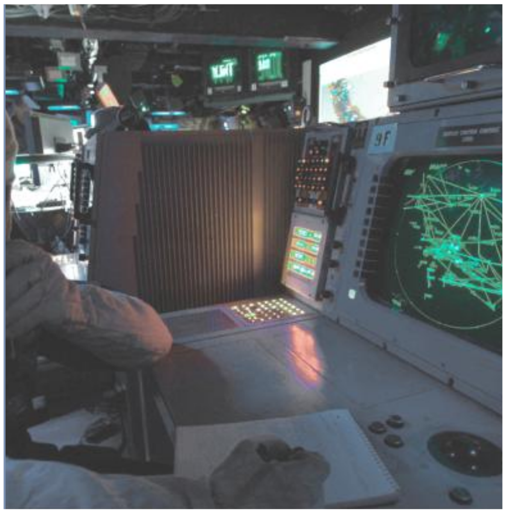
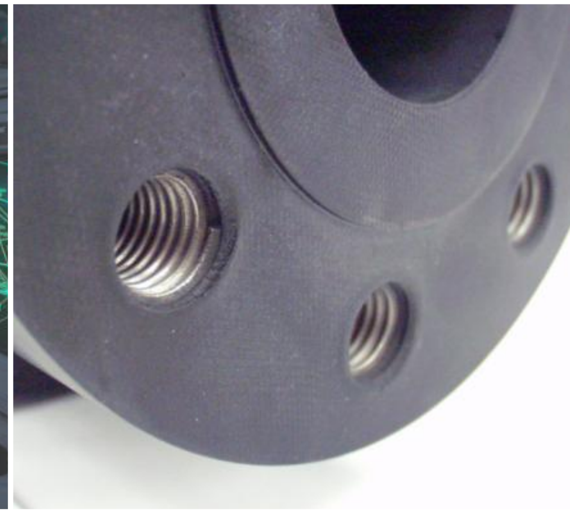
Intelligent

Fluid Control Technology





White Paper

Mike Germinario, Electronics Systems Manager

MAROTTA

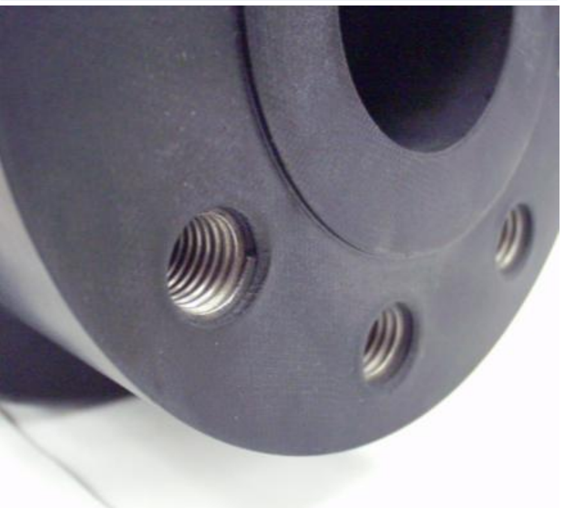


Table of Contents

MAROTTA

1. Executive Summary

The continuing evolution of embedded processor and networking technology combined with proven sensor and servo techniques can provide intelligence to fluid control in valve applications.

There are many benefits:

- Remote control operation
- Autonomous operation
- Increased survivability
- Reduced manning
- Health monitoring for true condition based maintenance
- Simpler control wiring

Marotta's approach to valve design features:

- Increased reliability
- Emergency back up power
- Open architecture
- Proven technologies

These benefits are possible by adapting proven electronics technologies to a balanced pressure valve design. The balanced design requires low power to actuate, making electronic control feasible. Add embedded signal processing and industry standard network options, and you have a system solution that achieves the goals outlined above. Together, with a proven Marotta valve, you have ***Intelligent Fluid Control.***

Because the ***Intelligent Fluid Controller*** can be connected to a data network, all the advantages of what we are familiar with in computer networks are obtained. Network connectivity allows for distributed control, by virtue of strategically placed control nodes that control and monitor many such "smart valves". Should a portion of the network be damaged, or should piping circuits be damaged, the control nodes can reconfigure the piping and networking systems. This aspect increases reaction time, survivability and reduces the manpower required to operate such a system during the damage control situations.

In a dire situation where the valve is completely cut from the network, the valve will autonomously operate to a pre-determined state. Even if power is lost as well, the Intelligent Fluid Controller contains power backup that will continue to power valve actuation for a finite period.

Marotta, a world-class provider of mission-critical fluid controls for the space, defense and specialty commercial markets, is developing an Intelligent Fluid Controller specifically tailored to our ***In-Line Valve Series***.

