consisting of many operations, including decision-making.

A command consists of ASCII characters and contain two parts: the ***command*** and its ***argument***. The command is a case-sensitive letter which represents a specific type of action to perform. The argument follows the command letter and determines how the command will execute. For example, the command “D1200" tells the pump to dispense (“D”) 1200 steps.

Commands which make decisions have *two* arguments. The first is a number which works the same way as for other commands. The second is a letter, which determines what the outcome of the decision will be depending on the circumstances. For example, the command “i2F” checks input (“i”) #2 for a low level. If the level is low, the program goes to the label “F” (a label is a “place marker” in a program). Other two-argument commands will be explained as they are listed in Section 4.

3.6.2 Command Addressing

All commands and command strings must begin with a device address. The device address determines which devices will respond to a particular command string. In this way, many devices can be connected together on a single communications line without interfering with each other. The character which signifies an address is the forward slash, “/”. When the slash is seen by a pump, the pump reads the character which follows as an address to determine if that pump should accept the command string. The individual device address is set via the Address Switch or by the Address pin wiring on the card edge connector.

For example, if the Address Switch is set to “3", a command string which begins with “/3" will be accepted by the pump. If the string were to begin with “/2", the pump would ignore the string.

Pumps may be addressed individually or in groups. The groups may be in pairs, groups of four, or all pumps on a single communications line. The details of pump addressing are given in Sections 6.1 and 6.2.

3.6.3 Pump Replies

When the pump receives a command string, it checks the string for correctness and sends a reply. The reply always begins with “/0", which is the address of the PC or controlling device. At least one character follows immediately after the “/0". This character is the ***status byte***. The status byte informs the controller of the current status of the communication and the pump.

There are two types of status: “ok” and “error”. There is a unique letter assigned to each type of error the pump can recognize. For every error, the status letter may be capitalized or small-case. If the status byte is capitalized, the pump is ***busy*** doing something. If the status byte is lower-case, the pump is not busy, and is ***ready*** for another command. The “ok” status has two special characters to indicate “busy” or “ready”: the accent mark “`” indicates “ready”, and the ampersand “@” indicates “busy”. A typical response is “/0`” or “/0@”. Both these responses indicate the pump and command string are ok.

Most command strings cannot be accepted until the previous command string is completed. The exception to this rule is queries. A query asks the pump to *report* something, not to *do* something. A query can be asked any time and will be answered when it is received, even if the pump is busy.

The commands are given and explained in Section 4. A command summary is listed in Appendix A. A complete listing and explanation of the status bytes is given in Section 5 and is summarized in Appendix B.

3.6.4 Configuring the Pump

Before the pump can be used, it must be ***configured***. Configuring a pump determines the way it will operate. The operating configuration is set by ***parameters*** stored in non-volatile memory (***NVM***). The NVM acts like a solid-state disk drive. The parameters determine such things as the type of valve, the communications baud rate, and other operating characteristics.

The parameters are set by the ***configuration commands***. Each parameter is represented by a letter which may be upper-case or lower-case. The pump recognizes a letter as a configuration command because the letter is preceded by a tilde "~". Following the tilde and letter, a number sets the configuration.

For example, the configuration command "~V8" sets the valve type to 6-way distribution. The "~" denotes a configuration command. The "V" denotes the valve parameter, and the "8" sets the valve to a six-way distribution. The valve parameter is the only parameter which MUST be set before the pump can be used.

Look up the valve parameter which corresponds to the valve type to be mounted to the pump. The parameters are listed in Section 4.2.2. Then send the command

/1~Vn <Enter> (Substitute the number of the valve type in place of "n".)
<Enter> means to press the **Enter** key on the keyboard.

3.6.5 Calibrating the Syringe

The syringe zero position must be calibrated prior to the first use of the syringe whenever a new syringe, valve, or syringe washer is installed. This is a simple procedure using the buttons on the front panel.

(1) With the syringe and valve already mounted to the pump, press the lower of the two front panel buttons, the **INITIALIZE** button. This will cause the syringe to move to a position a small distance below the top-of-stroke. This position is internally fixed and is sometimes called the ***soft limit***.

(2) When the INITIALIZE move completes, the syringe motor power will be Off. (Normally, when a move ends, the motor is left at half-power.) Rotate the **Thumbwheel** at the lower left corner to move the syringe piston upward until it barely contacts the top of the syringe. This will be the ***zero position***, also called ***Home***. In some applications, the position may be slightly below the top-of-stroke position if a small air gap is desired.

The zero position MUST be set ABOVE the INITIALIZE position by at least some small distance or errors will result.

(3) Press the upper button, the SET HOME button. The syringe will move downward to the INITIALIZE position and then return to the zero position.

When step (3) above executes, the location of the zero position is stored in NVM. This value will remain even after power is removed from the pump. The zero position will be remembered by the pump whenever the pump is powered up.

Do NOT do the calibration procedure each time the pump is powered up. Do the procedure ONLY when the syringe, valve, or syringe washer is changed.

3.6.6 Sending Some Commands

All the basic setup procedures are now complete. This section introduces some basic commands and illustrates the difference between individual commands and command strings. The notation <Enter> means to press the **Enter** key on the keyboard. The "R" at the end of each command means "Run the command now."

(1) Enter the command: /1W4R <Enter>

This initializes the syringe just as the INITIALIZE button did on the front panel.

(2) Enter the command: /1A6000R <Enter>

This causes the syringe to move to the position 6000 steps below the zero position. "A" means "go to the Absolute position". This will be half-way down for a 12000-step model or all the way down for a 6000-step model.

(3) Enter the command: /1o3R <Enter>

The valve will move clockwise (viewed from the front) to port "C". The "o" denotes a valve move and the "3" corresponds to port "C" (1=A, 2=B, etc.).

(4) Enter the command: /1D4000R <Enter>

The syringe will move 2/3 the distance to the zero position (syringe at 6000 moves upward by 4000 to position 2000).

The preceding sequence of single commands could have executed as a single command string, as happens next.

Enter the command: /1W4A6000o3D4000R <Enter>

The same sequence of commands is executed as for the individual commands, but without any delays and as if a single, more complex command had executed. This is an example of a command string. Next, a query will be illustrated.

Enter the command: /1? <Enter> (Query the syringe position)

The reply should be: /0`2000 (the position is at 2000 absolute)

Since queries are executed when they are received, no Run command was needed. This is true for all queries and configuration commands. For other commands, the command or command string will execute when the "R" command is sent, either at the end of the string or as the next command sent. For example,

/1A6000 <Enter> place the command in the pump
. /1R <Enter> now run the command

4.0 COMMAND SET

This section presents the commands supported in the VersaPump 3. The first column lists the command syntax. The values in parenthesis ( ) indicate the range of values. The value in brackets [ ] is the factory default value. The notation "@n" signifies the argument may be an indirect variable. Indirect variables are explained in Sections 8.1.4 and 8.3.7.

The non-volatile memory is limited to 10,000 writes. For this reason, use configuration commands only when a specific operating configuration must be changed. A configuration setting is stored for the life of the pump or until changed.

4.1 SYRINGE COMMANDS

There are two syringe resolutions: 6000 steps and 12000 steps, depending on the model of pump.

4.1.1 Positioning Commands

These commands cause the syringe to move to a commanded position along its range of motion. An absolute position is a specific point. A relative position is a distance offset from the current position. Absolute vs relative positions are illustrated in Figure 4-1.

It is highly recommended that the upper case form of the "An", "Bn", and "Cn" commands be used so that busy status can be ascertained. The lower case "an", "bn", and "cn" do not reveal busy status upon query.

In each of the commands below, the "n" value is expressed in *steps*, where "0" is at top-of-stroke (0 volume).

An Go to ***Absolute position*** "n", with the BUSY status bit set to "busy". (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

an Go to ***absolute position*** "n", with the BUSY status bit set to "ready". (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

Dn ***Dispense*** "n" steps from the current position, with the BUSY status bit set to a "busy". The dispense direction is upward, towards the valve. (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

dn ***dispense*** "n" steps from the current position, with the BUSY status set to I "ready". The dispense direction is upward, towards the valve. (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

Pn ***Aspirate*** ("Pick up") "n" steps from the current position, with the BUSY status bit set to a logic "1". The aspirate direction is downward, away from the valve. (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

pn ***Aspirate*** ("pick up") "n" steps from the current position, with the BUSY status bit cleared to a logic "0". The aspirate direction is downward, away from the valve. (n: 0...6000 steps or 0...12000 steps, @n) [n/a]

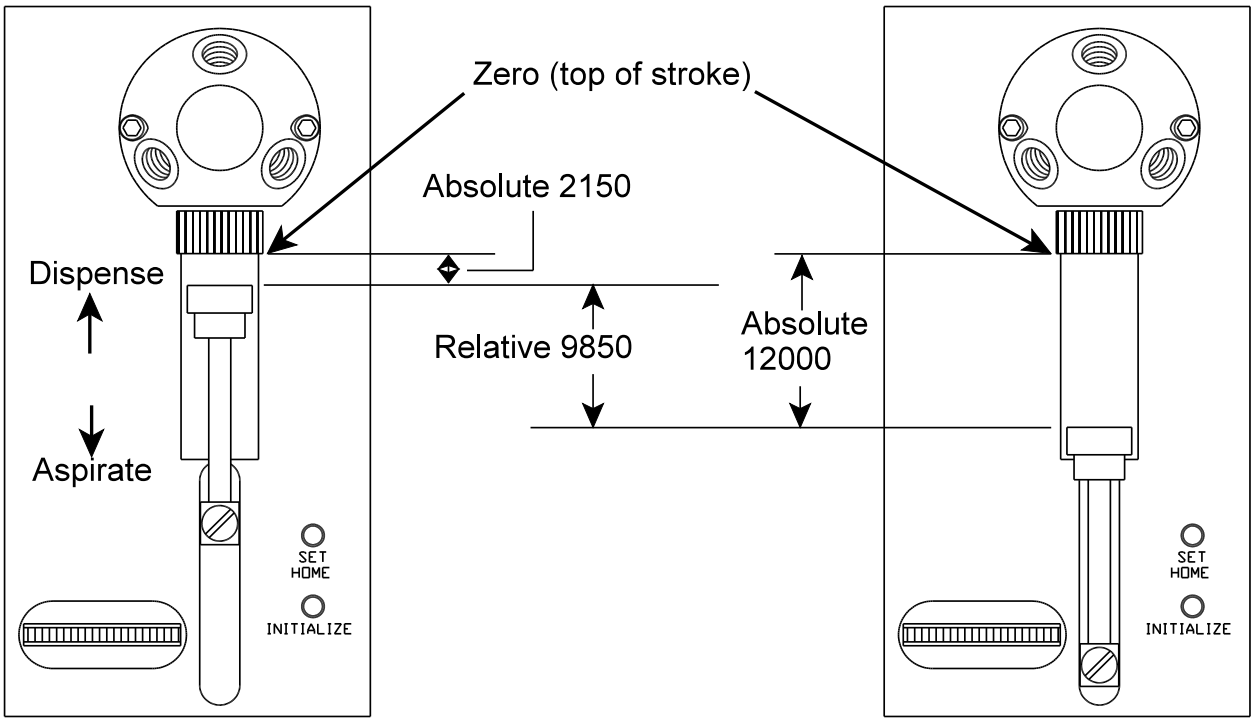


Figure 4-1 Relative vs Absolute Positions

Referring to Figure 4-1, *relative position* is measured from the *current position* to the target position. *Absolute position* is measured always from *zero position* (top of stroke). In the figure above, a move from the upper position at 2150 absolute to the lower position at 12000 absolute can be done with either a relative aspirate (move downward) or an absolute (go to position) command as follows.

Absolute move: A12000 (final position measured from zero)

Relative move: P9850 (final position measured from 2150)

Both commands will result in the syringe moving to the position shown on the right. In general, any move which goes to the zero or maximum (full-stroke) positions should use an absolute positioning command (e.g, “A0" or “A12000"). A move which goes from one position to another position which is not at either end of the stroke would use a relative positioning command (“Pn” or “Dn”), although an absolution positioning command could also be used.

All moves to *Zero* or to the *full-stroke* positions should use an *Absolute* position command (e.g., “A0" or “A12000").

Use the capitalized version of the An, Pn, and Dn commands. Lower-case versions will not report a “busy” status if the pump is queried while moving.

hn Do a ***handshake dispense***, using User Input #n and User Output #n for the handshake signals. See Section 8.3.3 for details about programming a handshake dispense application.
(n: 1...3, @n) [n/a]

h-n Trigger a ***handshake dispense immediately***, without an external input stimulus.
(n: 1...3, @n) [n/a]

The handshake dispense is a coordinated sequence between two pumps in which one pump dispenses while the other pump aspirates. When one pump completes its dispense, the other pump begins its dispense. By summing the outputs of the two pumps, a continuous flow can be synthesized.

The coordination between the two pumps is done automatically by the pumps when their inputs and outputs are connected as explained in Section 8.3.3. The value of "n" in the handshake dispense commands determines which of the user inputs will be used for the handshake coordination. For example, if the command is "h2", then the pump will use input #2 and output #2.

As each pump nears the end of its dispense, it provides an advance trigger signal to the other pump, which immediately begins its own dispense. The timing on the trigger signal is automatically adjusted to compensate for different acceleration settings.

4.1.2 Motion Variables

The syringe axis uses the following variables to determine the speeds, accelerations, and drive compensation moves. See Section 8.2.3 for tips on setting speed and acceleration values.

During power up of the pump, default values in the operational memory are recalled from the NVM. The operational values can be set at any time a move is not in progress. *Top Speed* is an exception, as it can be set "on-the-fly".

Except as noted, all these commands require a "R" (Run) command to execute immediately.

Cn Set the ***Stop speed*** to "n" steps per second (sps).
(n: 40...8000, @n) [650]

cn Set the ***Stop speed*** to "n" steps per second (sps).
(n: 40...8000, @n) [650]

Kn Set the number of syringe ***backlash steps*** to "n" steps. Backlash compensates for mechanical slack in the drive system. Too little backlash compensation will result in an error in the initial dispense movement following an aspirate move.
(n: 0...500, @n) [100]

Ln Set ***acceleration and deceleration*** slopes to "n", where the actual acceleration value in steps per second per second = n x 2500 sps/sec.
(n: 1...20, @n) [7]

In Set ***deceleration*** slope independently to "n", where the actual deceleration value in steps per second per second = n x 2500 sps/sec.
(n: 1...20, @n) [7]

Example: L12 set the acceleration and deceleration parameters both to “12"

I15 set only the deceleration parameter to “15"

Sn Set a predefined ***syringe speed***. The speeds in the table below are in steps per second (sps). (n: 0...33, @n) [n/a]

Sn	sps	Sn	sps	Sn	sps	Sn	sps
0	6400	9	1800	18	190	27	100
1	5600	10	1600	19	180	28	90
2	5000	11	1400	20	170	29	80
3	4400	12	1200	21	160	30	70
4	3800	13	1000	22	150	31	60
5	3200	14	800	23	140	32	50
6	2600	15	600	24	130	33	40
7	2200	16	400	25	120		
8	2000	17	200	26	110		

Vn Set the syringe ***Top speed*** to "n" steps per second (sps). The *Top speed* is the rate at which dispenses and aspirates operate. *Top speed* can be changed "on-the-fly" during a syringe move. For speeds above 1000 sps, changes in speed which are too large may stall the syringe motor. A “R” command is not required for this instruction.
(n: 40...8000, @n) [3500]

vn Set the ***Start speed*** to "n" steps per second.
(n: 40...1000, @n) [650]

! Store the current values of *Top speed*, *Start speed*, *Stop speed*, and *Backlash* as the default values to be used after each power-up or reset. This command may not be stored within a program.

For most applications, only the *Acceleration* and *Top speed* are adjusted. The remaining parameters are left at the default settings. If the *Top speed* should be set to a value lower than the *Start speed*, the pump will begin the move at the *Top Speed*. If the *Top speed* is set lower than the *Stop Speed*, the move will end at the *Top Speed*. For this reason, values of *Top speed* which are set lower than either the *Start Speed* or the *Stop Speed* do not require any adjustment in *Start speed* or *Stop Speed*.

4.1.3 Initialization

The syringe position must be initialized (calibrated) after each power-up, reset, or syringe overload condition. Until the syringe has been initialized, other syringe movement commands will not be accepted. This is because the syringe position cannot be absolutely known after the preceding conditions occur. An initialization command causes the syringe to go to the *INITIALIZE* position. This is the only

absolutely known location on the syringe stroke when position information is lost or corrupted. All other positions can be determined once this position is known.

Initialization may use one of three commands: Wn, Yn, or Zn. Each operates in the same way except for the definition of the valve port positions used during initialization. For all initialization commands, the argument "n" denotes an initialize move (n = 4) or a “set home” operation (n = 5).

The “W4” command always initializes the syringe using port “A”. The “Y4” and “Z4” commands initialize the syringe using the valve port which has been set by the “~Yn” or “~Zn” commands, respectively. This permits three different ports to be used for syringe initialization.

The front panel *INITIALIZE* button executes only the “W4" command. The *SET HOME* button effectively executes all three “W5", “Y5", and “Z5" commands, as there is no practical difference between these three versions.

The initialize commands require a “R” command to execute immediately.

Wn ***Initialize*** the syringe. This must be used on systems with no valve.
(n: 4 or 5) [n/a]

n=4 Move the syringe to the *INITIALIZE* position after moving the valve to port A.

n=5 Set the current syringe position as the "Zero" position. The result is automatically stored in non-volatile memory (NVM).

Yn ***Initialize*** the syringe after moving the valve to the port corresponding to the number stored for the "~Yn" configuration command.
(n: 4 or 5, refer to command "Wn" for explanations of "n" values) [1]

Zn ***Initialize*** the syringe after moving the valve to the port corresponding to the number stored for the "~Zn" configuration command.
(n: 4 or 5, refer to command "Wn" for explanations of "n" values) [1]

~Yn Select the valve position which the valve will use while initializing the syringe. This parameter value is used by the "Y4" command. This command checks the “~V” parameter to determine which port numbers are acceptable.
(n: 1...8) [1]

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

~Zn Select the valve position which the valve will use while initializing the syringe. This parameter value is used by the "Z4" command. This command checks the “~V” parameter to determine which port numbers are acceptable. See the “~Yn” command for the number-to-port letter translation.
(n: 1...8) [1]

4.1.4 Syringe Queries

? Query the syringe *absolute position*.

?1 Query the syringe *Start speed* ("vn" value) in equivalent steps per second.

?2 Query the syringe *Top speed* ("Vn" value) in equivalent steps per second.

?3 Query the syringe *Stop speed* ("cn" value) in equivalent steps per second.

?29 Query the contents of the *syringe position snapshot* memory.

?30 Query the *acceleration* and *deceleration* numbers ("Ln" and "lm" values). Two numbers are returned. The first number is the acceleration number and the second is the deceleration number.

~Y Query the *valve port number* used by the "Y4" syringe initialization command.

~Z Query the *valve port number* used by the "Z4" syringe initialization command.

4.2 VALVE COMMANDS

The valve ports are not inherently directional. The actual direction of fluid flow at any port is determined by the relative motion of the syringe. An aspiration draws fluid into a port and a dispense ejects fluid from a port.

For non-distribution valves, some valve positions block the syringe port, preventing fluid from entering or leaving the syringe. The pump does not allow syringe moves in those positions with such valves.

For each move command, the argument "n" determines both the destination port and the direction of valve rotation The default direction is clockwise.

4.2.1 Valve Type Setting

The VersaPump 3 uses a universal valve position encoder which can accommodate different valve types. The valve type is selected by sending the valve configuration command "~Vn". The value of the parameter "n" is automatically stored into the non-volatile memory (NVM) when command is received. Once stored, it should not be set again unless the valve type is changed. The valve type is stored even when power is removed from the pump. The valve configuration command cannot be placed within a program.

~Vn Set the valve type. [default = 0]
(n: 0 = no valve
1 = 3-way non-distribution 2 = 3-way distribution
3 = 4-way non-distribution 4 = 4-way distribution
5 = 5-way non-distribution 6 = 5-way distribution
7 = 6-way non-distribution 8 = 6-way distribution) [n/a]

4.2.2 Valve Position Commands

The valve position commands require a “R” (Run) command to be appended to cause immediate execution.

B Move a three way standard valve to the "bypass" position (port A-to-port B).

I Move a three way standard valve to the "input" position (port A-to-syringe).

O Move a three way standard valve to "output" position (port B-to-syringe).

The preceding three commands are used with a *3-way non-distribution valve only*.

on Move the valve to the position selected by "n". This command is the preferred command for all valve moves. The values of “n” must be consistent with the configured valve type (see Configuration Commands). Positive numbers cause clockwise rotation as viewed from the front. Negative numbers cause counterclockwise rotation as viewed from the front.
(n: -8...8, not including 0, where 1= port A, 2 = port B, etc., @n) [n/a]

Example:	/1o4R	Move the valve on pump #1 (“/1") clockwise to port 4 (port “D”), and do it now (“R”)
Example:	/3o-2R	Move the valve on pump #3 (“/3") counter-clockwise to port 2 (port “B”) now

When a valve fails to tum the commanded amount, a *valve stall* has occurred. The valve automatically decreases its speed by half and tries again. If the second attempt fails, the valve decreases its speed by half again and makes a third attempt. If the third attempt also fails, a ***valve overload error message*** is generated. See Section 5 for error messages.

> Due to automatic valve move retries after a valve motor stall, the time for a valve move can vary significantly. Do ***NOT*** use timing loops in controller software to assume a valve move has completed.

When writing software to control the pump, do not assume a valve move will complete in a certain time. In the event of a motor stall and subsequent automatic error recovery attempt, the time required for the valve to complete a valve move can increase substantially beyond the normal time for a move. Instead, query the pump status with a carriage return (hex 0D, decimal 13) character to determine if the pump is busy or the move has finished.

Example:	command	/1<carriage return>	Query the “busy” status
	reply	/0@	/0 = host address (fixed) @ = status is ok and busy
	Command	/1 <carriage return>	Query “busy” status again
	Reply	/0'	` = ok, not busy (done)

4.2.3 Valve Queries

Valve queries require no "R" command to execute. They are executed immediately after they are received by the pump. These commands can not be embedded within a program.

?8 Query the current valve position. Return the ASCII numerical value. (1= port A, 2 = port B, etc.)

$ Query the number of valve stalls. Send the result to the host as an ASCII number. The value of the returned number is the number of times a stall and subsequent automatic error recovery occurred. "0" = no error. If the third attempt fails, a valve overload error is generated.

% Query the number of valve movements since the last power-up or Reset. Return an ASCII number.

~V Query the valve type setting. Return the value of the "**~Vn**" parameter. (See Section 4.2.1 for the values.)

4.3 I/O COMMANDS

4.3.1 Output Commands

These commands set a User Output logic level or send an output byte via the Serial Expansion I/O port. All these commands require a "R" command to execute immediately.

sn Send a serial byte from the User Serial expansion Port, MSB first. The value of the ASCII number "n" is the base 10 representation of the value of a binary byte. For transmitted bytes, positive logic applies ("1" = high logic level). In the 2-byte serial mode, "n" represents the second byte sent. The first byte is the same as the first byte sent by a "sn,m" instruction. See Section 4.5 for an explanation of "@n" usage.
(n: 0...255, @n) [n/a]

Example: s85 Send the decimal number "85" in binary format. The serial I/O device will receive the binary number 01010101 (= 85 in decimal - base 10 - format). A "1" is a high logic level and a "0" is a low logic level.

sn,m Send two bytes from the User Serial expansion Port, byte "m" first and then byte "n" second. Both bytes are sent MSB (most significant bit) first. The values of "n" and "m" are expressed as the ASCII base 10 representation of the binary bytes.
(n: 0...255, m: 0...255, @n) [n/a]

Example: s85, 129 Send the decimal numbers 85 and 129 as binary numbers. The external serial I/O device will receive the binary numbers 01010101 10000001. A "1" is a high logic level and a "0" is a low logic level.

Example: s@10, 35 Send two numbers. The first is the same first number sent when this command was last used, and the second number is “35" (00100011). See Section 4.5 for an explanation of "@n" usage.

Un Turn the user parallel output "n" ON (low logic level) or turn on a serial I/O port output bit.
(n: 1...3 = parallel outputs 1...3
11...18 = serial byte 1, bit 1...8 of the serial expansion port
21...28 = serial byte 2, bit 1...8 of the serial expansion port) [n/a]

Example: U2 Turn On (set to low logic level) user output #2

Example: U25 Turn On bit 5 in byte #2 of the serial expansion I/O

un Turn the user parallel output "n" OFF (open-circuited) or turn off a serial I/O port output bit.
(n: 1...3 = parallel outputs 1...3
11...18 = serial byte 1, bit 1...8 of the serial expansion port
21...28 = serial byte 2, bit 1...8 of the serial expansion port) [n/a]

A special syntax is available for controlling the outputs while the pump is executing other commands or a program. This allows immediate, real-time control of the outputs. The syntax is a variation of the preceding output commands. The syntax is

U#n Turn ON (set low) an output immediately.

u#n Turn OFF (set high) an output immediately.

These commands use the same values for “n” as the Un and un commands.

4.3.2 Input Query Commands

Input query commands are sent from a host controller and request a status reply from the pump. These commands are executed when they are received by the pump and do not require a “R” command. These commands can not be embedded in a program string.

?4 Query the "User Input 1" status. Send the value to the host as an ASCII "1" if "true" (low logic input level) or an ASCII "0" if "false" (high logic input level).

Example:

command	/5?4	Query User Input #1 status on pump #5
reply	/0'1	/0 = host address (fixed assignment) ‘ = status is “not busy” and “no errors” 1 = input is “true” (low input logic level)

?5 Query the "User Input 2" status. Send the value to the host (see "?4").

?6 Query the "User Input 3" status. Send the value to the host (see "?4").

?7 Query the analog input value at the Digital Voltmeter input. Send the value to the host controller as an ASCII base 10 number. Voltage = number x 0.02 volts.

Example:

command	/1?7	Query Digital Voltmeter input on pump #1
reply	/0'157	/0 = host address (fixed assignment) ‘ = status is “not busy” and “no errors” 157 = 157 x .02 = 3.14 Volts

?10 Query the value of the *first* byte received from the Expansion I/O port input. An input byte is shifted in (MSB first), and the numerical value of the first input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). In 1-byte mode, this is the only byte. In 2-byte mode, this is the first of two bytes.

Example: The inputs for the first byte are 11001001 (201 decimal)

sent	/2?10	Query pump #2 Expansion input, byte #1
reply	/0'201	/0 = host address (fixed assignment) ‘ = status is “not busy” and “no errors” 201 decimal = binary 11001001

?20 Query the value of the *second* byte received from the Expansion I/O port input in 2-byte mode. Two input bytes are shifted in (MSB first), and the numerical value of the second input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). This instruction is not valid in 1-byte mode. See “?10" above for an example.

?n Query the state of the Expansion I/O port input bit designated by "n". A serial byte is input (MSB first), and the state of the designated bit is reported as an ASCII "0" if the bit is "false" (high input logic level) or an ASCII "1" if "true" (low input logic level).
(n: 1...3 = parallel outputs 1...3
11...18 bit 1...8 in Expansion input byte #1
21...28 bit 1...8 in Expansion input byte #2)

4.3.3 Input Test and Jump Commands

The value of an input can be checked and its status can be used to cause a program to change the path of the instructions to be executed. This is called a ***conditional jump***. The general format is

If the input is “true”, then jump to the place marked by the program label

These commands are used to control the way a program executes, depending upon the state of an input variable. The commands are intended to be embedded within a program string and not to be executed alone. See Section 4.4.3 for more information about program jumps and labels.

inp If the input level is true (low input level), jump to label "p". This checks if a user input pin on the card edge connector is at a low level. There are three user inputs. If an ***I/O Expansion Board*** is used, the number of inputs increases by 16, organized as two bytes of eight bits each.
(n: 1...3 User input number 1...3
11...18 bit 1...8 in Expansion input byte #1
21...28 bit 1...8 in Expansion input byte #2
p: a...z, A...Z) [n/a]

Example: i18b Test bit #8 in Expansion byte #1. If it is at a low level, begin executing the instructions at program label “b”. If it is not at a low level, continue with the next instruction after this one.

i<np If the analog input (DVM) value is less than the number in the command, jump to label “p”. The input voltage range of 0 to 5V is converted into one of 255 levels. The number “n” is the numerical value of the level. This can be found as n = 51 x input volts, truncated to an integer number.
(n: 0...255, @n p: a...z, A...Z)

Example: i<126s Test the Digital Voltmeter input, and if the voltage is less than 2.48 V, then go to program label “s”. (126 = integer part of 51 x 2.48.)

i>np If the analog input (DVM) value is greater than the number in the command, jump to label “p”. The input voltage range of 0 to 5V is converted into one of 255 levels. The number “n” is the numerical value of the level. This can be found as n = 51 x input volts, truncated to an integer number.
(n: 0...255, @n p: a...z, A...Z)

4.4 USER PROGRAM COMMANDS

Commands, command strings, and programs are executed in the pump RAM (temporary) memory. The pump can also store programs in non-volatile memory (NVM). The NVM acts like a solid-state disk drive. See Section 7 for details on the pump’s internal memory.

User *program storage* commands can load, save, run, or erase user programs in the pump memory. Program *execution* commands are used to stop or start programs. Program *control* commands determine the order of execution (flow) of a program.

4.4.1 Program Storage

These commands control the storage, retrieval, and erasure of a user program in the non-volatile user program memory (NVM). These command execute when received and can not be placed within a program. A “R” command is not required.

En Store the current command string into non-volatile memory. Maximum program length is 170 characters.
(n: 1...10) [n/a]

en erase a stored command string in non-volatile memory.
(n: 1...10) [n/a]

qn Return a copy of a program currently stored in the non-volatile program memory (NVM).
(n: 1...10) [n/a]

?9 Query the number of unused bytes (characters) in non-volatile program memory. (390 maximum)

?19 Query which program numbers are currently used to store a program. Return a list of the numbers in use, separated by a space between numbers.

4.4.2 Program Execution

The non-volatile user-program memory and its "auto-start" capability are unique to Kloehn pumps. The external "Stop" input function is also an added feature on Kloehn pumps. Only the "H" command can be used within a program. These commands do not require a “R” command for immediate execution.

~An Enable or disable *autostart* for a program in NVM. If “n” is not zero, begin executing the numbered program when power is applied or after a reset. If autostart is disabled, a stored program is started with the "r n" command.
(n: 0 = disable, 1...10 = enable, @n) [0]

~A Query the autostart state. Return "0" if disabled, "1" if enabled.

H Halt the executing command string or program. This is used to create *breakpoints* in program execution. The "H" command is for inclusion within a program string and cannot be used as a command sent externally to a running program. A program stopped by an "H" command within the program may resume execution with the command following the "H" command if a "R" command is subsequently sent.

r n run stored program #n in the non-volatile program memory. (External command)
(n: 1...10, @n) [n/a]

jn Do stored program #n and then continue with the present program.
(n: 1...10, @n) [n/a]

R *Run* the command string in RAM. If the command string has been stopped by an "H" command, resume execution.

T Terminate execution of current command string. An externally-sent command only, it is executed when received. A valve move in progress will go to completion when a "T" is received. If the “T” command is used while the syringe is moving above about 2000 steps per second, the pump may generate a “Z” error when it passes up through the INITIALIZE point.

The “T” command may cause the syringe to “loose steps” and generate a “Z” error if the “T” command is used to stop the syringe motion at a high speed.

4.4.3 Program Control

4.4.3.1 Jumps and Labels

A program *jump* provides a means to change the order of execution of program commands. The point from which a jump occurs is a *jump command*. Program execution is changed from the location of the jump command to the destination *label* ("p") specified in the jump command.

A jump may be *unconditional*, which executes every time it is encountered, or it may be *conditional*. Conditional jumps are “if...then” commands. The jump to a label will occur only if the specific test condition in the command is true. Remember “Do if True”. Jumps and labels are unique to Kloehn pumps.

:p Declare the program label "p" (case sensitive).
(p: a...z, A...Z)

Jp Jump unconditionally to program label "p". This is the only unconditional jump command.
(p: a...z, A...Z)

fnp If the flag is set (=1), then clear it and jump to label “p”. This is useful to change the way a program executes if the path has already been done once before. The program will jump the first time this instruction is encountered, but not when it is encountered after the first time. A ***flag*** is a bit which can be set (turned “on”), cleared (turned “off”) or tested (if...then). There are eight flags, numbered 1 through 8.
(n: 1...8 p: a...z, A...Z)

f-np If the flag is clear (=0), jump to label “p”.
(n: 1...8 p: a...z, A...Z)

inp If the input level is true (low input level), jump to label "p". This tests if a user input pin on the card edge connector is at a high or a low level. There are three user inputs. If an ***I/O Expansion Board*** is used, the number of inputs increases by 16, organized as two bytes of eight bits each.
(n: 1...3 User input number
11...18 bit 1...8 in Expansion input byte #1
21...28 bit 1...8 in Expansion input byte #2
p: a...z, A...Z)

i<np If the analog input (DVM) value is less than the number in the command, jump to label “p”. The input voltage range of 0 to 5V is converted into one of 255 levels. The number “n” is the numerical value of the level. This can be found as n = 51 x input volts, truncated to an integer number.
(n: 0...255, p: a...z, A...Z)

i>np If the analog input (DVM) value is greater than the number in the command, jump to label “p”. The input voltage range of 0 to 5V is converted into one of 255 levels. The number “n” is the numerical value of the level. This can be found as n = 51 x input volts, truncated to an integer number.
(n: 0...255, p: a...z, A...Z)

k<np If the software counter is less than "n", jump to label "p". A software counter is internal to the pump and can be set to a number, added to, subtracted from, and tested. It is useful for counting program events and for the temporary storage of internal variables such as syringe or valve position. See Section 4.9.1 for more information on software counters.
(n: 0...65535, @n p: a...z, A...Z)

k=np If the software counter is equal to "n", jump to label "p".
(n: 0...65535, @n p: a...z, A...Z)

k>np If the software counter is greater than "n", go to label "p".
(n: 0...65535, @n p: a...z, A...Z)

s<np If the Expansion I/O input byte has a value less than "n", jump to label "p". This reads in the value of the *first* I/O Expansion input byte and compares the numerical value of the byte against the number in the command.
(n: 0...255, p: a...z, A...Z)

s>np If the Expansion I/O input byte is greater than "n", go to label "p".
(n: 0...255, @n p: a...z, A...Z)

y<np If the syringe position is less than "n", jump to label "p". This is useful in loops which repeatedly aspirate or dispense until some event occurs. This test can prevent the error which occurs if a move is commanded beyond zero or full-stroke.
(n: 0...6000 or 0...12000, @n p: a...z, A...Z)

y=np If the syringe position is equal to "n", jump to label "p".
(n: 0...6000 or 0...12000, @n p: a...z, A...Z)

y>np If the syringe position is greater than "n", go to label "p".
(n: 0...6000 or 0...12000, @n p: a...z, A...Z)

4.4.3.2 Repeat Loops

A program *loop* causes a group of commands to repeat. A loop may be constructed from a jump command and a label. Such a loop will repeat indefinitely unless a conditional jump is included within the loop to cause an exit from the loop. The ***repeat command*** offers a better way when the number of repeats is known.

The ***repeat command*** causes a group of instructions to repeat a specific number of times. The syntax is "g...Gn". The "g" command marks the beginning of the group of commands to be repeated, and the "Gn" command marks the end of the group. The value "n" denotes the number of times the loop is to be repeated.

g Mark the beginning of a group of commands to be repeated.

Gn Mark the end of a repeat string, to be repeated "n" times.
(n: 0...30000) [n/a]

Example: go1P6000o3A0G10

g...G10 repeat the sequence of commands ten times

o1	set the valve to port “A” (1 = A)
P6000	aspirate 6000 steps
o3	move the valve to port “C” (3 = C)
A0	dispense all the contents of the syringe (go to zero)

“o1P6000o3A0", the command string between “g” and “G10", will be repeated ten times.

4.4.3.3 Time Delays

A time delay is a pause in a program. These are useful for timing events such as generating pulses, very slow syringe moves, and event synchronization.

Mn Delay (pause) "n" milliseconds. The "Mn" command will wait for "n" milliseconds before moving to the next command. 1000 milliseconds = 1 second.
(n: 1...60000) [n/a]

4.5 VARIABLES

A variable is command *argument* (command value) which permits a command to use a value which is determined at the time the command executes within a program, rather than being set to a fixed value when the program is written. This permits more general programs to be written and stored.

There are two types of variables: *general* and *indirect*. General variables are set by the user and are declared before a program is run. Indirect variables use values obtained from hardware inputs or internal pump values. All variables use the syntax “@n”, where the @ symbol denotes a variable and the value of “n” denotes the source of the variable.

4.5.1 General Variables

There are eight general variables, z1 through z8. There are two forms of syntax used with the general-purpose variables: one to use the variable in a command and one to set the value of the variable.

4.5.1.1 Setting a General Variable

The value of a general variable is set with the syntax:

zn = m	“z” denotes a general variable “n” is the variable identification number “m” is the value assigned to the variable

Example: z3=4500 The general variable is “z3" and the value 4500 is assigned to it. In the example of Section 4.5.1.2, the dispense would be 4500 steps, given this declaration.

The value of a general variable may be declared at any time prior to the execution of the program using the variable. The value of the variable must be valid for the command in which it is used. If an invalid value is used, an error message results.

Example: z1=45z2=4500z5=12000r7 A typical run-time declaration for a stored program

z1=45	Set general variable z1 = 45
z2=4500	Set general variable z2 = 4500
z5=12000	Set general variable z5 = 12000
r7	“r7" means to run the stored program #7 in the non-volatile memory using these variable settings.

The "zn" command executes as soon as the pump recognizes the command. The "zn" command cannot, therefore, be stored as part of a program. The values of all "zn" commands are stored into RAM, and are lost if the power is removed from the pump or if the pump is reset. The default value of all zn variables is zero after a reset.

4.5.1.2 Using a General Variable

The syntax for a general variable is:

@1n where The @ symbol denotes a variable.
The “1" denotes a general variable
The “n” denotes which general variable to use
(n: 1...8)

The general variables and their argument values are:

Argument	Variable	Argument	Variable
@11	z1	@15	z5
@12	z2	@16	z6
@13	z3	@17	z7
@14	z4	@18	z8

Example: D@13 Dispense an amount equal to the value of the general variable “z3".

4.5.2 Indirect Variables

Indirect variables are determined by the value of an input or by some internal condition. The variable syntax is “@n”, where “@” denotes a variable and “n” denotes the source of its value. The indirect variables are listed below.

@1 Numerical value of Expansion input byte #1, read as a two-digit packed BCD number (0...99)

@2 Numerical value of Expansion input byte #2 #1, read as a two-digit packed BCD number (0...99)

@3 Digital Voltmeter input (0...255)

@4 Digital Voltmeter input (two-digit BCD, normalized to 0...99. Normally used for external displays driven from the Expansion port.)

@5 Current Software Counter value (0...65535)

@6 Current valve position (1...number of ports for valve type)

@7 Current syringe position (steps, normally used in other commands)

@8 Current syringe position (two-digit BCD, normalized to percent of full stroke, 0...99. Normally used for external displays driven fro the Expansion port.)

@9 most recently-sent value of the byte #2 sent with the sn,m command

@10 most recently-sent value of the byte #1 sent with the sn,m command

4.5.3 List of Commands Using Variables

The commands listed in this section may use variables. The column labeled "Scaled" indicates if the variable is scaled for use with a particular command. Variables which are not scaled are used as the actual numeric value of a command argument. Variables which are scaled are used to compute a proportional amount of the argument's range. The proportion is

argument value = (variable value / maximum variable) x maximum argument

Example: o@3 Not scaled. Use the number as the value. If the number were "6", the command would be "o6".

Example: V@3 Scaled. The value used for the command will be proportional to the maximum value of the number. In this case, if the value of @3 were "127", the actual argument would be 3984. This is computed as follows:

Maximum V = 8000, maximum analog value (@3) = 255.

Value = (127 / 255) x 8000 (The value is to 8000 as 127 is to 255.)

In the preceding example, the DVM input accepts a dc voltage from 0 to 5 Volts and converts this voltage to a parameter value. A parameter value may be scaled. Thus, if a potentiometer is used to input a voltage, the potentiometer dial could be calibrated to read from 0 to 100 percent, and would then be applicable to any scaled parameter.

A given variable is not restricted to use by one command nor to one instance of a command. However, the value of a variable must be compatible with all commands which use it. The following commands can use a variable in place of a fixed value for "n". Variables can not be used for labels.

Instruction		scaled
An, an	move syringe to absolute position	yes
cn	set stopping speed	yes
Dn, dn	dispense, relative to current position	yes
g...Gn	repeat loop	no
inp	if serial input bit true, jump to "p"	no
i>np	if analog input > "n", jump to "p"	no
i<np	if analog input < "n", jump to "p"	no
jn	do program #n, then return	no
Kn	set number of backlash steps	yes
kn	set software counter = "n"	no
k+n	add "n" to software counter	no
k-n	subtract "n" from software counter	no
k<np	if counter < "n", then jump to "p"	no
k=np	if counter = "n", then jump to "p"	no
k>np	if counter > "n", then jump to "p"	no
Ln	set acceleration slope	no
ln	set deceleration slope	no
Mn	delay "n" milliseconds	yes
on	move valve to position "n"	no
Pn, pn	aspirate, relative to current position	yes
Sn	set top speed	no
sn	send SIO byte	no
sn,m	send SIO double byte	no
s<np	if serial input < "n", then jump to "p"	yes
s>np	if serial input > "n", then jump to "p"	yes
Vn	set top speed (steps/sec)	yes
vn	set start speed (steps/sec)	yes
y<np	if syringe position < “n”, jump to “p”	no
y=np	if syringe position = “n”, jump to “p”	no
y>np	if syringe position > “n”, jump to “p”	no
~An	set autostart program number	no
~Bn	set communications baud rate	no

4.6 CONFIGURATION COMMANDS

Configuration commands are used to determine the operating parameters of the pump. All configuration commands begin with a tilde, “~” and have two forms: the *set* form and the *query* form. The set form uses a numerical argument to set the value of a parameter. The query form is the command with no number attached. The query form reports the present value of the parameter.

All configuration parameters are automatically saved into the non-volatile memory (NVM) when they are set. The settings will be remembered even without power for the life of the pump or until they are changed.

Configuration commands execute when they are received and do not require a “R” command. They can not be used within a program. Either upper or lower-case letters may be used.

~An Select the program to auto-start when the power is turned on. A selection of "0" means no program is selected for an autostart. If the value is not zero, the number is the program number to be autostarted after power-up or

Reset. If no parameter "n" is entered, the current value of "n" is returned. (n: 0...10, @) [0]

~Bn Select the communications baud rate. If no parameter "n" is entered, the current value of "n" is returned.
(n: 0...7) [3]

n	Baud rate	n	Baud rate
1	38,400	5	2,400
2	19,200	6	1,200
3	9,600	7	600
4	4,800	8	300

~Hn Set the SET HOME button mode on the faceplate. If no parameter "n" is entered, the current value of "n" is returned. This parameter determines if the front panel SET HOME button is working or not working. This is useful for preventing users from resetting the Home position of the syringe.
(n: 0 = the button operation is enabled.
1 = the button operation is disabled.) [0]

~in Enable or disable the valve power-up initialization mode. If no parameter "n" is entered, the current value of the parameter is returned. When power is first applied to a pump or immediately after a Reset, the valve normally performs a move to home (port "A"). In systems with several pumps, it may be desired to inhibit this initialization move to prevent a large current demand on the power supply due to all pumps moving at the same time. If the power-up move is inhibited, the first valve move command or the first syringe initialize command will cause the valve to perform an initialization move as the first part of the command.
(n: 0 = the move is enabled and will occur
1 = the move is inhibited and will not occur) [0]

~Ln Set User Input #3 operating mode. If "n" is omitted, the current value of the operating mode will be returned. The default is 0. Regardless of the operating mode, the *syringe position snapshot* feature is active (See "?29" in Section 4.7).

n	Operating mode	
0	Normal	The input is a normal logic input
1	Limit	A syringe dispense will stop when the input goes true (low), and the input can still be read and tested like a normal logic input.

~Pn Select the communication protocol. If no parameter "n" is entered, the current value of the parameter is returned.
(n: 1=DT, 2=OEM) [1]

~Sn Select the Expansion I/O mode. This determines if one or two bytes will be sent and received for each I/O operation. If the I/O Expander Board is used, the two-byte mode must be selected. If no parameter "n" is entered, the current value of the parameter is returned. The factory default is 1-byte.
(n: 1=1-byte transfers, 2=2-byte transfers) [1]

~Vn Set the valve type. If no "n" is entered, the current value of the parameter is returned. The factory default is “0" for units ordered without a valve drive. (n: 0...10) [1]

n	Valve Type	n	Valve Type
0	no value		
1	3 way non-distribution valve	2	3 way distribution valve
3	4 way non-distribution valve	4	4 way distribution valve
5	5 way non-distribution valve	6	5 way distribution valve
7	6 way non-distribution valve	8	6 way distribution valve
9	8 way non-distribution valve	10	8 way distribution valve

~Yn Select the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Y4" command. The "~Vn" value is checked for a valid entry before accepting the value of "n". This permits a port different from “A” to be used for the syringe initialization move. (n: 1...8) [1]

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

~Zn Select the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Z4" command. The "~Vn" value is checked for a valid entry before accepting the value of "n". This permits a port different from “A” to be used for the syringe initialization move. (n: 1...8) [1]

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

4.7 QUERY COMMANDS

Query commands are executed when they are received. They return a value or set of values to the query. A query command can be sent at any time, even if the pump is busy doing something else, and a reply will be sent.

All query commands are executed when they are received and can not be placed within a program. Query commands do not require a “R” command to execute immediately.

Q Return the status byte. (See Section 5.0 for status replies.)

The simplest form of status query is a Carriage Return (hex code 0D). The command “/*address* <*carriage return* >” returns only a single-character ASCII status byte. Example: /1<Cr>

q List the command string stored into non-volatile user program memory. This is used to view programs stored in non-volatile memory.

x? Report the last error that was trapped by an error trap instruction.

? Query the syringe absolute position. Return the value in steps from zero position (top-of-stroke).

?1 Query the syringe Start speed (vn) in steps per second.

?2 Query the syringe Top speed (Vn) in steps per second.

?3 Query the syringe Stop speed (cn) in steps per second.

?4 Query the status of the User Input #1. Return “1" (“true”) if low or “0" (“false”) if high.

?5 Query the status of the User Input #2. Return “1" (“true”) if low or “0" (“false”) if high.

?6 Query the status of the User Input #3. Return “1" (“true”) if low or “0" (“false”) if high.

?7 Query the voltage at the Digital Voltmeter input. Send the value to the host controller as an ASCII base 10 number. Voltage = number x 0.02 volts.

?8 Query the valve position.

?9 Query the *number of unused bytes* (characters) in non-volatile program memory. (170 maximum)

?10 Query the *first* byte value of the Expansion I/O port input. An input byte is input (MSB first), and the numerical value of the input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). In 1-byte mode, this is the only byte. In 2-byte mode, this is the first of two bytes.

?19 Query which *program numbers are currently used* to store a program. Return a list of the numbers in use, separated by a space between numbers.

?20 Query the numerical value of the *second* byte of the Expansion I/O port input in 2-byte mode. Two input bytes are received (MSB first), and the numerical value of the second input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). This instruction is not valid in 1-byte mode.

?29 Query the contents of the *syringe position snapshot* memory. When the User input #3 transitions from high to low, the current value of the syringe position is stored in the snapshot memory. The last two consecutive snapshots are saved and reported.

?30 Query the acceleration and deceleration values. Return the acceleration value first and the deceleration value second.

?n Query the state of the Expansion I/O port input bit designated by "n". A serial byte is input (MSB first), and the state of the designated bit is reported as an ASCII "0" if the bit is "false" (high input logic level) or an ASCII "1" if "true" (low input logic level).
n: 1...3 = parallel outputs 1...3
11...18 = serial byte 1, bit 1...8 of the serial expansion port
21...28 = serial byte 2, bit 1...8 of the serial expansion port

F Report the communications buffer status.
1 = command in buffer, 0 = buffer empty

& Report the firmware version. Return: Pxyy, where xyy is a three-digit number which denotes revision x.yy)

$ Query the *number of valve stalls*. Send the result to the host as an ASCII number. The value of the returned number is the number of times a stall and subsequent automatic error recovery occurred. "0" = no error. If the third attempt fails, a valve overload error is generated.

% Report the number of valve movements since the last power-up or Reset.

***** Report the supply voltage in decimal volts, rounded to the nearest 1/10 volt. The value is averaged over not less than 8 readings.

~A Query the NVM user program autostart state. Return "0" if disabled. If enabled, report the program number to autostart.

~B Query the communications baud rate. Return the baud number "n".

n	Baud rate	n	Baud rate
1	38,400	5	2,400
2	19,200	6	1,200
3	9,600	7	600
4	4,800	8	300

~H Query the operating mode of the front panel SET HOME button.
n: 0 = The button operation is enabled
1 = The button operation is disabled

~i Query the mode of the power-up (post Reset) valve initialize move.
n: 0 = The move is enabled and will occur
1 = The move is inhibited and will not occur

~L Query the User Input #3 operating mode.

n	Operating mode	
0	Normal	The input is a normal logic input (see Section 4.6)
1	Limit	A syringe dispense will stop when the input goes true (low), and the input can be read and tested like a normal logic input.

~P Query the communications protocol. Communications protocols are explained in Section 6.3. The default is the DT protocol.
n: 1 = DT (data terminal)
2 = OEM

~S Query the Expansion I/O operating mode.
n: 1 = 1-byte transfers
2 = 2-byte transfers

~V Query the valve type setting.

n	Valve Type	n	Valve Type
0	no valve		
1	3 way non-distribution valve	2	3 way distribution valve
3	4 way non-distribution valve	4	4 way distribution valve
5	5 way non-distribution valve	6	5 way distribution valve
7	6 way non-distribution valve	8	6 way distribution valve
9	8 way non-distribution valve	10	8 way distribution valve

~Y Query the valve port to be used by the Yn initialization command.

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

~Z Query the valve port to be used by the Yn initialization command. See "~Yn" above for the returned values.

4.8 ERROR TRAPPING COMMANDS

Errors may occur during pump operation, in the structure of a user program, during communications, or in the way a command is given. The pump recognizes these errors. Normally, an error causes a program or instruction to halt and generates an error message to be reported in reply to the next received command. This normal response to an error can be redefined by a user program using a ***trap***.

A ***trap*** is an instruction which directs the pump to go to a label in a program if a particular error should occur. The commands following the label then determine what actions will be taken as a result of the error. An ***exit*** command marks the end of the error-handling command string (the "handler") and determines what will happen next.

A user error handler is thus made from three parts: the *label* which marks the beginning of the handler, the commands which are the *body* of the handler, and the *exit* command which marks the end of the handler.

4.8.1 Trap Declarations

A trap instruction takes effect when it is declared in the program. It remains in effect as written unless it is changed afterwards. Thus error traps can be re-defined "on-the-fly" in a program. The syntax for an error trap is

xnp where "x" denotes an exception (trap) instruction
"n" denotes the error number to be trapped
"p" denotes the program label which starts the error handler routine

If error #n should occur after a trap for error #n is set, the program will jump to the label “p”. By declaring the same trap with a different label, different error handling routines can be used for the same type of error in different parts of a program.

A trap will operate any number of times if the error occurs externally to the error handling routine. If the error recurs while executing the error handler (before the error handler exit), the program will terminate with a standard error exit. In general, if an error persists in recurring, it can not be solved with a trap. The trap exists to deal with occasional errors, but cannot fix system errors external to the pump or serious pump mechanical failures.

Traps can provide graceful recovery or controlled exits from occasional error conditions. A trap can *NOT* fix system problems or overcome serious mechanical difficulties.

4.8.2 Trap Exits

The last instruction of an error handler (exception program) MUST be a trap exit command. Trap exit commands mark the end of an error handler and specify what action the program is to take when exiting the error handler.

The general syntax is

tn where “t” denotes a trap routine exit
“n” specifies the action to be taken after exiting

(n: 1 = Return program execution to the instruction following the instruction which caused the error
2 = Restart the program from the beginning
3 = Perform a normal error exit with an error message
4 = Retry the instruction which caused the error) [n/a]

If the exit type “4" is used, some means must be used to prevent an “endless loop”: error -> handler -> error -> handler...

4.8.3 Error Trap Query

The pump may be queried at any time to report the last error encountered by a trap. The syntax is

x? Report the *last* error that was trapped.

This command executes when received and does not require a “R” command. This command can not be placed within a program.

4.9 MISCELLANEOUS COMMANDS

4.9.1 Software Counters

The pump contains eight *software counters*. A software counter is a register in the RAM which can hold a number and with which simple arithmetic and tests can be done. These counters are useful for holding numbers for other uses, for counting program cycles, for tracking external events, or for offsetting numbers input externally.

The counters are organized as one active and eight exchangeable memory locations. All operations are performed on the active counter. To use one of the other counter memories, that memory must be exchanged with the active counter. The value of the active counter will then be placed in the memory location and the contents of the memory will be placed into the active counter.

The symbol for the counters is “k”. The counter instructions require a “R” command to execute immediately. The test-and-jump instructions must be used within a program.

k Query the current value of the active counter

kn Set the active counter equal to the number “n”

k+n Add the number “n” to the active counter

k-n Subtract the number “n” from the active counter

k^n Exchange the contents of counter memory “n” with the active counter.

k<np If the active software counter is less than "n", jump to label "p". A software counter is internal to the pump and can be set to a number, added to, subtracted from, and tested. It is useful for counting program events and for the temporary storage of internal variables such as syringe or valve position. See Section 4.9.1 for more information on software counters.
(n: 0...65535, @n p: a...z, A...Z)

k=np If the active software counter is equal to "n", jump to label "p".
(n: 0...65535, @n p: a...z, A...Z)

k>np If the active software counter is greater than "n", go to label "p".
(n: 0...65535, @n p: a...z, A...Z)

Example: memory 1 (#1) = 13, memory 3 (#3) = 45, active counter (ac) = 122
Increment #3.

```
k^3    #1 = 13,   #3 = 122,   ac = 45
k+1    #1 = 13,   #3 = 122,   ac = 46
k^3    #1 = 13,   #3 = 46,    ac = 122
```

Example: Count cycles and jump when a limit is reached.

```
k+1        Increment the active counter
k>250A     if the count exceeds 250, jump to program label “A”
```

4.9.2 Flags

Flags are software switches which can be *set* (“turned on”), cleared (“turned off”), and tested. Flags are used to indicate the status of something or to change the way something is done after the first time.

There are six general-purpose flags (f1...f6) and three special-purpose flags (f7...f9). The flag instructions require a “R” command to execute immediately. The test-and-jump instructions must be used within a program.

fn+ set flag “n”
(n: 1...9) [n/a]

fn- clear flag “n”
(n: 1...9) [n/a]

fn? query the status of flag “n”. Return a “0" is cleared or a “1" if set.
(n: 1...9) [n/a]

fnp test the status of flag “n”. If it is set, then clear it and jump to program label “p”. This is useful for altering the way something is done the first time this instruction is encountered. The first time will see the flag set and subsequent times will see it cleared.
(n: 1...8) [n/a]

fn-p test the status of flag “n”. If it is clear, then jump to program label “p”. This is useful for altering the way something is done after the first time it is encountered.
(n: 1...8) [n/a]

4.9.3 SET HOME Button Control

The *SET HOME* button on the front panel can be inhibited, thus preventing it from being inadvertently activated by a user. There are two ways this can be done, one of which is a long-term control and one of which is intended to be dynamically set “on-the-fly”.

When the button is enabled, pressing the button will perform the “W5" command function, which sets the current syringe position as the “zero”, or top-of-stroke position and stores the result into non-volatile memory. This is an operation which should be done only when the valve, syringe, or washer has been changed or when the top-of-stroke position needs to be changed.

When the button is disabled, pressing the button has no effect. The two means of controlling the activation of the SET HOME button are:

~Hn Set the SET HOME button mode. If no parameter “n” is entered, the current value of "n" is returned. Use this as a long-term enable or inhibit. The number times the SET HOME function can be done is limited to 10,000.
(n: 0 = the button operation is enabled.
1 = the button operation is disabled.) [0]

f9+ Inhibit the SET HOME button operation. This command operates in RAM (temporary memory) and is effective as long as power is applied. Use this command to inhibit button operation “on-the-fly”.

f9- Enable the SET HOME button operation. This command operates in RAM (temporary memory) and is effective as long as power is applied. Use this command to enable button operation “on-the-fly”.

f9? Query the status of the button flag “f9". Report “1" is disabled or “0" if enabled.

The ~Hn and f9 flag interact. If the ~H is set to inhibit, the button will be inhibited regardless of the state of the f9 flag. On useful application of the flags is to set f9 when the system initializes and clear it only when a technician enters an access code into a controller or activates a User Input to service the pump.

4.9.4 External Syringe Motion Limit Input

For applications in which a dispense must be terminated by some external event or condition, the User Input #3 can be configured as an external limit input. Such situations may include dispensing to a fixed level, dispensing to a PH, or creating an external safety stop button.

The normal operating mode for User Input #3 is a logic input. The "~Ln" pump configuration command (see Section 4.6) can be used to set input #3 into the "limit" mode. In the limit mode, a true (low) input will halt a syringe move in the dispense direction, but has no effect in the aspirate direction. The behavior of the external limit input can be modified by the action of either flag #7 or flag #8. The syntax for flags is given in section 4.9.2.

Once stopped, the syringe cannot be moved further in the dispense direction unless the Limit input changes to an "off" (high) condition or unless the flag #7 is set. Moves in the aspirate direction can still be made at any time. If flag #7 is set, then a dispense may be initiated against an active limit input. When the move has begun, the flag is automatically cleared so that the next limit input transition from high-to-low will cause the syringe to stop again. This is useful in applications where successive dispenses are to be made under the control of an external signal, such as filling containers using a fill-until-signal.

For some applications, it is desired to stop a dispense after the second high-to-low limit input transition. This is accomplished by setting flag #8. Such a limit action is useful for titrations where the transition is measured optically and a pair of pulses is generated through the transition region. If this feature is used in conjunction with the "snapshot" feature, fully automatic titrations can be done.

Even in the "Limit" mode, the User Input #3 can still be used for the normal logic functions of reporting Input #3 status to a host and for "test-and-branch" decisions within a program.

4.9.5 Motor Power Control

The syringe and valve motors can be turned “on” and “off” individually. The syringe motor normally idles at half-power to conserve energy and reduce idle motor heating. The syringe motor automatically goes to full power at the beginning of a move and returns to half-power after the move completes.

The valve motor is normally off. The valve motor automatically turns “on” at the beginning of a valve move and turns “off” at the end of a valve move. There are no rotary forces acting on a valve and the combination of the internal friction in a valve and the motor detent torque are sufficient to hold the valve in place between moves.

The individual motor powers can be controlled by the command

mn where “n” denotes the motor and action to take.
n: 0 = turn off the syringe motor
1 = turn on the syringe motor
2 = turn off the valve motor
3 = turn on the valve motor

When a move takes place in either the syringe or valve motor, the normal motor power operation for the move overrides the current state of the “mn” command.

Example:

m0	turn off the syringe motor	(motor is off)
A1200	send the syringe to position “1200"	(motor is on during and after move)

4.9.6 Repeat Command String

An entire command string can be repeated in its entirety by sending the string repeat command. The syntax is:

X Repeat the last command string

This command can be used repeatedly and will repeat the same command string each time. This command does not work for queries and configuration commands.

Example:

o2A12000o-1A0R	Move the valve to port B, fill the syringe, move the valve to port A, empty the syringe.
X	Do all of the above commands again in the same way.
X	Do all the commands listed above again.

5.0 STATUS & ERROR MESSAGES

A status byte is returned after about 12 milliseconds following receipt of the carriage return in each command string sent to the unit. Every pump reply contains a status byte immediately following the host address "/0".

Example: /0@125

/0	host address (fixed)
@	status byte (ok, busy)
125	a value returned in response to a query

5.1 STATUS SUMMARY

Each status byte has two forms: *busy* and *ready*. "Busy" means the device is executing a command or program. "Ready" indicates the device is ready to receive another command. The status messages are:

ASCII		Error	Decimal		Binary	Status
busy	ready	#	busy	ready	76543210	
@	'	0	64	96	01X00000	no error
A	a	1	65	97	01X00001	syringe failed to initialize
B	b	2	66	98	01X00010	invalid command
C	c	3	67	99	01X00011	invalid argument
D	d	4	68	100	01X00100	communication error
E	e	5	69	101	01X00101	invalid "R" command
F	f	6	70	102	01X00110	supply voltage too low
G	g	7	71	103	01X00111	device not initialized
H	h	8	72	104	01X01000	program in progress
I	i	9	73	105	01X01001	syringe overload
J	j	10	74	106	01X01010	valve overload
K	k	11	75	107	01X01011	syringe move not allowed
L	l	12	76	108	01X01100	cannot move against limit
O	o	15	79	111	01X01111	command buffer overflow
P	p	16	80	112	01X10000	use for 3-way valve only
Q	p	17	81	113	01X10001	loops nested too deep
R	r	18	82	114	01X10010	program label not found
S	s	19	83	115	01X10011	end of program not found
T	t	20	84	116	01X10100	out of program space
U	u	21	85	117	01X10101	HOME not set
V	v	22	86	118	01X10110	too many program calls
W	w	23	87	119	01X10111	program not found
X	x	24	88	120	01X11000	valve position error
Y	y	25	89	121	01X11001	syringe position corrupted
Z	z	26	90	122	01X11010	syringe may go past home

Bit 5 of the status byte, denoted by "X" above, is set to "0" if the pump is busy, and is set to a "1" if the pump is not busy. The Error # is the number used by the error trapping command.

5.2 DETAILED EXPLANATIONS

@, ` The device is operating normally. No error condition has been detected.

A, a An attempt to initialize the syringe has failed. No syringe move command other than an initialize command will be valid until initialization is complete. This error is usually the result of a syringe overload. Check the fluid paths for restrictions or obstructions. Check the valve ports for alignment. If a reduced speed succeeds, try a shorter fluid path or larger diameter fluid path.

B, b A command just sent was not recognized as valid. A character was sent that is not part of the command set. A typing error may have occurred. For example, "N1000" is not valid because "N" is not a legal command.

C, c The number sent with a command is not valid. The command itself was valid, but the value sent with it was out of the allowed range of values for that command. For example, "A25000" has a value, "25000", which is not within the range of available values. This most frequently occurs when a series of relative dispenses is commanded, and the last dispense command exceeds the volume remaining.

D, d The checksum or sequence number was incorrect (OEM protocol only). The message should be retransmitted with a new sequence number. The sequence number is adjusted each time a command is repeated to prevent a repeated command from being executed more than once. See Section 6.6.3 for the checksum and sequence number definitions.

E, e A “R” (Run) command was sent with a command which does not require it.

F, f The device supply voltage was too low. The condition may be caused by a low power supply voltage or by voltage transients on the power supply wiring near the pump.

G, g A move command was sent while the device was in an uninitialized state. The device must be initialized before a move command will be accepted. An initialized state results after a power-up, a reset, or a syringe overload error.

H, h A program or command is executing. A new command (other than queries, “Vn” and “T”) cannot be sent until the present command completes.

I, i The load on the syringe drive axis was too great. The syringe motor stalled. A stall does no damage to the drive system. There are several possibilities:

(1) A fluid path was constricted or blocked. Check for kinks in tubing, valve washers which may have a shrunken hole, other valves sticking, and other sources of constriction.

(2) The syringe velocity was too high. Back pressure increases with the square of velocity. Available thrust force also decreases with velocity. Reduce the syringe top speed ("Vn" or "Sn").

(3) The acceleration is too high. High acceleration places a power demand upon the syringe motor in addition to the friction and fluid back pressure demands. Decrease the acceleration value ("Ln").

(4) The flow path inside diameter is too small for the fluid flow rate. A larger diameter, shorter path, or lower velocity may be required. The

back pressure varies as nearly the fourth power of the diameter of the path and directly with the length

J, j The valve motor failed to complete a commanded move. Some possibilities are:
(1) The valve is wearing out and needs replacement.
(2) There is particle contamination in the valve. Particles may come from another place and be transported into the valve or may result from crystal deposits in the valve.
(3) The chemistry results in swelling or softening of the valve materials, resulting in binding. Check chemical compatibility.
(4) The fluid or operating environment is too hot, resulting in swelling and binding of the valve.
(5) There is a misalignment of the valve drive and the valve stem. This typically results in binding at one point in the valve rotation.
(6) A fitting is screwed in too tight, distorting the valve and causing binding.

K, k A syringe move command was not allowed because the valve is in a bypass position (syringe port blocked), or because the supply voltage was too low.

L, l The User Input #3 limit input is active. The syringe cannot dispense against an active limit input.

O, o A command was sent while another was executing. The last command which was sent was not executed and was discarded.

P, p An instruction was sent which applies only to a three-way non-distribution valve only (**O**, **I**, **B**) with the valve type set to other than a three-way non-distribution.

Q, q There are too many loops within loops in the program.

R, r A program label called by a jump instruction was not found in the program. Remember that the labels are case-sensitive. A label may have been changed or deleted when editing a program.

S, s A program stored in the non-volatile memory (NVM) does not have the required end-of-program indicator. The NVM may have been corrupted. Try saving the program again into NVM.

T, t There is not enough program memory to hold the entire program.

U, u The HOME (zero) position has not been set. The syringe axis requires calibration. See Sections 3.2 and 4.1.3.

V, v A called program has called another program. Only one program can be called at the same time.

W, w The program called or commanded to execute cannot be found in memory.

X, x The valve position is not valid. This error occurs when the valve position code wheel sensor fails to see a slot after all valve motion has ceased.

Some possible causes are:
(1) The valve failed to complete the preceding move.
(2) The valve position has been displaced since the last move completed.
(3) Contamination has blocked one slot in the valve opto disk or a valve sensor face is contaminated.

Y, y The current computed syringe location is in error. The position value is outside the range of acceptable values. The syringe position memory has likely been corrupted.

Z, z The syringe may try to go upwards past the Home (zero) position. This message is generated whenever a check of the computed syringe position exhibits an out-of-tolerance error. Syringe “crashes” are avoided by this means.

When the syringe position is calibrated, the distance from the INITIALIZE position to the top-of-stroke (zero) is stored into NVM. Each time the syringe passes up through the INITIALIZE point, the computed position is compared to the stored value. If the two values do not match within a given error band, the syringe is stopped and the error message is generated.

The two most common sources of this error are (1) having the Home position set at the INITIALIZE point and (2), having “lost” (not counted) steps during a move. Steps can be lost when the “T” command is used to stop a syringe which is moving at speeds above about 2000 steps pers second or when a syringe overload occurs.

6.0 COMMUNICATIONS

Up to 15 devices may be operated on the same RS485 communications bus. Pumps may be addressed individually, in pairs, in groups of four, or all at once. A response from a device will only occur for individual addressing. In the multiple-device addressing modes, no device will provide a status response. Status messages are saved until an individual device is addressed.

6.1 INDIVIDUAL DEVICE ADDRESSING

In the table below, the *Switch Setting* column is the number to which the Address Switch is set on the pump. The *ASCII Char* column refers to the ASCII character (also the keyboard character) corresponding to the address switch setting. Devices addressed in this mode will respond with a status byte and an answer to a query.

Switch Setting	Hex Address	ASCII Char	Switch Setting	Hex Address	ASCII Char
0	Reserved for controller		8	38	8
1	31	1	9	39	9
2	32	2	A	3A	:
3	33	3	B	3B	;
4	34	4	C	3C	<
5	35	5	D	3D	=
6	36	6	E	3E	>
7	37	7	F	3F	?

6.2 MULTIPLE DEVICE ADDRESSING

Multiple pump addressing sends a command string to more than one pump on the communications bus at the same time. To prevent bus conflicts, the pumps will not provide a response to a command in one of these multiple-pump addressing modes.

6.2.1 Dual Device Mode

In the *dual* device addressing mode, a group of two pumps is addressed. In this mode, individual devices do not provide status responses to commands.

Pump group	1, 2	3, 4	5, 6	7, 8	9, A	B, C	D, E
Hex address	41	43	45	47	49	4B	4D
ASCII character	A	C	E	G	I	K	M

6.2.2 Quad Device Mode

In the *quad* device addressing mode, a group of four pumps is addressed. In this mode, individual devices do not provide status responses to commands.

Pump group	1, 2, 3, 4	5, 6, 7, 8	9, A, B, C	D, E, F
Hex address	51	55	59	5D
ASCII character	Q	U	Y	]

6.2.3 Global Mode

In the *global* device addressing mode, all devices on the bus are simultaneously addressed. In this mode, individual devices do not provide status responses to commands. The address character is the underscore, "_", hexadecimal 5F.

6.3 COMMUNICATIONS PROTOCOLS

The communications software protocols are the command and response formats used send commands and receive responses from pumps. There are two protocols: DT (data terminal) and OEM (original equipment manufacturer). Both software protocols use the same hardware protocol stated in Section 11.6. The status responses to commands should be monitored by the user's controlling software to ensure overall system operational integrity.

The DT protocol is a simple data terminal protocol which is compatible with nearly all terminal emulation programs and basic communications drivers. This is the preferred protocol in most situations.

The OEM protocol provides explicit error checking and a repeated-command sequencing algorithm. These features are not implemented in any standard terminal programs. Kloehn offers software which can communicate using this protocol. The KSerial driver can be called from within a user program and handles the communications overhead.

6.3.1 DT Command Protocol

This section describes the command package of the DT protocol. A command packet is a sequence of bytes sent by a host computer from the host to a device. The packet consists of a starting character, a device address, a command or command sequence, and an ending character.

Byte #	Description	ASCII	Hex
1	Start Character	/	2F
2	Address Character	(see Sections 6.1 and 6.2)	
3 to N	Command Characters	(see Section 4)	
N+1	End (Carriage Return)	<CR>	0D

Explanation of bytes:

Byte 1: The starting character signals the beginning of a new packet. It is the front slash character "/" on the computer keyboard, 2F hex.

Byte 2: The device address is a address number for a device or for a group of devices. It can address a total of 15 devices in the network mode.

Byte 3: The command or a sequence of commands starts with byte 3. A command or a command sequence with length n bytes, uses from byte 3 to byte 3+n-1.

Byte 3+n: The ending character indicates the end of a packet. It is 0D hex, the carriage return on the keyboard.

6.3.2 DT Response Protocol

This section describes the device response packet format of the DT protocol. The device response packet is a sequence of bytes sent by a device from that device to a host computer after receiving a command package. The format of the packet is described as follows:

Byte #	Description	ASCII	Hex
1	Start Character	/	2F
2	Controller Address	0	30
3	Status Byte	(See Section 5)	
4 to N	Response (if required)	(See Section 4)	
N+1	End of Text	<ETX>	03
N+2	Carriage Return	<CR>	0D
N+3	Line Feed	<LF>	0A
N+4	End (Blank)	<Blank>	FF

Explanation of bytes:

Byte 1: The starting character, 2F hex, which signals the beginning of a new packet, is the front slash character "/" on a computer keyboard,.

Byte 2: The host address, 30 hex (ASCII 0), is the address number for the host computer.

Byte 3: The status and error byte describes the device status. Refer to Appendix C for the definitions of the status and errors.

Byte 4: There may or may not be response byte(s) for a command. In general, all query commands, "read an input value" commands, and configuration query commands (~A, ~B, ~P, ~V, etc) cause response bytes. Other commands do not cause a response.

Byte 4+n: The end-of-response mark is 03 hex.

Byte 4+n+1: Carriage return is 0D hex.

Byte 4+n+2: End of packet character is the line feed character, 0A hex.

Byte 4+n+3: The extra ending character, FF hex, is an extra character to ensure the packet is properly sent. This character might not be displayed by the host terminal.

6.3.3 OEM Command Protocol

This section describes the command packet format of the OEM protocol. The OEM command format is identical to the Cavro OEM protocol. The command packet is used to send commands from the controlling host device to the syringe drive. Explicit synchronization and error checking are key aspects of this protocol.

Byte #	Description	ASCII	Hex
1	Line synchronization character	<blank>	FF
2	Start Transmit character	<STX>	02

3	Device address	(See Sections 6.1, 6.2)	31-5F
4	Sequence number	(See following text)	
5	Command(s) (n bytes)	(See Section 4)	
5+n	End of command(s)	<ETX>	03
5+n+1	Check sum	(See following text)	

Explanation of bytes:

Byte 1: The line synchronization character, FF hex, indicates a command packet is coming.

Byte 2: The start transmit character, 02 hex, signals the beginning of a new packet.

Byte 3: The device address is a address number for a device or for a group of devices. Up to 15 devices can be addressed.

Byte 4: The sequence number. If an error occurs during the communication, the host sends the last packet again to the device with a new sequence number. The sequence number starts with 31 hex (ASCII 1). When repeating a command, the host sets bit 3 of the sequence number byte to 1 and increases the sequence number by 1. The valid sequence numbers are hexadecimal 31 for the first packet, hexadecimal 3A for the second packet (the first repeated packet), 3B for the third packet, and etc. The maximum number of repeat is 7 with a sequence number of 3F.

Byte 5: The command or a sequence of commands starts with byte 5. A command or a command sequence with length n bytes uses byte 5 to byte 5+n-1.

Byte 5+n: The end-of-command(s) character, 03 hex, indicates the end of a command or command sequence.

Byte 5+n+1: The check sum is calculated by an exclusive-or operation on all bytes except line synchronization byte and check sum byte.

6.3.4 OEM Response Protocol

This section describes the response packet format in the OEM protocol. The OEM response format is identical to the Cavro OEM response format. The response packet is used to send status and responses from the syringe drive to the controlling host device.

Byte #	Description	ASCII	Hex
1	Line synchronization character	<blank>	FF
2	Starting character	<STX>	02
3	Host address	0	30
4	Status and error byte	(see Section 5)	
5	Response, if any (n bytes)	(see Section 4)	
5+n	End-of-response mark	<ETX>	03
5+n+1	Check sum	(see following text)	
5+n+2	Extra ending character	<blank>	FF

Explanation of bytes:

Byte 1: The line synchronization, FF hex

Byte 2: The starting character, 02 hex, signals the beginning of a new packet.

Byte 3: The host address, 30 hex, is the address number for the host computer.

Byte 4: The status and error byte describes the device status. Please refer to Appendix C for the definitions of the status and errors.

Byte 5: There may or may not be response byte(s) for a command. In general, all query commands, read input commands, and configuration query commands (~A, ~B, ~P, ~V, etc) produce response bytes. Other commands do not produce a response.

Byte 5+n: The end-of-response mark, 03 hex, indicates the end of the response byte(s).

Byte 5+n+1: The check sum is calculated by an exclusive-or operation on all bytes except the line synchronization byte and the check sum byte.

Byte 5+n+2: The extra ending character, FF hex, is an extra character to ensure the packet is properly sent. This character might not be displayed the host terminal.

6.4 COMMUNICATIONS SETTINGS

There are four communications settings: address, bus termination, baud rate, and protocol. Baud rate and protocol are set by the configuration commands “~Bn” and “~Pn” as explained in Section 4.6. The address is set via the Address Switch or the wiring on the card edge connector, as explained in Section 2.5.2 and Section 3.4.2. The bus termination setting is explained in Section 2.5.1 and Section 3.4.1.

6.5 CONNECTING MULTIPLE DEVICES

Up to 15 devices may be connected to the same RS485 communications bus. The bus consists of three wires: "A", "B", and signal ground. The interface is normally done via pins on P1, identified in Section 2.4.1. A proper bus structure consists of the bus wiring and terminations at each end of the bus.

6.5.1 Bus Wiring

The bus wiring should connect all RS485 "A" pins to one wire, all "B" pins to another wire, and all comm ground pins to a third wire. The connections begin at one device and proceed from that device to the next, one device after another. The three wires connecting one device to the next should be twisted together with a twist rate from one to three twists per inch. A wiring diagram is shown in Figure 6-1. The wiring to connect a PC to the first drive unit is shown in Figure 3.5.

The RS485 multi-pump bus MUST be wired from pump-to-pump in a serial fashion.

6.5.2 Bus Terminations

Each end of the bus must be terminated in a network which both biases the bus and provides the proper impedance. Terminations are made only on the *first* and *last* devices along the bus as shown in Figure 6-1. Terminating networks are provided on each drive for these purposes. To terminate the bus, set toggle switches 1 and 2 to the "ON" position for the first and last pumps on the RS485 bus. All pumps between the first and last must have these toggles set to "OFF".

Only the pump at each end of the RS485 bus may have the RS485 Bias switched "on". All pumps between the two end pumps MUST have their RS485 Bias Switched "off". See Figures 2-1 and 2-3.

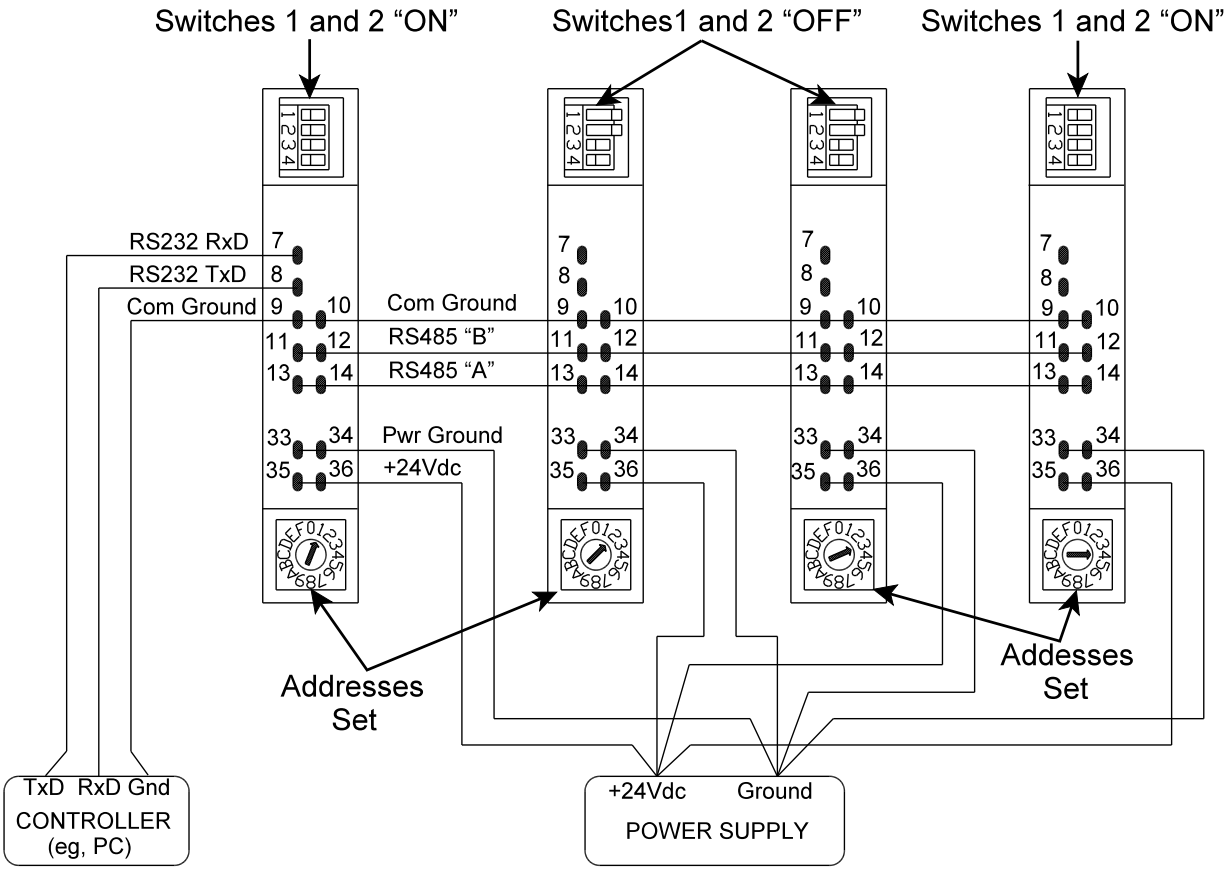


Figure 6-1: Multi-device Wiring Diagram

6.6 COMMUNICATIONS CHECKS

This section presents some procedures for determining whether a device is communicating with a host controller. The checks are predicated upon the use of some form of *terminal emulator* program running on a PC. This is a type of program which sends ASCII characters typed on the keyboard to a serial port and displays the ASCII responses received. Before using such a program, determine the number to which the Address Switch, shown in Figure 3-3, is set. The Address Switch setting determines the value (from the tables in Sections 6.1 and 6.2) which must be substituted for the notation "<addr>". Each new command string must begin with a front slash (/) followed by the value of <addr>. Each command string must end with a carriage return (the "return" or "enter" key). See Section 4 for the command syntax, and Section 6.3.1 for the DT command protocol. Note that each key is sent when the key is pressed, so typed characters cannot be edited. Editing keystrokes will be sent to the syringe drive and will result in syntax errors.

After the communications wiring is connected and the PC serial port cable has been connected to the first device on the bus, turn on the pumps. When the power-up valve move is complete, send a Query of the module status as shown next. If needed, see Section 3.3, Section 3.4, and Section 3.5 for communications setup instructions.

type	/1<enter>	Query the status of pump #1
	/0'	Response is "not busy, no errors"

If a response occurs, communications is operating properly. A valid response from a communicating module will always begin with "/0". This is the default address of the host controller. If there are no errors to be reported, the next character after the "/0" will be either an accent (') or a “@”. The accent signifies that the module is not busy and is ready to accept any commands. The "@" signifies that the module is busy and therefore only queries and the Terminate (T) command are acceptable.

Note: If the query is sent while the power-up initialization sequence is in progress, no response will be seen. The pump does not "listen" until the power-up sequence is completed.

If an apostrophe (`) or an "at sign" (@) is not returned, and a letter is returned in its place, then the module is reporting an internal error condition. The interpretation of such letter codes is given in Section 5.

If there is no response, then if the pump is not powered up, the communications hardware connection is not properly made, or the communications program is either not properly configured or not operating correctly. Check the items below:

(1) Insure that the communications connector is inserted properly into the RS-232 connector and NOT into the RS485 connector.
(2) Try another comm port selection in step (5) of the Terminal program setup procedure (Section 3.5.1).
(3) Using a voltmeter, with the communications cable connected to the RS-232 pins on P1, measure voltages from the "GND" pin to the "RXD IN" pin and the "TXD OUT" pin. Each pin should measure -6 Vdc to -15Vdc. If they do not, the following errors may exist.

    (a) "RXD IN" fails the check: the host PC port is not functioning, the

communications cable is defective, or it is plugged in backwards.

(b) "TXD OUT" fails the check: the RS-232 converter board or the communications cable is defective, or the module is not powered on.

6.7 COMMUNICATIONS DRIVERS

A communications driver is a program, module, procedure, or function which can be called by a program to send and receive ASCII strings to and from a pump. In general, drivers should be designed to "trap" (receive and recognize) the status codes returned by a syringe drive in response to a command.

Kloehn Company provides a driver called ***KSerial*** which operates from the command line and can be called from within a user's program. *KSerial* handles all the communications overhead with Kloehn pumps in both DT and OEM protocols.

Appendix C provides a sample QBasic program which emulates a terminal in the DT communications mode. This code can be updated to Visual Basic® code or used as a model for a simple, user-written DT protocol communications driver.

7.0 PROGRAM MEMORY

The VersaPump 3 has the ability to store and execute command strings. A command string is a group of commands run together, without spaces, to form a single line of legal ASCII characters. Such a string is also called a *program*. For example, the commands

I	*move valve to input position*
A0	*move syringe to fully-closed position*
A3000	*fill syringe*
M500	*delay 500 milliseconds*
O	*move valve to output position*
D1500	*dispense half of syringe*

can be placed into a single command string (program) as follows:

IA0A3000M500OD1500

In a command string, each new command will execute immediately after the preceding command has completed. The command sequence will run in the minimum possible time without the need to query the drive to determine whether it is busy or ready for the next command. This can eliminate much communications overhead. Such a program can be executed immediately or some time after the program is sent to the drive. It can be executed from temporary memory (RAM) or from non-volatile memory (NVM).

7.1 TEMPORARY MEMORY

When a command string is sent to the drive, the string is entered into temporary memory (RAM). This memory retains its contents while power is applied to the drive unit. When power is removed, the contents of RAM are lost. After a command string is executed, it may be repeated by sending the "X" command.

To execute a program at the time it is sent, append a "R" (“Run”) command to the string. If no "R" command is appended, the program will execute when a subsequent "R" command is sent. If another command is sent after the program string and before the "R", or if the "R" is appended to another command, the original program string will be overwritten by the last command string.

For example, the command "D1000R" will execute as soon as it is received by the drive. The command "D1000" will be stored into RAM, but will not execute until a separate, subsequent "R" is sent.

7.2 NONVOLATILE MEMORY

Non-volatile memory (NVM) will retain its contents even after power has been removed. The minimum retention time is about 15 years. Thus the NVM acts as if it were a "solid-state disk drive". Up to ten programs can be stored in the NVM. The maximum number of times a program string may be written into the NVM is 10,000. After 10,000 writes, the integrity of a stored program cannot be guaranteed. There is no limit to the number of times a stored program can be read or executed.

7.2.1 Saving and Erasing a Program

A program string is saved into the NVM by sending it to the RAM without a "R" run command appended, and then sending the "En" command as a separate command. When the “En” command is received, the string in RAM is transferred into the NVM as stored as “program #n”. To erase a command string in NVM, either overwrite it with another command string or send the "en" (erase) command.

> The maximum number of times a program string may be written into the NVM is 10,000. After this, the integrity of a stored program is not guaranteed.

Because of the limitation on writes, NVM should not be written every time an application is run. It should be used to store a command sequence or program if that program will be long-lived in the application. Short-term programs such as programs which can change often, should be executed from RAM. Some program which vary in the numbers but not in structure can use general variables, as explained in Section 4.5.

7.2.2 Listing a Program

A program saved into NVM can be queried with the "qn" (program query) command. When the "qn" command is received, the drive will respond by sending the complete command string, if any, found in the NVM. The command string will be terminated with a period. If no command string is found, only the period will be returned after the status byte.

7.2.3 Auto-Starting an NVM Program

The VersaPump 3 has the ability to automatically begin executing a program stored in NVM when power is applied. This feature is known as "Autostart". This is useful for those applications which may require rapid and automatic pump initialization or in cases where a program sequence is controlled with User Inputs or Expansion I/O.

The Autostart feature is enabled by setting the "~An" parameter to "1" with the "~A1" command. The auto-start can be disabled by setting the "~An" parameter to "0" with the command "~A0". These commands require no "R" command.

> The COMM DEFAULT toggle switch must be set to OFF for the Auto-Start feature to function. The toggle in the ON condition will inhibit Auto-Start.

When writing an Auto-Start program, remember that the syringe cannot be commanded to move until it has first been told to initialize to the soft limit with a "W4", a "Y4", or a "Z4" command. However, all commands other than a syringe move command can be executed before (or without) executing a "W4", "Y4", or "Z4". It is therefore recommended that one of these commands, followed by an "absolute position" move to zero position ("A0"), be included at the beginning of an Auto-Start program.

7.2.4 Externally Starting a Program

The User inputs and the input test-and-jump instructions provide the means to "trigger" a program running in the pump. The program can be self-starting on power-up (see Section 7.2.3 for details). The program would be programmed to read an input and wait for an active signal to continue program execution. Doing a series of identical dispenses using a probe and pushbutton (or foot switch) is a common application of this technique. See Section 8.3.1 for programming examples of waiting for an input signal.

8.0 PROGRAMMING TECHNIQUES

This section presents some application techniques for good system design. Some sections discuss means of using some of the pump's special features, while some deal with the best programming practices for host controller software development.

8.1 CONTROLLER INTERFACE SOFTWARE

This section discusses best practices when writing software to control the pump. These techniques represent years of practical experience in developing applications.

8.1.1 System Initialization

When a pump is installed into a system, the pump may not have the configuration parameters set to the needed values (see Section 4.6 for configuration parameters). Such parameters include valve type, I/O operating modes, and initialization parameters. The overall system reliability in the field is greatly enhanced if the controller software can perform the setting of these parameters *as needed* when a pump is installed.

The parameters are set in non-volatile memory (NVM) by the configuration commands. The number of writes to NVM is limited. For this reason, the parameters should only be set when they are incorrect, and not each time the system is powered on.

> Do *NOT* set the configuration values each time the system is powered-on.

A good system programming technique is to read the parameters at system power-on, compare the values to the desired values, and set only those parameters which are not correct. The general form of such code would be

Query <parameter>
if <parameter> is not the <desired value> then Set <parameter>

For example, if the valve type should be "6", the code might look like this in Basic:

```
OPEN  "COM2: 9600, N, 8, 1, CS0, DS0, CD0, RS" FOR RANDOM AS #1
PRINT #1, "/1~V"; CHR$(13)          'Query valve type (add <CR>)
FOR n = 0 TO 1000: NEXT n           'Pause to receive entire reply
In$ = INPUT$(LOC(1), #1)            'get reply string from pump
IF MID$(In$, 4, 1) <> "6" THEN      'If parameter not correct, then
      PRINT #1, "/1~V6";CHR$(13)    'set it to the correct value
END IF
CLOSE #1
```

Using this technique, factory installations and field replacements will always be correctly configured. This technique can also be used to ensure any required user programs are stored into the NVM. If an external text-based configuration file is used, servicing the system software becomes an easy matter.

8.1.2 Sending Single Instructions

A common error in application programming is to assume a given instruction or instruction sequence will take a fixed length of time to execute. The next instruction is then sent after this fixed delay. This programming technique can lead to system failures.

> Commands might NOT execute in the same time if an error condition occurs. Do *NOT* use timing loops to determine when to send the next command.

The only valid way to determine if the pump is ready to accept another command is to query its status. The simplest way to do this is to send just the address and a carriage return character (hex 0D or decimal 13). A typical query might be:

/1<Carriage Return>

Wait for the reply and check the status byte to see if the pump is ready or busy (see Section 5.1 for the status codes). The queries should not be sent too fast. Checking at a rate of eight times per second or less is adequate for nearly all systems. This also permits the controlling software to discover error conditions much sooner than would otherwise occur.

Two situations are deserve special acknowledgment: valve moves and traps. If a valve motor stall occurs, the valve will automatically attempt a recovery (see Section 4.2). The recover attempt can take up to several seconds. An error trap causes the program to go to a user program to handle the error (see Section 4.8). This can extend the time required for a program sequence to complete.

A second way to determine when the pump has completed a task or operational cycle is to program the pump to set a User Output to ON when each instance of the task is done. A controller can sample the controller input to which the pump output is connected. This technique avoids the communications overhead.

In general, it is better to send commands as groups rather than individually, as each command will execute immediately after the preceding command has finished, without any controller overhead. Periodic status queries are still a good idea.

8.1.3 Using Stored Subroutines

Many tasks are repetitive. These include priming cycles, wash cycles, and some fixed I/O routines. The essential nature of such command sequences is that they never vary; they always execute exactly the same way. Such a routine is a good candidates for a stored program. By storing such a routine in the NVM, the overhead of repeating it in a program or sending a long command string can be avoided. A program can “call” a stored program with the call command “jn”. A host software program can call the routine with the stored program “run” command “r n”.

Calling stored routines is a very efficient way to handle repetitive tasks. With the use of general variables (see Section 4.5.1), even tasks which vary only in the numbers, but not in the sequence of events, can be stored and called, with the numbers set when the routine is called.

8.1.4 Protecting the User

The pump has two buttons on the front panel. The INITIALIZE button simply moves the syringe to the internal calibration point. If a user presses this button, no harm is usually done. The upper button is the SET HOME button. If a user presses this button, the location of the zero point is reset to some indeterminate (and probably wrong) location and errors in operation are likely to result.

Button-induced user errors can be avoided by using the HOME button inhibit features. The button can be inhibited long-term using the configuration command "~Hn", which inhibits the button via the NVM. This is useful when only a service technician is allowed to replace syringes, valves, or washers.

If the user is to be allowed to set a new HOME position, there may be an advantage in inhibiting the SET HOME button as part of the system initialization. The user, like a technician, would then enter a "setup" mode to enable the button. The button would be disabled when the setup mode is exited. For this operation, use the "f9" flag, as this is not written to NVM. See Section 4.9.3 for operational details.

8.2 PUMP PROGRAMMING TIPS

This section offers techniques for programming the pump using pump command strings. These techniques extend the usefulness of the pump.

8.2.1 Programming Very Slow Moves

The lowest speed at which the pump can be programmed to move by using the *Top Speed* command ("Vn") is 40 steps per second (sps). Much slower speeds are possible using a "step-and-delay" technique.

In the step-and-delay technique, a short program sequence is used in place of a discrete speed setting. The sequence is:

Function	Dispense	Aspirate	Time delay
Mark start of repeat loop	g	g	0
Move one step	D1	P1	24 msec
Pause "n" milliseconds (msec)	Mn	Mn	"n" msec
Repeat for "m" steps	Gm	Gm	0

Thus the complete program string for a dispense is then "gD1MnGm". The equivalent speed is found as the reciprocal of the time to execute one pass through the loop.

Speed = 1/Time

Example: gD1M17G6000 (Start Speed = 650)

Time = 24 + 17 msec = 41 msec (.041 seconds)
Speed = 1/Time = 1/.041 = 24.39 steps per second for 6000 steps

The calculations above may require fine adjustment in "n" for greater accuracy in very slow moves.

8.2.2 Programming Error Traps

Errors can occur during operation of the pump. Errors can range from incorrect commands to motor overloads. The pump can detect most error conditions (see Section 5). For some systems, the robustness of the design can be enhanced by programming the pump to take corrective action automatically. This is called ***trapping*** and the part of the user program designed to handle the error is called the ***error handler***, or ***exception handler***. The syntax to do this is given in Section 4.8. This section will provide an examples of error trapping.

Example: Trap a syringe overload error. Save the value of the syringe position, initialize the syringe to the input port, then return to the stall position and continue the dispense. Note: this assumes the dispense was intended to deliver all the contents of the syringe.

In the main user program, the trap is set by declaring:

x9V If a syringe overload (#9, see Section 5), occurs, go to label "V".

At the end of the program, where error handlers are normally located, the handler might be as follows:

```
:V    label identifies start of handler (label used in trap instruction above)
k@7   store current syringe position in Software Counter for later use
k^1   exchange with counter memory #1
k@6   save current valve port position in Software Counter
Y4    initialize syringe to reservoir port (~Yn set which port this is)
o@5   move valve back to previous port position
k^1   place previous syringe position back in Software Counter
A@5   move syringe back to stall position
A0    Complete dispense
t1    Resume program execution with the next instruction
```

There are some limitations on error trapping. The error trapping feature is designed to provide a graceful recovery from errors, but it can not fix system errors. Any error induced by mechanical or fluidic problems cannot be fixed by a program. Such things must be fixed at the external root cause. In some cases, a syringe overload might be handled by reducing the syringe speed and trying again.

> Error trapping can NOT fix external mechanical or fluidic problems. Trapping is intended to provide graceful systems exits from error conditions.

Example: Recover from a valve overload by initializing the valve and then repeating the valve move. An "error cycle counter" is included to prevent a run-away loop.

In main program, zero counter memory #2 and declare a trap:

```
k^2   exchange counter with counter memory #2 (preserve k value)
k0    set current counter to zero
k^2   restore current counter and place zero in counter memory #2
x10p  If a valve overload (error #10) occurs, go to program label "p".
```

At the end of the program, where error handlers are normally located, the handler might be as follows:

```
:p      label identifies start of handler (label used in trap instruction above)
o1      initialize valve position
k^2     get counter #2
k+1     increment error loop counter
k>5q    if more than 5 valve errors, go to label “q”
k^2     if not, restore previous counter value
t4      try the valve move again
:q      label q means more than 5 valve errors (from k>5q)
k^2     restore previous counter value
U3      signal terminal error (via User Output #3)
t3      do a normal program error exit (stop program and make error
        message.
```

In the preceding example, the “t4" exit retries the instruction which caused the error. If the initialize move works, but there are more than 5 retires without success, the handler exits the program after setting an external “error” signal. If the initialize move fails, a program exit would occur. If an error occurs while in the error handler routine, a normal error exit takes place, superceding any user error handler.

> If an error occurs while an error handler is executing, the program will perform a normal program error exit, regardless of the error handler.

Example: If any error occurs, set the User Output #2 low, set User Output #1 high, save the current Digital Voltmeter input value, and then exit the program.

Set the error trap in the main program:

```
x*s     if any error (*) occurs, go to program label “s”.
```

At the end of the program, where error handlers are normally located, the handler might be as follows:

```
:s      label marking start of error handler
U2      Set User Output #2 low
u1      Set User Output #1 high
k@3     Save the current Digital Voltmeter input value
t3      Do a normal error exit
```

8.2.3 Setting the Speeds

For most applications, the factory default values for syringe accelerations and speeds are adequate. Usually, only the *Top Speed* is changed for different syringe rates. If the *Top speed* is set lower than the *Start speed*, the pump will begin a move at the *Top Speed*. If the *Top speed* is set lower than the *Stop Speed*, the move will end at the *Top Speed*. For this reason, values of *Top speed* which are set lower than either the *Start Speed* or the *Stop Speed* do not require any adjustment in *Start speed* or *Stop Speed*.

The default values of the Start and Stop speeds have been set to perform well for nearly all normal applications. On occasion, it may be useful to change the speeds from the default settings. This section explains the considerations involved.

The syringe uses three speeds and two accelerations which can be set. The speeds are *Start Speed*, *Top Speed*, and *Stop Speed*. The two accelerations are the *Ln* and *In* values which set acceleration and deceleration rates, respectively.

The syringe motor does not start at zero speed and accelerate smoothly to the *Top Speed* (at which syringe moves normally occur). Rather, the motor jumps abruptly from zero to the *Start Speed* and then accelerate smoothly to the *Top Speed*. The move proceeds at the Top Speed. As the destination is approached, the motor decelerates from the *Top Speed* to the *Stop Speed*. When the *Stop Speed* is reached, the motor performs an abrupt stop at the target position. The speed profile is thus trapezoidal, as shown in Figure 8-1.

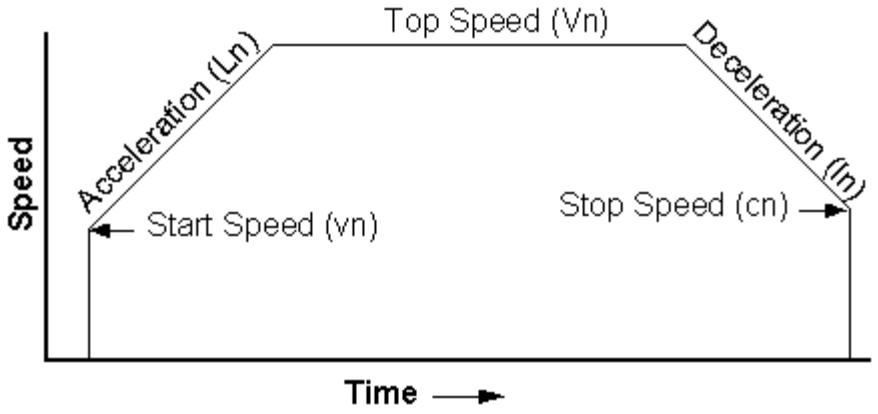


Figure 8-1 Normal Syringe Speed Profile

If a high Top Speed and low acceleration are combined with a very short move, the syringe speed may not reach the programmed Top Speed and the profile of Figure 8-2 will result.

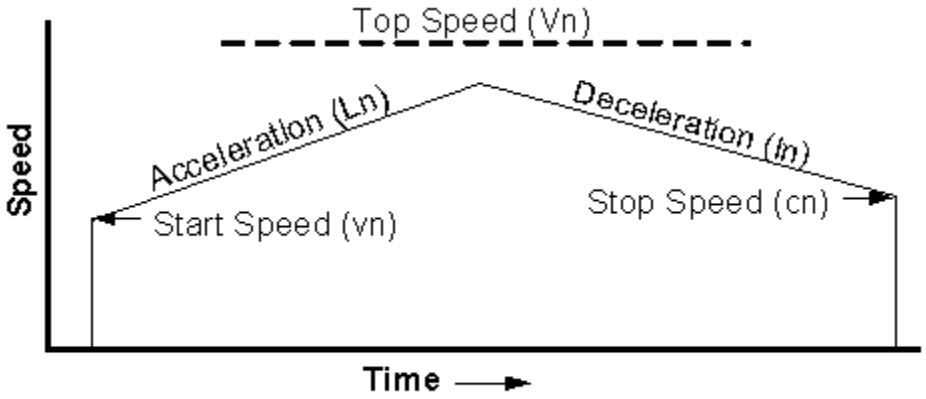


Figure 8-2 Slow Acceleration or Short Move Speed Profile

In actual practice, a typical move spends nearly all the time at the Top Speed and the acceleration and deceleration are very small parts of the total move.

When selecting *Acceleration* and *Top Speed*, there is a trade-off between the two values. The acceleration of the system inertia (pump inertia + fluid inertia) uses part of the available motor power. The motion of the fluid requires additional motor power to overcome back-pressure. If the sum of acceleration power and back-pressure power exceeds the capacity of the motor, the syringe motor will stall and the pump will generate a "syringe overload" error. One or both of the values for *Top Speed* and *Acceleration* would need to be reduced.

The back-pressure of a fluid in motion is greater at the syringe than at the delivery point. The difference between the two is the *pressure rise*. The pressure rise can exceed several hundred psi (tens of atmospheres) in some cases. Here are some of the factors which contribute to the pressure rise and consequent back-pressure:

Factor	Effect
Path diameter	Pressure varies as fourth power of diameter
Path length	Pressure varies directly with length
Fluid velocity	Pressure varies with square of velocity
Temperature	Temperature changes viscosity, which changes back-pressure. Over 5:1 variations are possible.

All these effects are cumulative. Bar far the most sensitive is the path diameter. An increase of just 19% in inside diameter of the tubing or an orifice can drop the back pressure by as much as 50%. One source of gradually increasing back-pressure is too much torque on the fittings used with the valve. The valve requires Teflon® washers to seal the fitting-to-valve connection. If the fittings are tightened too much, the pressure of the connection will cause the Teflon to "cold flow" in a way that reduces the size of the hole in the washer. In extreme cases, the hole can shrink to a pin-hole.

Higher fluid velocities have two reinforcing effects: (1) the pressure increases as the square, and (2) the available motor power decreases with increases in speed. If syringe overloads are occurring, small reductions in *Top Speed* can produce major improvements in system reliability.

If a move fails to begin, the problem may be too high a Start Speed or a blocked fluid path. In general, the default value of Start Speed is a good compromise.

If the pump generates frequent "Z" errors (error #26), the cause may be too high a Stop Speed. An abrupt stop from too high a speed may cause syringe position to become corrupted, resulting in the error message. In nearly all cases, no value of programmed deceleration will result in this problem.

When adjusting the speeds, consider the trade-offs and consequences. Most problems are the result of too high a Top Speed or too high a Stop Speed. The Top Speed must be set to accommodate the dimensions of the fluid path, the fluid viscosity, and the decreasing thrust force as speed increases.

8.2.4 Counting Program Cycles

The number of times a given event has occurred can be determined with the Software Counter (see Section 4.9.1). In the example below, the number of times a programmed dispensing sequence has occurred is counted so a controller can query the pump to determine the number of dispenses which have occurred since the program was initiated.

Example: Count the number of times a dispense has been made in an automated dispensing cycle:

```
k0          set the counter to zero (start of dispense program)

:B          mark start of filling of syringe
o-1         move valve to reservoir port
A12000      fill syringe (12000-step model)
o3          move valve to dispense port

:A          mark start of dispense loop
y<1500B     if not enough left to dispense, refill (go to label :B)
D1500       Dispense 12.5% of a syringe (12000-step model)
k+1         increment the software counter
JA          do another dispense loop
```

In the example above, the program begins by setting the counter to zero. the syringe is refilled each time the syringe position is too small to do another dispense. After each dispense, the counter is incremented by “1'. The counter can be queried at any time to read how many dispenses have occurred. The complete program string would be:

```
k0:Bo-1A12000o3:Ay<1500BD1500k+1JA
```

8.2.5 Converting Volume to Steps

The conversion of syringe volume to steps (syringe increments) can be easily done using a proportion.

$$\frac{\text{steps required}}{\text{total steps in full stroke}} = \frac{\text{desired volume}}{\text{total volume of full stroke}}$$

Example: Assume a total syringe volume of 5 mℓ (5000 µℓ), a desired volume of 250 µℓ, and a 12,000 step model syringe drive. The required number of steps can be found as

Set up proportion:

$$\frac{\text{steps required}}{12{,}000} = \frac{250\ \mu\ell}{5000\ \mu\ell}$$

Solve for desired quantity

$$\text{steps required} = 12{,}000\ (\ 250 / 5000\ )$$
$$= 600$$

The preceding proportion can be used to find speeds also if the “steps required” is replaced with “steps per second” and the “desired volume” is replaced with “volume per second”.

8.3 I/O INTERFACE PROGRAMMING

User Inputs and User Outputs (I/O) can be used to preform a variety of interfacing tasks. In stand-alone operation, without a serial communications controller, the I/O can be used to trigger program operations and to indicate operational status. In multiple-pump operations, the I/O can be used to coordinate and synchronize the operations of the pumps. One special case is the synthesis of continuos fluid flow using two pumps. This section provides some interfacing techniques to aid in using the pump I/O.

8.3.1 Waiting for an Input

In many applications, it is desirable for a pump to wait for an external input signal to start an operation. Test-and-jump commands are used to sense the state of an input signal at a User Input and control the program operation. There are two basic scenarios: wait for a high level and wait for a low level.

Example: Wait for a high input level:

```
:A      program label “A”
i2A     if input #2 is low, go back to label “A”
```

When input #2 goes high, the “i2A” instruction will be “false” and the jump back to label “A” will not be taken. The next instruction in line will be executed. It should be noted the inputs have internal pull-up resistors, so in the absence of a signal connection, the default input level will be high.

Example: Wait for a low input level:

```
:r      program label “r”
i3T     if the input #3 is low, go to label “T”
Jr      jump always to label “r”
:T      label “T”
```

While the input is high, the test for input #3 to be low will fail and the jump to “T” will not be taken. The next command, “Jr” is therefor executed. The “Jr” command send the program execution back to the “r” label and the test will be repeated. When input #3 goes low, the jump to label “T” will be taken. Label “T” then leads to the next instruction in the program.

8.3.2 Handshaking Between Pumps

Handshaking between pumps uses the techniques in Section 8.3.1 to synchronize the operations of two or more pumps. Each pump sends a signal to the other pumps while monitoring the signals from the other pumps. Each pump therefor waits for another pump to trigger its next operation. The example below illustrates the nature of the bidirectional trigger signaling, called a *handshake*.

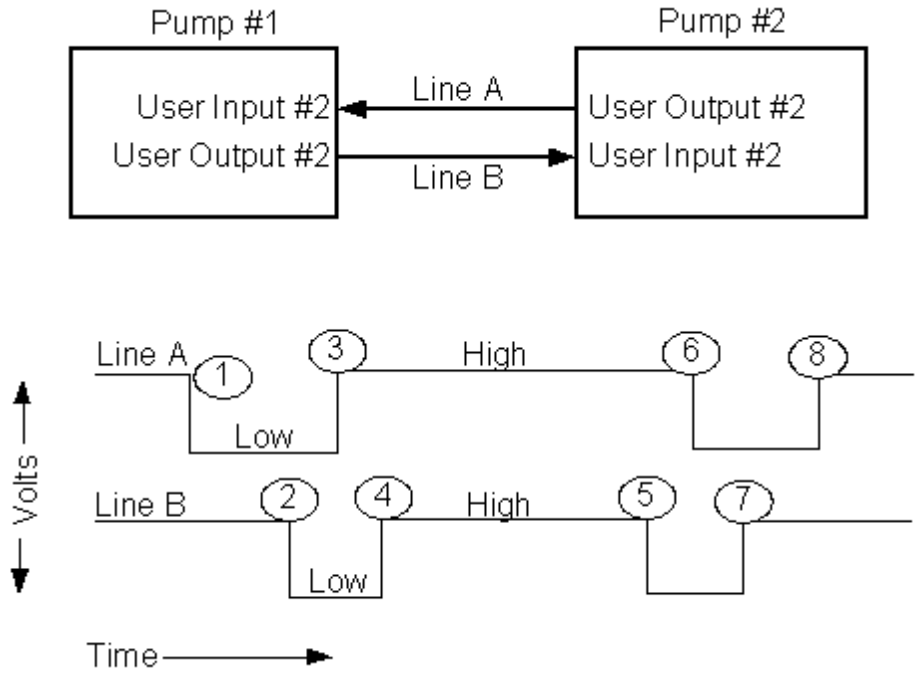


Figure 8-3 Handshake Operation

Figure 8-3 shows the wire connections for a handshake. It is assumed the necessary ground connection between the pumps is present. Each pump has one output connected to and input on the other pump. This allows each pump to send a signal to the other pump. The sequence of operations is illustrated in the voltage-time diagram of Figure 8-3.

First Handshake:

At the beginning, both outputs are idle at the high level.
At (1), pump 2 sets its Output #2 low to signal pump 1 to begin its next operation.
At (2), pump 1 sees the signal and sets its Output 2 low to indicate “signal seen”.
At (3), pump 2 sees the response from pump 1and resets its output back high.
At (4), pump 1 sees the return high from pump 2 and sets its output back high.
After (4), pump 1 begins its next operation and both outputs are in the initial state.

Second handshake:

Initially, both outputs are back in the idle high state.
At (5), pump 1 sets its Output #2 low to signal pump 2 to begin its next operation.
At (6), pump 2 sees the signal and sets its Output 1 low to indicate “signal seen”.
At (7), pump 1 sees the response from pump 2and resets its output back high.
At (8), pump 2 sees the return high from pump 1 and sets its output back high.
After (8), pump 2 begins its next operation and both outputs are in the initial state.

The handshake command strings are the same for each pump. Any of the User Inputs and Outputs could have been used. The handshake command strings for the preceding example are as follows.

Starting a handshake:

```
U2    set output #2 to signal "Go" to the other pump
:A    label "A"
i2B   if input is low, go to label "B"
JA    if not low, go to label "A"
:B    input is low
u2    set Output #2 high again to say "signal is seen"
```

Receiving a handshake:

```
:C    label "C"
i2D   if input is low, go to label "D"
JC    if not low, go to label "C"
:D    input is low
u2    set Output #2 low to say "signal is seen"
:E    label "E"
i2E   if input is still low, check it again
u2    input went high, so set out back to high
```

One special case of a handshake is the *handshake dispense*, described in Section 8.3.3. This command provides an automatic handshake sequence.

8.3.3 Programming Continuous Flow

When a continuous fluid flow is required, the handshake dispense commands may be used to synthesize the flow using two pumps. The resulting flow is continuous, with no gaps in delivery. The handshake connections and signal sequences explained in Section 8.3.2 are used, but the handshaking is an inherent part of the instructions and does not require any programing.

The input ports of both pumps are connected with a "T" fitting so a single source line is used. The output ports of both pumps are connected together with a "T" connection to sum the two outputs into a single delivery line.

As one pump is dispensing, the other pump is refilling. When pump A approaches the end of its dispense, it signals pump "B" to begin to dispense. While pump B is dispensing, pump A refills itself. The handshake signals which tell each pump to begin its dispense are generated by the dispensing pump *just prior to finishing* a dispense. As one pump is finishing a dispense, the other begins and the fluid flow is thus continuous.

The syntax of the handshake dispense is hn (handshake dispense)

When this instruction is encountered, the pump begins testing User Input #n for a low level. When a low level is seen, a dispense begins. *The dispense is always from the current syringe position to zero* (the full-dispense position). As the dispense nears the zero position, the User Output #n is set low just before the dispense ends. This is used as advance notice to the other pump to start its own handshake dispense. All these I/O operations are automatic.

To begin a handshake dispense without an external trigger signal, use the syntax "h-n". This is useful to start a handshake dispense operation or to resume one that has been stopped.

The handshake sequences below assume the syringes are both filled and the valves are both at the dispense port.

Initiating pump:

V2000	Set the dispense speed
h-n	Begin the handshake dispense immediately
:S	Label “S”
o-1	Move the valve to the input port
V6000	Set the filling speed
A12000	Fill the syringe
o3	Move the valve to the dispense port
V2000	Set the dispense speed
hn	Do a standard handshake dispense
JS	go to label “S” for another cycle

Other pump:

:S	Label “S”
o-1	Move the valve to the input port
V6000	Set the filling speed
A12000	Fill the syringe
o3	Move the valve to the dispense port
V2000	Set the dispense speed
hn	Do a standard handshake dispense
JS	go to label “S” for another cycle

Note the initiating pump differs only in the first two lines, which are needed to start the overall process. Once begun, both pumps use the same handshake command sequence. Special note should be taken of the speeds. The refill speed must be faster than the dispense speed by a difference which allows the refilling pump to make two valve moves and refill the syringe before the dispensing pump completes its dispense.

8.3.4 The DVM as a Selector Switch

The Digital Voltmeter (DVM) input can be used as a selector switch. If repeatable voltage levels can be applied to the DVM input, a series of tests can be made to determine what the program should do next. These levels can be generated from a digital-to-analog converter or from a series of resistors soldered around a selector switch to form a tapped voltage divider. In the following command sequence, each test level is chosen to be half-way between the actual voltage levels, not at the voltage levels. This is done for noise immunity.

Example: Assume six discrete voltage levels at 0, 1, 2, 3, 4, and 5 volts. The test thresholds would be at 0.5, 1.5, 2.5, 3.5, and 4.5 volts for a total of five possible selections.

The actual test numbers are found as: number = volts x 51

Selection 1:	0.5 volts = 25
Selection 2:	1.5 volts = 76
Select ion 3:	2.5 volts = 127
Selection 4:	3.5 volts = 178
Selection 5:	4.5 volts = 229

The test sequence uses the numbers calculated above.

```
:A          label "A" marks start of test loop
i>229B      if selection is 5, go to label "B" (start of selection 5)
i>229C      if selection is 4, go to label "C" (start of selection 4)
i>229D      if selection is 3, go to label "D" (start of selection 3)
i>229E      if selection is 2, go to label "E" (start of selection 2)
i>229F      if selection is 1, go to label "F" (start of selection 1)
JA          if no selection, test loop again
```

The order of the tests is critical. If the order were reversed, all selections would satisfy the test for selection 1. Each label "B" through "F" denotes the place in the program at which the commands for each different selection begins. The command sequence of reach selection must end with a jump back to Label "A" ("JA") so the selection process will continue when each selection is done.

8.3.5 Position Snapshots

When the precise location of the syringe at the time of an external event must be known, the pump provides a means to record this. Such information is useful in titrations and other applications in which an external sensor detects an event while the syringe is in motion. Although the syringe position can be queried while the syringe is in motion, the communications overhead prevents the exact syringe position from being determined through on-the-fly position queries. The *snapshot* feature overcomes these limitations and provides exact measurements.

The snapshot feature uses the User Input #3. Each time the User Input #3 transitions from high-to-low, the current location of the syringe is stored in memory. The snapshot memory retains the positions for the two most recent input transitions. The syringe positions for these two points can be queried at any time with the "?29" query. This feature is always available regardless of the input #3 operating mode.

The snapshot feature is very useful for titrations using optical detection, where the detector outputs a double pulse and the two positions at the time of the pulses must be known. It is also useful in any application in which the amount to be dispensed is unknown in advance and must ve determined on-the-fly during the process.

8.3.6 Using the Expansion Port

The V3 includes three digital inputs, three digital outputs, and a Digital Voltmeter input as part of the standard unit. For those applications which need more I/O or different I/O, an Expansion I/O port is also included. The Expansion I/O port is a synchronous serial port which can increase the I/O by either one byte (eight bits of input + eight bits of output) or two bytes (16 bits of input + 16 bits of output). Kloehn makes an I/O Expander Board (P/N 50765) which implements the two-byte expansion.

The 50765 I/O Expander Board is an example of the I/O increase possible with the Expansion port. The 50765 provides 16 extra inputs which can be operated as two bytes or bit-by-bit, and 16 extra outputs, each of which can switch up to 250 milliamperes at up to 40 Vdc. These can be used to control solenoid valves, relays, indicator lights, or other motors.

The Expansion I/O port consists of four signals and two power leads which provide +5 Vdc power for external circuits. The details of the signals are given in section 11.7.4.

The Expansion I/O is managed by extensions of the basic I/O commands as listed in Section 4.3. The relevant commands are listed next, emphasizing the Expansion syntax. The outputs are controlled by these commands, which may be included in a program:

sn Send a serial byte from the User Serial expansion Port, MSB first. The value of the ASCII number "n" is the base 10 representation of the value of a binary byte. For transmitted bytes, positive logic applies ("1" = high logic level). In the 2-byte serial mode, "n" represents the second byte sent. The first byte is the same as the first byte sent by a "sn,m" instruction. See Section 4.5 for an explanation of "@n" usage.
(n: 0...255, @n) [n/a]

sn,m Send two bytes from the User Serial expansion Port, byte "m" first and then byte "n" second. Both bytes are sent MSB (most significant bit) first. The values of "n" and "m" are expressed as the ASCII base 10 representation of the binary bytes.
(n: 0...255, m: 0...255, @n) [n/a]

Un Turn the user parallel output "n" ON (low logic level) or turn on a serial I/O port output bit.
(n: 11...18 = serial byte 1, bit 1...8 of the serial expansion port
21...28 = serial byte 2, bit 1...8 of the serial expansion port) [n/a]

un Turn the user parallel output "n" OFF (open-circuited) or turn off a serial I/O port output bit.
(n: 11...18 = serial byte 1, bit 1...8 of the serial expansion port
21...28 = serial byte 2, bit 1...8 of the serial expansion port) [n/a]

The inputs are read by these commands, which are executed immediately upon receipt and cannot be included in a program:

?10 Query the value of the *first* byte received from the Expansion I/O port input. An input byte is shifted in (MSB first), and the numerical value of the first input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). In 1-byte mode, this is the only byte. In 2-byte mode, this is the first of two bytes.

?20 Query the value of the *second* byte received from the Expansion I/O port input in 2-byte mode. Two input bytes are shifted in (MSB first), and the numerical value of the second input byte is reported in a base 10 ASCII format. The value uses a negative logic convention (low level = 1, high level = 0). This instruction is not valid in 1-byte mode.

?n Query the state of the Expansion I/O port input bit designated by "n". A serial byte is input (MSB first), and the state of the designated bit is reported as an ASCII "0" if the bit is "false" (high input logic level) or an ASCII "1" if "true" (low input logic level).
(n: 11...18 bit 1...8 in Expansion input byte #1
21...28 bit 1...8 in Expansion input byte #2)

Program control using the Expansion I/O is possible with the next command, which can be included in a program:

inp If the input level is true (low input level), jump to label "p". This checks if an Expansion input bit is at a low level.
(n: 11...18 bit 1...8 in Expansion input byte #1
21...28 bit 1...8 in Expansion input byte #2
p: a...z, A...Z) [n/a]

The byte value of an expansion I/O byte can be used to control program flow with the Software Counter test-and-jump commands (see Section 4.9.1) using an indirect variable (see Section 4.5.2).

Example:

k@1	load Software Counter with first Expansion input byte
k<np	if counter < “n” (value of first byte) then go to label “p”

Expansion hardware design is simple, as most common shift registers can be used to transfer data into or out of the Expansion I/O port, as shown in Figure 8-4.

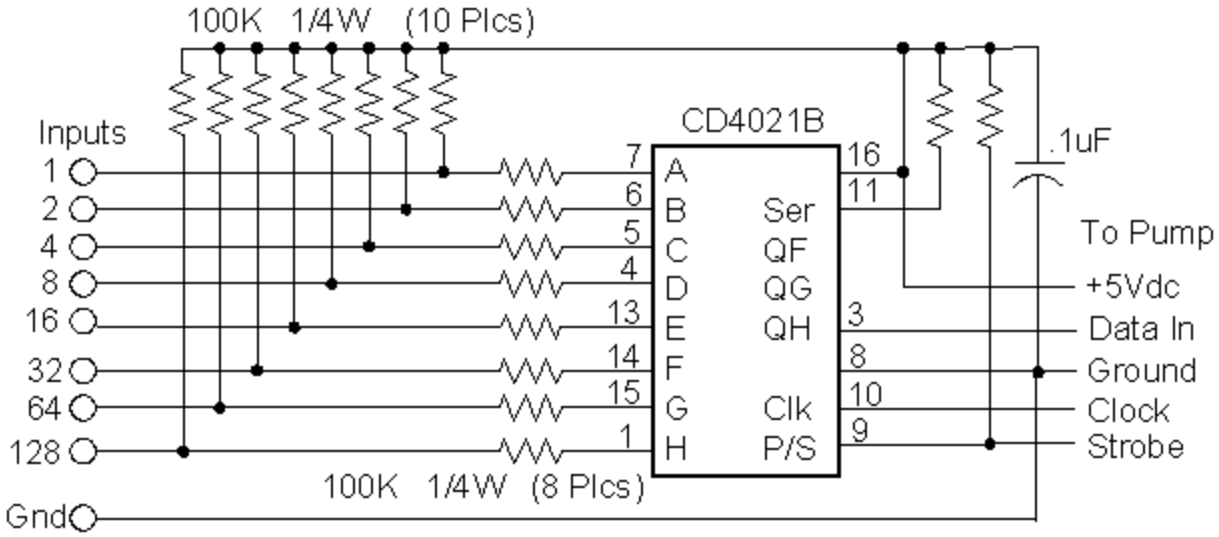


Figure 8-4 Sample 8-bit Input Circuit for Expansion I/O

In the circuit of Figure 8-4, the user inputs are labeled with their equivalent binary weights, with “128" as the most significant bit. The inputs are shown with pull-up resistors (4.7K) and series input protection resistors (100K). These resistors are highly recommended. This circuit will provide an extra eight bits of input in the one-byte mode (see Section 4.6).

If a two-byte version is needed, a second CD4021B should be added. The “QH” of the second chip should be connected to the “Ser” input of the first chip and the two “Clk” inputs should be connected together.

8.3.7 Generating External Pulses

In some applications, it may be useful to generate pulses on one of the User Outputs. This can be done with a simple repeat loop as shown below:

g	Start of repeat loop
U2	Turn on output #2
M10	Make the negative pulse width 10 milliseconds
u2	Turn off output #2
M20	Make the high pulse width 20 milliseconds
G16	Generate 16 pulses

The complete command string is: gU2M10u2M20G16

If the two time delays are omitted to obtain the maximum pulse rate, the resulting pulse rate is about 400 pulses per second.

8.3.8 A Binary Input Selector

In some applications, one of several selections must be made via a selector switch or PLC logic lines. The most economical approach is to encode the inputs as binary numbers. This section describes a way to program a *binary selection tree*. This is a way of making the input bits act as if they have a binary weighting (e.g., 1, 2, 4, etc.). This illustration uses all three inputs as a seven-way selector. The Expansion I/O could also have been used to input the bits with the same instructions (see Section 8.3.6 for Expansion I/O commands). Figure 8-5 shows a flow chart of the algorithm.

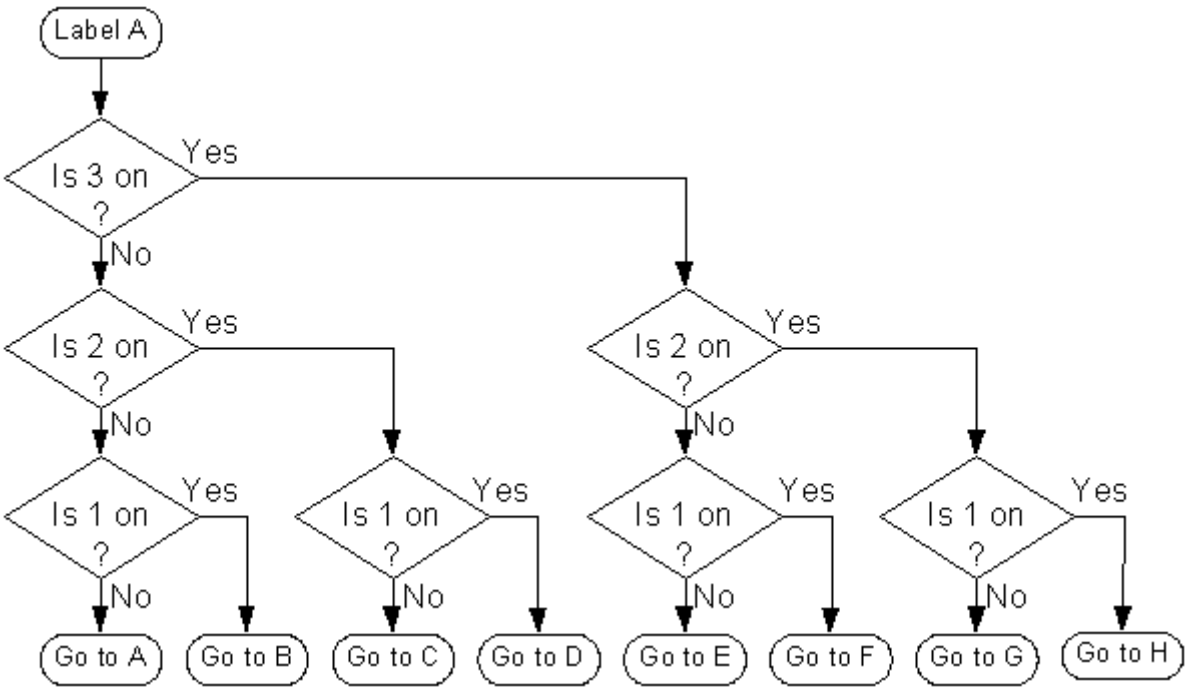


Figure 8-5 Binary Selection Tree Flow Chart

The corresponding commands are:

```
:A      label "A" marks start of selection tree
i3K     Is 3 on?  If yes, go to label "K"
i2L     Is 2 on?  If yes, go to label "L"
i1B     Is 1 on?  If yes, go to label "B"     (selection = B)
JA      Go to label "A" (no selection)
:L      label "L"
i1D     Is 1 on?  If yes, go to label "D"     (selection = D)
JC      Go to label "C"                       (selection = C)
:K      label "K" (second half of binary tree)
i2M     Is 2 on?  If yes, go to label "M"
i1F     Is 1 on?  If yes, go to label "F"     (selection = F)
JE      Go to label "E"                       (selection = E)
:M      label "M"
i1H     Is 1 on?  If yes, go to label "H"     (selection = H)
JC      Go to label "G"                       (selection = G)
```

A three-way selection tree would use only the commands from ":A" through "JC". Each of the labels "B" through "H" is the start of the command sequence which corresponds to the input selection. Each selection command sequence must end with a "JA" (jump to label "A") so the input selection procedure can continue when a process is done. Note the selection "A" goes back to the start of the selection tree. This is done to provide a "no selection" position. If some other means of initiating the selection process (other than a "valid" selection) is used, then label "A" can be used for an eighth selection.

8.3.9 Driving External LEDs

External LED (light-emitting diode) indicators can be driven from the User Outputs. The diode anode should be connected to +5Vdc through a 470-ohm resistor. The LED cathode is connected to the output. When the output is turned "on", the output level will go low and turn on the LED. The output level will still be low enough to drive other external logic. A "super-bright" LED should be used.

An output could also drive the input to an opto-isolator. The internal opto-isolator LED should be connected as described above. The drive current will be about eight milliamps.

The *Error Out* output can also drive an LED. This output should be connected as described above, or the anode of the LED can be connected to the *Error Bias* pin, which provides an internal resistor to +5Vdc.

8.3.10 Wired-Or Error Signal

The *Error Out* signal is an open-drain MOSFET. This permits all the *Error Out* pins of several pumps to be wired directly together. This creates a single, composite *Error Out* signal for all pumps. This composite output can be wired to an LED, opto-isolator, other logic, or a relay (up to 160 mA). If any pump has an error, the output will be active.

9.0 POWER

This section describes the low voltage condition detection, the selection of power supplies, and good power distribution wiring practices.

9.1 POWER SUPPLY SELECTION

9.1.1 Capacity Selection

The power supply capacity should be consistent with the specifications of Section 11.3 of this manual. If a Kloehn power supply is used, these specifications will be met. One Kloehn P/N 17732 power supply has sufficient capacity to power two VersaPump 3 devices.

An output capacity of 25 watts at 24 Vdc is considered a practical value for a one-pump power supply for normal pump operation. The normal idle power consumption is about 6 watts. The 25 watt rating allows for the maximum power required during syringe and valve moves, with a small reserve for reliability.

For multiple pumps on one supply, the overall system operation should be considered. If there are N pumps, of which only M units will be making a syringe or valve move at the same time, then the *average* power capacity of the supply should be at least P = 25M + 6(N-M) watts. The pump automatically turns on the valve motor for moves and then turns it off when not moving. See section 8.2 for additional multiple-pump system wiring considerations.

At power-up, all the valve motors will make simultaneous valve calibration moves, demanding about 0.8 Adc each. To allow for the valve calibration moves, the power supply should have a *peak* power capacity of P = 25N watts. The peak capacity is often not specified directly. It can be calculated from the peak current specification (Ipk) as P = 24N(Ipk). If this results in an excessively large power rating for the normal system operation, the power-up initialize inhibit parameter can be set to prevent the power up moves (see Section 4.6).

In-rush current at initial power-up is the idle current plus the current required to charge the nominal 470 uF capacitance at each pump power input. For almost any power supply, this current will be well within its capacity.

9.1.2 Type Selection

There are three general types of power supply: unregulated DC, linear regulator types, and switching regulator types. Each has different selection considerations.

The *unregulated supply* is the cheapest and simplest. Its output voltage will typically vary about 5% to 20% from no-load to rated load. In addition, the output will vary in proportion to the input line voltage. Since the driver is specified for 24Vdc ± 10%, it is not recommended for use with the V3 pumps.

The *linear regulator* supply usually has a current limiting feature which must be set high enough to handle any current transients generated by the syringe drive. If the current limit is too low, erratic pump operation will result with no obvious cause.

Such a condition can be detected by monitoring the power with a storage oscilloscope. Another possible consequence of low current limit is a too-slow power rise at turn-on. Linear power supplies are inefficient, requiring larger power input, more space, and more weight than the switching power supplies.

A *switching power supply* is the preferred choice. It offers higher efficiency, lower heat generation, and a well-filtered output. Some switching power supplies have a minimum load current requirement. Since the pump can idle as low as 60 milliamps, the supply should be rated for a minimum load current equal to the minimum total system idle current. A ballast resistor may be added across the supply output to guarantee the minimum load requirement of the supply.

9.2 SYSTEM WIRING PRACTICES

In a system with two or more syringe pumps, the power distribution wiring can affect the system reliability. The best system wiring practice is to connect each drive module with an individual pair of power leads from the power supply to that individual module, as shown in Figure 6-1. The pair of leads for each module should be twisted together along their length to reduce radiated fields. Route the twisted pairs of power leads close to the chassis if a metal chassis is used for mounting. This aids in reducing unwanted stray electromagnetic fields in the overall equipment design.

The use of an output filter in each line can reduce radiated and conducted EMI. The simplest filter consists of a series inductance of about 10 uH to 20 uH (rated at 1.5 amps) inserted in-line with the positive power wire. Best results are usually obtained when the inductance is located nearest to the pump.

The J1 interface connector has two power input pins and two ground pins. Good wiring practice uses both opposing pins for the positive lead and both opposing pins for the ground lead. The redundant connections assure a low impedance, reliable set of power connections.

If communications upsets occur during ESD testing when high-voltage arcs are injected into either the controller or the syringe drive, insertion of a ferrite common-mode choke with good high-frequency impedance may eliminate the problem. The power and communications lines should be looped two or three times through a ferrite toroid having an outside diameter of about one inch.

Syringe drives should not share the same power leads as large, noisy electrical loads such as motors and large solenoids. While the syringe design contains filtering to reduce susceptibility to electrical noise conducted via the power supply wires, large current or voltage transients could be harmful to the pump.

9.3 LOW VOLTAGE CONDITION

If the pump supply voltage decreases below the internal reference minimum (20V), a "Low Voltage" error condition is generated. While the voltage remains below the minimum, valve and syringe moves are inhibited. For supply voltages down to about 8 Vdc, the internal control electronics and memory are not affected and other instructions, such as I/O operations and queries, will still operate normally after the low voltage error message has been reported or cleared.

Some power supplies will turn on gradually. If the rise time of the supply is slow enough, the internal computer may generate a "Low Voltage" error when the pump powers up. This will not cause any operational problems after the power has stabilized and communications has been established. The error message will have to be cleared before any other commands can be executed. The message can be cleared by querying the pump status.

If low voltage errors persist when a voltmeter check of the power supply appears to show a proper voltage, the problem may be transients on the power supply leads. Transients may be induced by wiring which passes close to other high-current electrical loads, by current-limiting operation of linear supplies, by transients passed through the power supply from the ac power source used by the supply, or by using a wire size which is too small for the length.

9.4 POWER CONSERVATION FOR BATTERY APPLICATIONS

The V3 pump draws a current which depends upon the power supply voltage, the idle logic current, and the motor currents. The current consumption can be minimized in some applications through the pump programming.

The supply voltage is inversely proportional the current consumption. This is because the pump is a *constant power* device. As the voltage increases, the current decreases so the product of the two will remain approximately constant. The capacity of a battery for portable operation is thus best estimated using a *watt-hour* rating (watt-hours = ampere-hours x volts).

The motor current is the sum of the valve motor and syringe motor demands. The valve motor draws current during a valve move, and automatically turns off when a valve ends. The valve motor automatically turns on at the start of a valve move.

The Syringe motor normally idles at half-power. When a syringe move begins, the syringe switches to full-power operation for the duration of the move. When the move ends, the power automatically switches back to half-power. If the syringe is not required to hold a significant back-pressure, the syringe motor can be turned off at the completion of each move, thereby reducing idle power to the logic idle power alone. The logic idle power alone is typically about 2.4 Watts.

10.0 MOUNTING & INSTALLATION

10.1 MOUNTING a SINGLE PUMP

The mounting dimensions of the VersaPump 3 are shown in Figure 10-1. The drive is usually *base mounted* using the holes in the bottom. The stacking holes on the back may also be used for mounting with a bracket.

It is recommended that the pump be mounted to a solid base. If the pump is mounted to an instrument panel, the panel should be reinforced to create a very stiff, rigid surface. If these precautions are not observed, any vibrations from the operation of the drive may be coupled into the instrument face. The instrument face can then act as a loudspeaker, amplifying all pump acoustics. Where possible, a vibration isolation material may be used between the pump and the mounting surface to improve acoustic isolation from the mounting structure. A material such as *Sorbothane* (see www.sorbothane.com) is recommended. A gasket cut from a mouse pad can serve in a breadboard as a convenient isolator. When selecting materials, remember that different materials are acoustically transparent at some frequencies and acoustically opaque at other frequencies. Mechanically "lossy" materials are best.

An instrument enclosure to which the drive is mounted should have good electrical conductivity to the system chassis ground. This will reduce radiated emissions from the equipment. A wire from the pump chassis to the equipment chassis will generally ***not*** provide a satisfactory system ground because it does not provide the high-frequency transient conductivity required. If possible, a metallic enclosure or a plastic enclosure with RF shielding is preferred.

The pump has been designed with a large operating ambient temperature margin. However, it is prudent to allow air venting for an enclosure to improve the system reliability. In many applications, a cooling air inlet at the bottom of an enclosure and a hot air vent near the top can provide adequate ventilation. Only when operating in ambient temperatures near the maximum would any kind of forced air cooing become desirable.

An alternate mounting technique uses the stacking holes on the rear panel of the pump to attach the pump to a mounting bracket. The bracket contains the threaded nuts to capture the mounting screws. The PEM company (www.pemnet.com) carries a well-designed and varied selection of such nuts.

10.2 STACKING DEVICES VERTICALLY

The V3 pump has been designed to permit stacking two devices vertically. The devices can be two V3 pumps or one V3 pump and one electronically-controlled selector valve such as the Kloehn *Intellect*. In the latter case, an Intellect would be the upper device and a pump would be the lower device. This arrangement also offers the advantage of the shortest possible distance between the pump and Intellect valves. This produces the lowest dead volume between valves, while providing 13 ports.

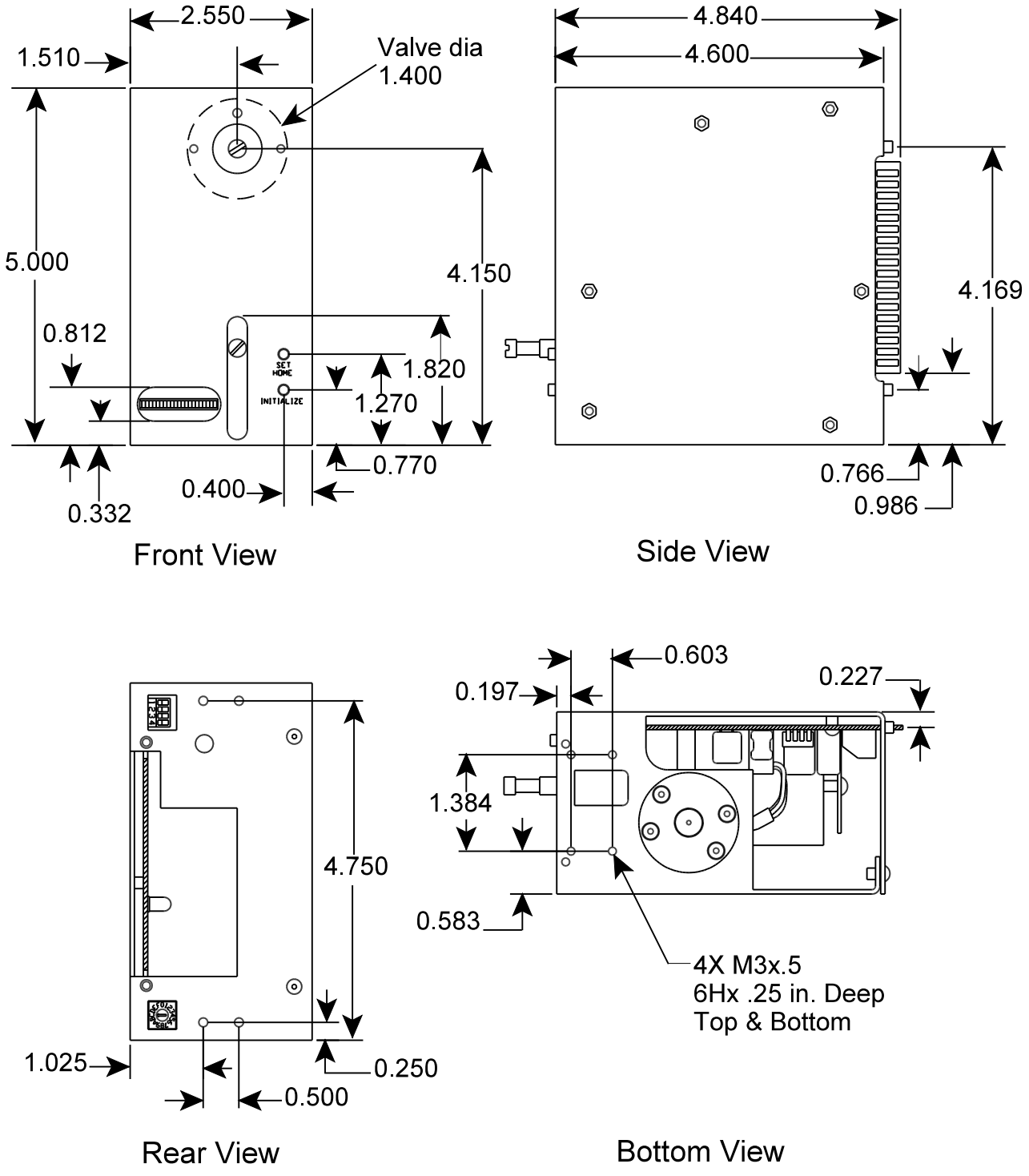


Figure 10-1: Mounting Dimensions for VersaPump 3

10.3 THERMAL CONSIDERATIONS

The Versa3 pumps are designed to operate throughout the specified operating temperature range with natural convection cooling. If the pumps are placed into an enclosed container or the mounting restricts cooling air flow, provision should be made for adequate ventilation.

Adequate ventilation can be achieved by providing a path for cooling air to enter and heated air to exit the pump's interior. Cooling air should be drawn from a point below the heated air exhaust. If the pump is mounted in its own enclosure or in a small enclosure, a fan may be required to provide adequate cooling.

A cooling fan of about 40mm x 40mm x 10mm with not less than an unloaded airflow of about 6 m^3/hr (3.5 ft^3/min) is recommended to blow air into the pump interior. A DC brushless motor type is recommended for reliability. The second model V3 is available with this fan included within the pump as an option.

External fans should be mounted to blow air into the lower portion of the pump's rear opening. Some examples of recommended fan types are the PAPST models 414F, 414, or 414H (www.papst.de/home.html), also available from Digi-Key as part numbers 381-1070-ND or 381-1082-ND.

> Do NOT disassemble a V3 pump to install an interior fan. Mount fans external to the pump or order a fan installed as a factory option.

11.0 SPECIFICATIONS

11.1 ENVIRONMENTAL

Temperature	
Operating	-25 to 55 °C (-13 to 131 °F)
Storage	-25 to 85 °C (-13 to 185 °F)
Humidity	5 to 95% RH, non-condensing
Altitude	
Operating	10,000 feet pressure altitude, maximum
Non-operating	40,000 feet pressure altitude, maximum

11.2 PHYSICAL

Height	5.00 inches	127 mm
Width	2.55 inches	64.77 mm
Depth	4.60 inches	116.8 mm
Weight	2.5 pounds	1.13 Kg

11.3 POWER

Voltage	20 to 30 Vdc, 24 Vdc nominal
Current (at 24 Vdc)	
Idle, syringe on	0.24 to 0.36 Adc
Idle, syringe off	0.12 Adc
Valve move	0.8 Adc + 0.7 Apk @ 1.67 KHz (sine)
Syringe move	0.5 Adc
Turn-on surge	1.25 A peak, 6 msec
Power consumption	
Idle, syringe off	3 Watts, max.
Idle, syringe on	9 Watts, max
Syringe or valve moving	20 Watts, max.

11.4 SYRINGE AXIS

The syringe axis is designed to drive a syringe having a full-stroke length of 3 cm.

11.4.1 Resolution

The syringe axis is available in two resolutions: 6000 steps and 12,000 steps for the same 3 cm stroke length. The resolution is predicated on mechanical design and is not electronically “inflated”. Which of the two resolutions is applicable depends upon which model is purchased.

11.4.2 Accuracy

Accuracy is described by two parameters: *accuracy* and *precision*. For both, the value given is expressed as a percentage of the full stroke of the syringe.

Accuracy measures how closely a dispensed amount of fluid corresponds to the ideal programmed value. *Precision* describes the ability of the drive to deliver the same quantity of fluid for the same size programmed dispenses.

By analogy, consider an archer shooting a group of arrows at a target. Precision is a measure of how closely the arrows are spaced on the target, called the size of the group. Accuracy is a measure of how far the center of that group is from the center of the target. The values for the VersaPump 3 series of pumps are:

Accuracy	0.10% CV (typical, full-stroke), 0.21% max
Precision	0.03% CV (typical, full-stroke), 0.06% max

Additional factors contributing to system accuracy are the total syringe size, any air bubbles or gaps, and any elasticity in the fluid path. The syringe tolerance is a maximum ±1% of total volume. This error contribution is proportional to the amount dispensed as a fraction of syringe volume. Air bubbles, gaps, and tubing elasticity can contribute errors due to compressibility or expansion of their volumes. Such errors are proportional to the positive or negative fluid pressures in the fluid path.

For small dispensed volumes, the accuracy of the volume can be sensitive to the means by which the volume is removed from the probe of tubing tip. Any meniscus can contribute several microliters of dispense error. To minimize these errors, submerge the tip into the destination fluid or "touch off" the tip against the container.

11.4.3 Speed

Syringe speeds are measures in steps per second. The definition of a step is one increment of motion.

Range, normal	40 to 8000 steps per second 5 minutes full-stroke to 1 seconds full-stroke
Range, extended	< 1 step per minute > 200 minutes full stroke.

11.4.4 Syringe Thrust and Pressure

Syringe thrust is related to syringe fluid pressure by the relation

psi = 19.3 x (Thrust - Friction) / Volume

where "Volume" is total rated syringe volume in milliliters (cc),
Thrust is drive force in pounds,
Friction is the syringe piston friction force in pounds.

The 12000-step model has a typical maximum thrust of about 43 pounds independent of the speed. For the 6000-step model, as the syringe speed is increased, the available syringe thrust decreases, as shown in the next table.

Syringe friction is larger for the larger syringes. The largest is the 5 mL, with

about three to five pounds of friction. The smallest syringes have about one to three pounds of friction.

Speed (sps)	Force (pounds)
4500 or less	60
6000	40
7000	38
8000	33

11.5 VALVE AXIS

The valve axis controls a user-selected valve mounted to the faceplate of the pump. The valve axis is configurable for different types of valves Thus a single model of the VersaPump 3 can accommodate any of the available valve types without modification. This is a feature of all Kloehn syringe pumps. Distribution and non-distribution types are available with from two to six ports.

11.6 COMMUNICATIONS

The VersaPump 3 syringe drive has two serial communications protocols: OEM and DT. The two protocols are compatible with the corresponding Cavro protocols. In each case, the pump acts as a *slave* device. It cannot initiate communications, but can only respond to commands from a controlling device. All communications are serial, half-duplex data transfers. The RS232 and RS485 interfaces are supported.
For both standards, the communications parameters are:

Baud rate	1200, 2400, 4800, 9600, 19200, 38400 baud
Data bits	8
Parity	none
Stop bits	1
Flow control	None
Physical protocols	RS485, RS232
Logical protocols	DT, OEM

All communications use ASCII characters for both commands and responses. All numbers are expressed as ASCII decimal numbers. The two protocols, DT and OEM, are explained in Section 6.3.

11.7 I/O INTERFACE

The following subsections describe the User Inputs/Outputs (User I/O) available on the 50300 Syringe Drive Unit. There are 3 parallel digital outputs, 3 parallel digital inputs, one digital voltmeter input, and a serial I/O expansion port for adding additional I/O externally.

11.7.1 Digital Outputs

There are three CMOS digital outputs. These are 5 volt “HC” outputs, compatible with 5V CMOS and TTL. The outputs can be controlled from within a

program or by external command.

DC or peak load current:	± 20 mA maximum per output, ± 40 mA total for all three outputs
Output resistance:	40 Ω typical
Output high:	> 4.8 Vdc nom, I_o = 20 µA
Output Low:	< .1 Vdc, I_o = 20 µA

11.7.2 Digital Inputs

There are three protected digital inputs, each of which has a 4.7 Kohm pull-up resistor to the internal +5 Vdc. See figure 2-2 for the input equivalent circuit.

The inputs may be used to control pump operation, or may be sampled at any time by an external controller. One input may be programmed to act as an external dispense “stop” command. One input may be used to take syringe position “snapshots” on-the-fly for later interrogation.

Logic compatibility:	TTL, 5V CMOS
Input voltage, Maximum:	100 V peak for 8.3 msec maximum +30 Vdc to -25 Vdc, continuous, maximum
Logic "true" level:	< 1.0 V
Logic "false" level:	> 3.5 V or open circuit

11.7.3 Digital Voltmeter Input

There is one digital voltmeter input. This input performs an 8-bit analog-to-digital conversion. An anti-aliasing input filter is included. See figure 2-2 for the input equivalent circuit.

The voltmeter specifications are:

Input impedance:	1 Megohm DC, 20 Kohm into 0.1 µF AC
Resolution:	8 bits (0 - 255), 20 mV/LSB
Accuracy:	+/- 20 mV (1 LSB)
Conversion time:	18 µsec
Range:	5.10 V full scale
Input Filter:	80 Hz lowpass, -6 dB/octave

11.7.4 Serial I/O Expansion Port

The Serial I/O Expansion Port (SIO) provides a means to expand the number of external inputs and outputs of the pump. An I/O Expander board (P/N 50765) is available to add 16 additional inputs and 16 additional outputs. Each of the expander outputs can sink up to 250 mA at voltages to 40 Vdc.

The SIO has one 6-pin interface which simultaneously shifts output data out from the port, input data into the port, synchronous clock pulses out from the port, and provides a timing strobe signal output. The strobe output is active low during a data I/O operation. +5V and ground, for powering external I/O circuits, are available on the connector.

There are two modes of operation: 1-byte and 2-byte. See section 3.5.4 for details of the serial port operation. See figure 11-1 for 2-byte waveform timing figure 11-2 for 1-byte waveform timing. The clock edge-to-data signal timing is the same for both 1-byte and 2-byte operating modes.

Inputs:

Logic "0"	+3.5 V to +5.0 V
Logic "1"	-0.3 V to +1 V
Input current	< 10 µA

Outputs:

Logic "0"	< 0.4 V at 1.6 mA sink
Logic "1"	> 4.2 V at 0.8 mA source
+5V output:	100 mA dc to load, maximum

Clock:

Quiescent level	Logic "0"
Active edges	Positive-going
Frequency	115.2 KHz

Data Strobe:

Quiescent level	Logic "1"
Data hold time	0 sec

Data transfer cycle time (strobe pulse width):

1-byte mode	93 ± 4 µsec
2-byte mode	187 to 262 µsec

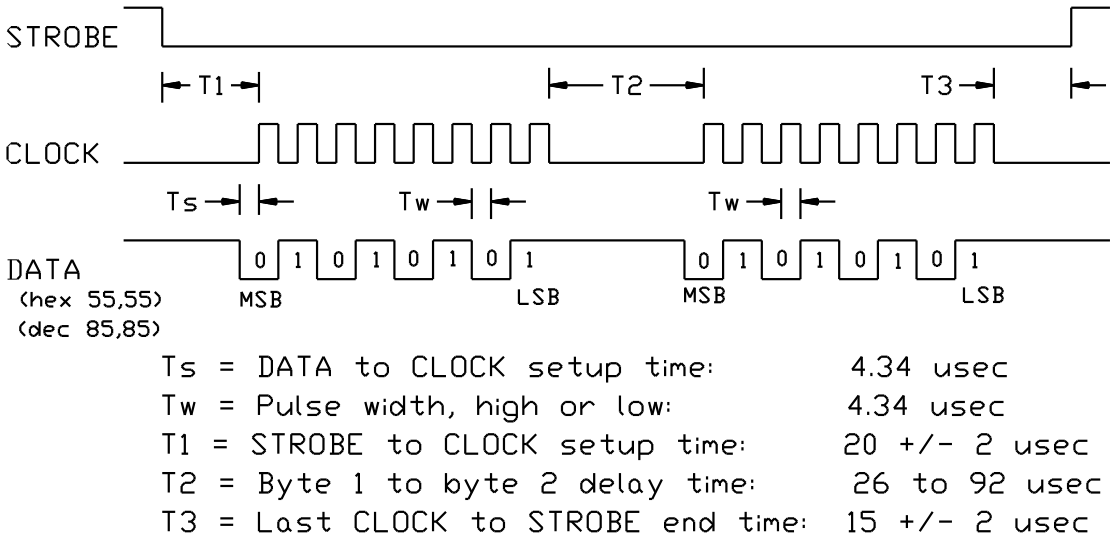
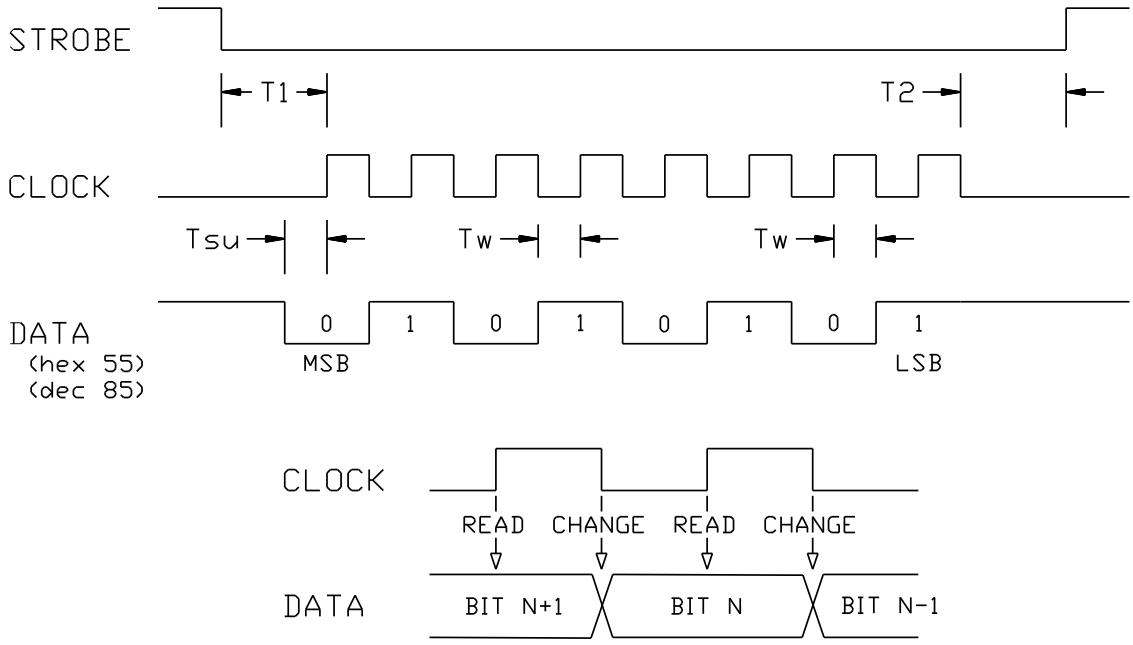


Figure 11-1 Serial Expansion I/O timing, 2-byte mode



Tsu	= DATA setup time	4.34 usec
Tw	= CLOCK pulse width, high or low	4.34 usec
T1	= STROBE to CLOCK start delay time	12.6 usec
T2	= last CLOCK to STROBE end delay time	15.3 usec

Figure 11-2 Serial Expansion I/O timing, single-byte mode

11.7.5 Error LED

The Error LED output provides drive for a light-emitting diode (LED) or external logic whenever an error condition exists within the pump. See Section 5 for a list and explanations of error conditions. Refer to Section 2.2.2 for Error output details.

Error +: internal +5 Vdc supply, internally current limited through 330 ohms
Error -: 5 ohm resistance to ground when in ON (error) condition, open-circuit (> 1 Mohm) when in OFF (normal no-error) condition

11.8 USER PROGRAM MEMORY

Communications Buffer/ RAM: 170 bytes
Non-volatile program memory: 390 bytes
Non-volatile program retention: 15 years, minimum
User program capacity: 10 programs

APPENDIX A: COMMAND SET SUMMARY

A.1 COMMANDS

The commands are presented in alphabetical order. The special notations are explained below:

1. (n) The argument range is in parenthesis.
2. [n] are the factory default values. If there is no default, the [n] is omitted.
3. (i) denotes a command which executes without a "R" (Run) command.
4. (p) denotes a command which can only be used within a program string.
5. {n.n.n} denotes the section in which the more detailed command description may be found.
6. The notation "12000 or 6000" refers to either the 12000-step model or the 6000-step model.

An absolute syringe move, busy (n: 0...12000 or 6000, @) {4.1.1}

an absolute syringe move, ready (n: 0...12000 or 6000, @) {4.1.1}

B move 3-way valve to bypass {4.2.2}

cn set stopping speed (n: 40...8000, @) {4.1.2}

Dn relative syringe dispense, busy (n: 0...12000 or 6000, @) {4.1.1}

dn relative syringe dispense, ready (n: 0...12000 or 6000, @) {4.1.1}

En (i) program save (n: 1...10) {4.4.1}

en (i) program erase (n: 1...10) {4.4.1}

F (i) query buffer status {4.7}

fn+ set program flag #n
(n: 1...6 = general-purpose use
7 = enable syringe move against User Input #3 Stop signal
8 = stop on second high-to-low User Input #3 transition
9 = disable the SET HOME button) {4.9.2}

fn- clear program flag #n (n: 1...9) {4.9.2}

fn? (i) query program flag #n status (n: 1...9) {4.9.2}

fnp (p) if flag #n is set, then clear it and jump to label "p"
(n: 1...8 p: a...z, A...Z) {4.9.2}

fn-p (p) if flag #n is clear, then jump to label "p" (n: 1...8 p: a...z, A...Z) {4.9.2}

g...Gn (p) repeat commands between g and Gn "n" times
(n: 0...30000, 0=forever, @) {4.4.3}

H (p) halt program (breakpoint) {4.4.2}

hn handshake dispense, external trigger (n: 1..3, @) {4.4.1, 8.3.3}

h-n handshake dispense, immediate execution (n: 1..3, @) {4.1.1, 8.3.3}

I (capital "i") move 3-way valve to input {4.2.2}

inp (p) if input bit is "true" (low level), then jump to label "p"
(n: 1...3 = User Inputs 1...3
11...18 = Expansion I/O input byte 1, bits 1...8
21...28 = Expansion I/O input byte 2, bits 1...8
@
p: a...z, A...Z) {4.3.3}

i>np (p) if Digital Voltmeter input is less than "n", then jump to label "p"
(n: 0...255, @ p: a...z, A...Z) {4.3.3}

i<np (p) if analog (digital voltmeter) input is greater than "n", then jump to label "p" (n: 0...255, @ p: a...z, A...Z) {4.3.3}

Jp (p) jump always to label "p" (p: a...z, A...Z) {4.4.3}

jn (p) execute program #n and then return to next instruction in this program
(n: 1...10, @) {4.4.3}

Kn (p) set number of syringe backlash steps (n: 0...500) {4.1.2}

k (i) query the value of the software counter {4.9.1}

kn set the software counter value to "n" (n: 0...65535, @) {4.9.1}

k+n add "n" to the software counter (n: 0...65535) {4.9.1}

k-n subtract "n" from the software counter (n: 0...65535, @) {4.9.1}

k^n exchange the contents of counter memory "n" with the active counter
(n: 1...8) {4.9.1}

k<np (p) if the software counter is less than "n", then jump to label "p"
(n: 0...65535, @ p: a...z, A...Z) {4.9.1}

k=np (p) if the software counter is equal to "n", then jump to label "p"
(n: 0...65535, @ p: a...z, A-Z) {4.9.1}

k>np (p) if the software counter is greater than "n", then jump to label "p"
(n: 0-65535, @ p: a...z, A...Z) {4.9.1}

Ln set syringe acceleration slope, Hz/sec = 2500 x "n" (n: 1...20, @) {4.1.2}

ln set syringe deceleration slope, Hz/sec = 2500 x "n" (n: 1...20, @) {4.1.2}

Mn delay "n" milliseconds (n: 1...60000, @) {4.4.3.3}

mn turn motors on/off (n: 0=syringe motor off, 1=syringe motor on, 2=valve motor off, 3=valve motor on) {4.9.5}

O move 3-way valve to output {4.2.2}

on move valve to position "n" (n: 1-8, @ valve-dependent) {4.2.2}

Pn relative pickup-aspirate, busy (n: 0...12000 or 6000, @) {4.1.1}

pn relative pickup-aspirate, ready (n: 0...24000 or 6000, @) {4.1.1}

Q (i) query pump status {4.7}

qn (i) read stored program #n (n: 1...10) {4.4.1}

R (i) run program in RAM {4.4.1}

r n (i) run stored program "n" {4.4.1}

Sn set syringe Top Speed (n: 0...33, @) {4.1.2}

sn send SIO byte (n: 0...255, @) {4.3.1}

sn,m send SIO double byte
(n: 0...255, @ 2nd byte m=0...255, @ 1st byte) {4.3.1}

s<np (p) if serial input byte value is less than "n", then jump to label "p"
(n: 0...255, @ p: a...z, A...Z) {4.3.3}

s>np (p) if serial input byte value is greater than "n", then jump to label "p"
(n: 0...255, @ p: a...z, A...Z) {4.3.3}

tn exit the error handler routine in the way determined by “n”
(n: 1 = Return program execution to the instruction following the instruction which caused the error
2 = Restart the program from the beginning
3 = Perform a normal error exit with an error message
4 = Retry the instruction which caused the error) {4.8.2}

T (i) terminate execution of command or program {4.4.2}

Un turn on an output bit; "on" (set to low)
(n: 1...3 = User Inputs 1...3
11...18 = Expansion I/O input byte 1, bits 1...8
21...28 = Expansion I/O input byte 2, bits 1...8
p: a...z, A...Z) {4.3.1}

U#n (i) turn on User Output bit “n” immediately (set to low) (n: 1...3) {4.3.1}

un turn off an output bit; "off"
(n: 1...3 = User Inputs 1...3
11...18 = Expansion I/O output byte 1, bits 1...8
21...28 = Expansion I/O output byte 2, bits 1...8
p: a...z, A...Z) {4.3.1}

u#n (i) turn off User Output bit “n” immediately (set to high) (n: 1...3) {4.3.1}

Vn (i) set syringe Top Speed in steps/sec (n: 40...8000, @) {4.1.2}

vn set syringe Start Speed in steps/sec (n: 40...1000, @) {4.1.2}

Wn initialize syringe and valve (n: 4=move valve to port 1, then move syringe to "soft limit"; 5=save current syringe position as zero) {4.1.3}

X (i) repeat last command string; does not apply to queries {4.9.6}

x? query error number (see Section 5.1) last trapped {4.8.3}

y<np (o) if syringe position is less than “n”, then go to label “p”
(n: 0...12000 or 6000 p=a...z, A...Z) {4.4.3}

y=np (o) if syringe position equals “n”, then go to label “p”
(n: 0...12000 or 6000 p=a...z, A...Z) {4.4.3}

y>np (o) if syringe position greater than “n”, then go to label “p”
(n: 0...12000 or 6000 p=a...z, A...Z) {4.4.3}

Yn initialize the syringe and select the port specified by the "~Y" parameter (n: 4...5, see "Wn") {4.1.3}

Zn initialize the syringe and select the port specified by the "~Z" parameter (n: 4...5, see "Wn") {4.1.3}

znp trap error #n and jump to a user error handler routine at program label “p”
(n: 1...26 p: a...z, A...Z) {4.8.1}

? (i) query the syringe position {4.1.4}

?1 (i) query the syringe Start Speed {4.1.4}

?2 (i) query the syringe Top Speed {4.1.4}

?3 (i) query the syringe Stop Speed {4.1.4}

?4 (i) query the User Input 1 status, reply "1" if at low level {4.3.2}

?5 (i) query the User Input 2 status, reply "1" if at low level {4.3.2}

?6 (i) query the User Input 3 status, reply "1" if at low level {4.3.2}

?7 (i) query the User Analog Input voltage, volts = reply x 0.02 {4.3.2}

?8 (i) query the valve position (1=A, 2=B, etc.) {4.2.3}

?9 (i) query the number of unused bytes in NVM {4.4.1}

?10 (i) query the numerical value of the serial I/O input byte, or of byte 1 for a 2-byte mode {4.3.2}

?n (i) query the status of a serial I/O input bit, report "1" if at low level
(n: 1...3 = User Inputs 1...3
11...18 = Expansion I/O input byte 1, bits 1...8
21...28 = Expansion I/O input byte 2, bits 1...8
p: a...z, A...Z) {4.3.2}

?19 (i) query NVM, reply list of program numbers in NVM {4.4.1 }

?20 (i) query numerical value of serial I/O input byte 2 {4.3.2}

?29 (i) query contents of the syringe position snapshot memory {8.3.5}

?30 (i) query the acceleration followed by the deceleration values {4.1.4}

$ (i) query number of "valve stalls" (reply: 0=no stall, 1=stalled once, 2=stalled twice) {4.2.3}

% (i) query number of valve movements since pump turned on {4.2.3}

& (i) query firmware revision number {4.7}

***** (i) query pump supply voltage, volts = number x 0.2 {4.7}

:p (p) set program label (p: a...z, A...Z) {4.4.3}

! (i) store current syringe speed and backlash values in NVM {4.1.2}

~? (i) query command operating mode (reply: "-1" if in configuration mode, else reply with syringe position) {4.7}

~A (**~a**) (i) query the autostart program number {4.6}

~An (**~an**) (i) set autostart program number to "n" (n: 0...10, 0=none) [0] {4.6}

~B (**~b**) (i) query the communications baud rate setting (see ~Bn) {4.6}

~Bn (**~bn**) (i) set communications baud rate [3] {4.6}

n	Baud rate	n	Baud rate
1	38,400	5	2,400
2	19,200	6	1,200
3	9,600	7	600
4	4,800	8	300

~H (**~h**) (i) query the HOME button mode {4.6}

~Hn (**~hn**) (i) set the HOME button mode (n: 0=enabled, 1=disabled) [0] {4.6}

~I (**~i**) (i) query the power-up valve move mode {4.6}

~In (**~in**) (i) set the power-up valve move mode (n: 0=enabled, 1=disabled) [0] {4.6}

~L (**~l**) (i) query User Input 3 operating mode (reply: 0=normal "logic", 1=dispense "limit") {4.6}

~Ln (**~ln**) (i) set User Input 3 mode (n: 0=normal "logic", 1=dispense "limit") [0] {4.6}

~P (**~p**) (i) query communication protocol {4.6}

~Pn (**~pn**) (i) set communications protocol (n: 1=DT, 2=OEM) [0] {4.6}

~S (**~s**) (i) query serial I/O mode (reply: 1=1-byte, 2=2-byte) {4.6}

~Sn (**~sn**) (i) set Expansion I/O mode to 1-byte or 2-byte transfers (n: 1=1-byte, 2=2-byte) [1] {4.6}

~V (**~v**) (i) query the valve type {4.2.3}

~Vn (**~vn**) (i) set valve type {4.2.1}

n	Valve Type	n	Valve Type
0	no value		
1	3 way non-distribution valve	2	3 way distribution valve
3	4 way non-distribution valve	4	4 way distribution valve
5	5 way non-distribution valve	6	5 way distribution valve
7	6 way non-distribution valve	8	6 way distribution valve
9	8 way non-distribution valve	10	8 way distribution valve

~Y Query the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Y4" command. {4.1.4}

~Yn Select the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Y4" command. {4.1.3}

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

~Z Query the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Y4" command. {4.1.4}

~Zn Select the valve position to which the valve will go just prior to moving the syringe to the soft limit using the "Z4" command. {4.1.3}

n	Port	n	Port
1	A	5	E
2	B	6	F
3	C	7	G
4	D	8	H

A.2 VARIABLES

This section lists the general and indirect variables which can be used with the “@n” syntax for command argument values. See Section 4.5 for details.

The general variables and their argument values are:

Argument	Variable	Argument	Variable
@11	z1	@15	z5
@12	z2	@16	z6
@13	z3	@17	z7
@14	z4	@18	z8

The indirect variables are:

@1 Numerical value of Expansion input byte #1, read as a two-digit packed BCD number (0...99)

@2 Numerical value of Expansion input byte #2 #1, read as a two-digit packed BCD number (0...99)

@3 Digital Voltmeter input (0...255, corresponds to 0...5 Vdc)

@4 Digital Voltmeter input (two-digit BCD, normalized to 0...99. Normally used for external displays driven from the Expansion port.)

@5 Current Software Counter value (0...65535)

@6 Current valve position (1...number of ports for valve type)

@7 Current syringe position (steps, normally used in other commands)

@8 Current syringe position (two-digit BCD, normalized to percent of full stroke, 0...99. Normally used for external displays driven fro the Expansion port.)

@9 most recently-sent value of the byte #2 sent with the sn,m command

@10 most recently-sent value of the byte #1 sent with the sn,m command

The instructions which can use these variables are:

Instruction		scaled
An, an	move syringe to absolute position	yes
cn	set stopping speed	yes
Dn, dn	dispense, relative to current position	yes
g...Gn	repeat loop	no
inp	if serial input bit true, jump to "p"	no
i>np	if analog input > "n", jump to "p"	no
i<np	if analog input < "n", jump to "p"	no
jn	do program #n, then return	no
Kn	set number of backlash steps	yes
kn	set software counter = "n"	no
k+n	add "n" to software counter	no
k-n	subtract "n" from software counter	no
k<np	if counter < "n", then jump to "p"	no
k=np	if counter = "n", then jump to "p"	no
k>np	if counter > "n", then jump to "p"	no

Ln	set acceleration slope	no
ln	set deceleration slope	no
Mn	delay "n" milliseconds	yes
on	move valve to position "n"	no
Pn, pn	aspirate, relative to current position	yes
Sn	set top speed	no
sn	send SIO byte	no
sn,m	send SIO double byte	no
s<np	if serial input < "n", then jump to "p"	yes
s>np	if serial input > "n", then jump to "p"	yes
Vn	set top speed (steps/sec)	yes
vn	set start speed (steps/sec)	yes
y<np	if syringe position < “n”, jump to “p”	no
y=np	if syringe position = “n”, jump to “p”	no
y>np	if syringe position > “n”, jump to “p”	no
~An	set autostart program number	no
~Bn	set communications baud rate	no

APPENDIX B: STATUS and ERROR CODES SUMMARY

Each status byte has two forms: *busy* and *ready*. "Busy" means the device is executing a command or program. "Ready" indicates the device is ready to receive another command. The status messages are:

ASCII		Error	Decimal		binary	Status
busy	ready	. # .	busy	ready	76543210	
@	'	0	64	96	01X00000	no error
A	a	1	65	97	01X00001	syringe failed to initialize
B	b	2	66	98	01X00010	invalid command
C	c	3	67	99	01X00011	invalid argument
D	d	4	68	100	01X00100	communication error
E	e	5	69	101	01X00101	invalid “R” command
F	f	6	70	102	01X00110	supply voltage too low
G	g	7	71	103	01X00111	device not initialized
H	h	8	72	104	01X01000	program in progress
I	i	9	73	105	01X01001	syringe overload
J	j	10	74	106	01X01010	valve overload
K	k	11	75	107	01X01011	syringe move not allowed
L	l	12	76	108	01X01100	cannot move against limit
O	o	15	79	111	01X01111	command buffer overflow
P	p	16	80	112	01X10000	use for 3-way valve only
Q	q	17	81	113	01X10001	loops nested too deep
R	r	18	82	114	01X10010	program label not found
S	s	19	83	115	01X10011	end of program not found
T	t	20	84	116	01X10100	out of program space
U	u	21	85	117	01X10101	HOME not set
V	v	22	86	118	01X10110	too many program calls
W	w	23	87	119	01X10111	program not found
X	x	24	88	120	01X11000	valve position error
Y	y	25	89	121	01X11001	syringe position corrupted
Z	z	26	90	122	01X11010	syringe may go past home

Bit 5 of the status byte, denoted by "X" above, is set to "0" if the pump is busy, and is set to a "1" if the pump is not busy.

APPENDIX C SAMPLE QBASIC COMMUNICATIONS PROGRAM

This section presents two typical driver functions: send and receive a string, and test for busy status. These functions have been written and tested in the QBasic syntax as supplied with DOS 6.x [TM]. The structures can be easily converted to Visual Basic or ANSI C. The "GOTO" statements can be used, or a more structured style can be employed.

The communications channel for the syringe drive is opened by the statement:

```
OPEN  "COM2: 9600, N, 8, 1, CS0, DS0, CD0, RS" FOR RANDOM AS #1
```

When the program ends, the statement below must be used to close the channel.

```
CLOSE #1
```

The preceding two QBasic statements will need to be developed as function calls in ANSI C or Visual Basic if an equivalent library function is not available. Windows programs should use the Windows Applications Programming Interface (API) for I/O handling whenever possible. The driver code presented in this manual is intended as a sample of driver structures to facilitate the development of user drivers.

Send and Receive a String

The following QBasic code accepts a string and send it to the syringe drive. It waits a short interval (>15 ms) and receives the response string. The response string is then parsed for the status byte. If an error status has been returned, the error is identified and an error message string is generated. The string value "Pump$" contains the string to be sent, including the pump address number. The response, if any, is returned in the string variable "PumpIn$". Error messages are printed from within the module.

```
'****************** UTILITY MODULE: GetPump subroutine *****************
sends command string, gets reply, parses reply
'       This is used by other subroutines for pump communications
'       Pump$ = command string to send,    pumpIn$ = response string returned
'       "eflag" indicates error status:  0 = no error,  1 = error status;  set to 0 before '
        entry into module.
'
GetPump:
'********* send pump command and get response ************
        PRINT #1, pump$; CHR$(13)               'send command string with <CR>
        FOR n = 0 TO 1000: NEXT n               'delay to receive entire reply
        In$ = INPUT$(LOC(1), #1)                'get reply string from pump
        IF MID$(In$, 1, 1) <> "/" THEN
                PRINT "COMM ERROR: no response from pump"
                eflag = 1                       'set error flag ON
                GOTO gp2                    'exit module
        END IF
'
```

```
'********** parse reply for errors *************
        status$ = MID$(In$, 3, 1)                   'get status byte value
        PumpErr$ = ""                               'clear error message string
        IF ASC(status$) <> 96 AND ASC(status$) <> 64 THEN       'if not  "OK" status
        SELECT CASE status$
                CASE "a", "A": PumpErr$ = "Syringe not initialized"
                CASE "b", "B": PumpErr$ = "Invalid command"
                CASE "c", "C": PumpErr$ = "Invalid operand"
                CASE "d", "D": PumpErr$ = "Communication error"
                CASE "g", "G": PumpErr$ = "Device not initialized"
                CASE "i", "I": PumpErr$ = "Syringe overload"
                CASE "j", "J": PumpErr$ = "Valve overload"
                CASE "k", "K": PumpErr$ = "No syringe move in valve bypass"
                CASE "o", "O": PumpErr$ = "Command buffer full"
        END SELECT
        PRINT "PUMP ERROR: "; status$; "  = "; PumpErr$
                        eflag = 1                           'set error flag to ON
        END IF

'        '********** extract any response string *********************
        n = LEN(In$)                        'begin from last character in reply
gp1:
        IF MID$(In$, n, 1) <> CHR$(3) THEN      'End of TeXt character
                n = n - 1                       'no, check next character
                GOTO gp1
        END IF
        n = n - 4                           'adjust for length of response
        pumpIn$ = MID$(In$, 4, n)           'delete "/0", status byte, & overhead
gp2:
        RETURN
```

When writing an ANSI C version of the preceding drivers, the statement "PRINT #1, Pump$" in the listing below must be replaced with a function call which handles the character-by-character details of string transmission. Also, the "In$ = INPUT$(LOC(1), #1)" statement requires a function call to handle the reception and construction of the reply string.

Check for Busy Status

This module checks to see if the syringe drive is busy or is ready for another command. It returns to the calling routine when the status is "ready". Note that it uses the communications module "GetPump" from Section 6.7.1.

```
'************** UTILITY MODULE: Check Pump for Busy Status************
'    wait for pump to retum a "not busy" status
'    no entry parameters, no return value
PumpBusy:
        pump$ = "/1Q"                               'set up status query string
        GOSUB GetPump                       'send status query
        IF PumpErr$ <> "" THEN GOTO pb2     'if pump status error, exit routine
        IF status$ = "@" THEN GOTO PumpBusy     'else check until "not busy"
pb2:
        RETURN
```

```
'****************** UTILITY MODULE: GetPump subroutine *****************
'       sends command string, gets reply, parses reply
'       This is used by other subroutines for pump communications
'       Pump$ = command string to send,    pumpIn$ = response string returned
'       "eflag" indicates error status:  0 = no error,  1 = error status;  set to 0 before '
            entry into module.
GetPump:
'********* send pump command and get response ************
        PRINT #1, pump$; CHR$(13)               'send command string with <CR>
        FOR n = 0 TO 1000: NEXT n               'delay to receive entire reply
        In$ = INPUT$(LOC(1), #1)                'get reply string from pump
        IF MID$(In$, 1, 1) <> "/" THEN
            PRINT "COMM ERROR: no response from pump"
            eflag = 1                           'set error flag ON
            GOTO gp2                    'exit module
        END IF
'
'********** parse reply for errors *************
        status$ = MID$(In$, 3, 1)               'get status byte value
        PumpErr$ = ""                           'clear error message string
        IF ASC(status$) <> 96 AND ASC(status$) <> 64 THEN       'if not  "OK" status
            SELECT CASE status$
                CASE "a", "A": PumpErr$ = "Syringe not initialized"
                CASE "b", "B": PumpErr$ = "Invalid command"
                CASE "c", "C": PumpErr$ = "Invalid operand"
                CASE "d", "D": PumpErr$ = "Communication error"
                CASE "g", "G": PumpErr$ = "Device not initialized"
                CASE "i", "I": PumpErr$ = "Syringe overload"
                CASE "j", "J": PumpErr$ = "Valve overload"
                CASE "k", "K": PumpErr$ = "No syringe move in valve bypass"
                    CASE "o", "O": PumpErr$ = "Command buffer full"
            END SELECT
            PRINT "PUMP ERROR: "; status$; "  = "; PumpErr$
            eflag = 1                           'set error flag to ON
        END IF

'       '*********** extract any response string ********************
        n = LEN(In$)                    'begin from last character in reply
gp1:
        IF MID$(In$, n, 1) <> CHR$(3) THEN      'ETX character ?
            n = n - 1                           'no, check next character
            GOTO gp1
        END IF
        n = n - 4                       'adjust for length of response
        pumpIn$ = MID$(In$, 4, n)       'delete "/0", status byte, & overhead
gp2:
        RETURN
```

When writing an ANSI C version of the preceding drivers, the statement "PRINT #1, Pump$" in the listing below must be replaced with a function call which handles the character-by-character details of string transmission. Also, the "In$ = INPUT$(LOC(1), #1)" statement requires a function call to handle the reception and construction of the reply string.

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This module checks to see if the syringe drive is busy or is ready for another command. It returns to the calling routine when the status is "ready". Note that it uses the communications module "GetPump" from Section 6.7.1.

```
'************** UTILITY MODULE: Check Pump for Busy Status************
'    wait for pump to return a "not busy" status
'    no entry parameters, no return value
PumpBusy:
        pump$ = "/1Q"                           'set up status query string
        GOSUB GetPump                           'send status query
        IF PumpErr$ <> "" THEN GOTO pb2         'if pump status error, exit routine
        IF status$ = "@" THEN GOTO PumpBusy     'else check until "not busy"
pb2:
        RETURN
```