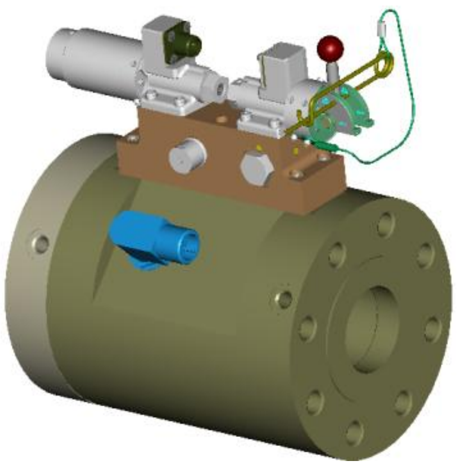
The valve's low power requirements together with the energy storage feature also enable solar cell and power-off-the-network, as supported by some network schemes, to be used as power sources. This flexibility allows deployment in applications that are not suited to conventional valves, where standard power sources are not available or are unreliable.

2. Overview

What makes the valve capable of **Intelligent Fluid Control** is the ability of the integrated digital controller software algorithms and valve system to react autonomously or execute commands from a remote host, which can include valve adjustment, initiation of built-in-test or read out of parameters (temperature, pressure, flow, valve position). The Intelligent Fluid Controller can even provide information on cycles of operation and degradation, which can be used to facilitate preventative maintenance or warn of impending failure.

This white paper describes an implementation and feature set of the Marotta Intelligent Fluid Controller. This controller will be specifically applied to the Marotta In-Line Valve, which uses a latching solenoid pilot valve, although it can be applied to any electric actuation type.

The In-Line Valve uses a balanced pressure poppet configuration for greatly reduced power requirements. As applied to the Intelligent Fluid Controller, low power provides the benefits of higher reliability on the motor and gear train and the feasibility of energy storage in the controller. Should power be lost but the network is still up, the valve can still be commanded to perform a set number of open and close cycles. If the Intelligent Fluid Controller has been disconnected from the network, it can operate autonomously to achieve a predetermined state.



The flexibility of Marotta's Intelligent Fluid Control allows deployment in applications that are not suited to conventional valves.

Flexibility allows Intelligent Fluid Control to be applied to ***any*** valve technology or method of actuation, be it solenoid or motor.

The controller will be a modular and open design such that the features listed below are standard or ***supported as options***, according to customer needs:

Valve Control

- Open/close
- Modulation
- Water-hammer effects alleviation
- Pressure/Flow control

Sensor Interfaces – can be internal to valve or external in system

- Voltage and Current Monitoring
- Limit Switch for Position Sensing
- LVDT
- Pressure
- Temperature
- Flow

Communication Interface Options

- Ethernet
- LonWorks
- Profibus
- Serial Interface – RS422/RS485, RS322, CAN
- Other fieldbusses
- Protocols (Software)
  - Network specific packet structure
  - Command and Data Catalog - Mutually Defined

Remote Programming & Communication

- Remote Operation
- Download motion control profiles
- Download open/close pressure thresholds
- Read back of valve position, system health status, sensors

Built-in-test (BIT)

- Health monitoring
  - Back-up power supply charge status
  - Elapsed time indication
  - Time to failure of position indication

- Valve position and velocity
    - Power supply status
    - Electronics check
- BIT mode
    - Power on
    - Initiated
    - Continuous

Emergency Back-up Power Supply

- Provides power to controller and valve drive in absence of primary power
- Uses super capacitor technology
- Energy storage will operate valve for at least three cycles

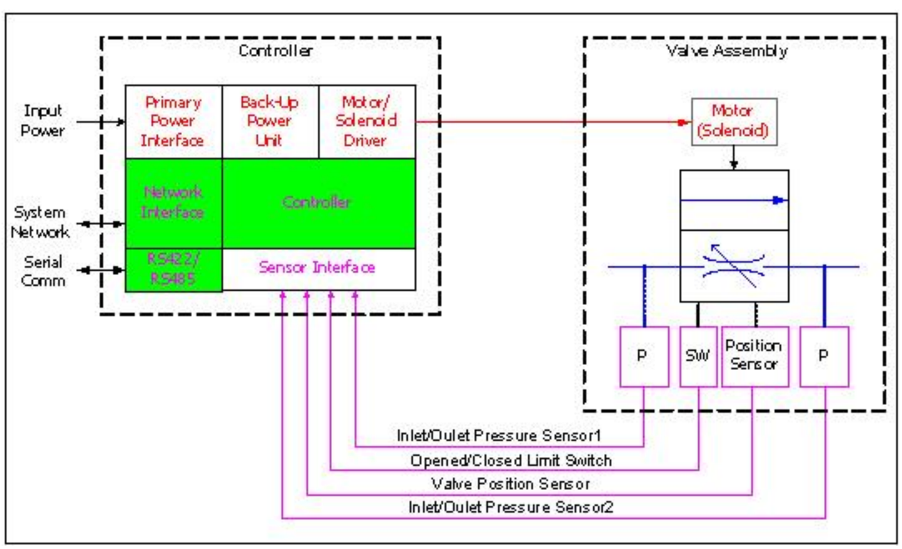
Physically the intelligent controller consists of an electronics assembly which has some of all of the following hardware functions:

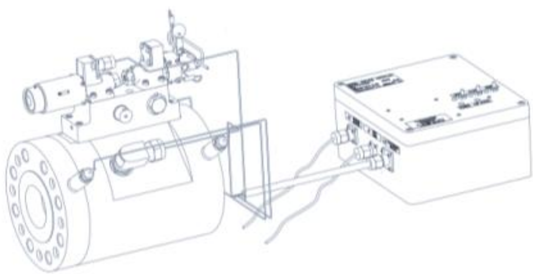
- Embedded Processor (Controller)
- Motor Drive Power Amplifier
- Sensor Data Acquisition Interfaces
- Network Interface Adapter(s)
- Backup Power Control Logic and Charging Circuit

The block diagram shown below, Figure 2.1, illustrates the functions of the Valve Controller design.

Figure 2.1—

Intelligent Fluid Controller Functions





Position sensors allow for precise control of the valve according to velocity and position profiles.

3. Technical Highlights

3.1 Embedded Processor (Controller)

Marotta has developed a family of controllers for motor and process control applications. It is called **"M-CONTROL",** Advanced Fluid Control Technologies. This platform applies microcontroller technology to cost effectively provide complex control solutions. The following sections describe the attributes and flexibility of the Marotta **M-CONTROL** Advanced Fluid Control Technologies Platform.

3.1.1 Control Processor

The processor selection strategy has the following characteristics in mind:

- Low Cost
- Low power consumption
- Small physically
- On chip memory
- On chip interfaces
- Compute power to process DC Brushless motor control algorithm as well as monitor functions, sensor data acquisition, compensations, communication and BIT
- Early maturity status in life cycle
- Rich development and tool chain
- JTAG support
- Serial interface support
- Extended temperature range

We have selected Texas Instruments DSP and ultra-low power MCU technology as a key part of the Marotta architecture. Motor controls are DSP based while solenoid actuated valves will use the MCU.

3.1.2 Debug Ports

The Intelligent Fluid Controller will support a robust development environment by providing interfaces for that purpose.

3.1.2.1 Serial RS232

The Intelligent Fluid Controller software supports interaction via a host terminal session or other Human-Machine Interface software using port communications.

The Intelligent Fluid Controller provides interfaces for virtually any sensor.

3.1.2.2 JTAG

Supported by most processors, JTAG or Joint Test Action Group Boundary Scan (standardized under IEEE 1149.1) allows interaction with the controller without affecting its function. The main advantage is that while debugging, the controller runs at speed and uses its own memory, which allows the developer to work in the actual target environment. Another advantage is the elimination of need for a special debug pod connector on the target; just a small low pin count connector is all that is required.

When development is completed and the unit is presented for qualification and production, the connector is not installed.

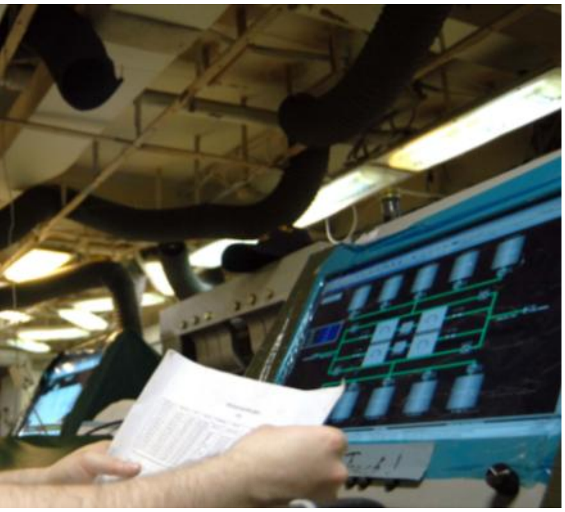
3.1.2.3 Motor Controller

For motor operated valves, the digital electronics will employ the TI TMS320F28xx DSP series. The processor provides highly integrated on-chip support for DC brushless motor drives as well as overall controller implementation. Control system algorithms are implemented to provide motion control. The control function supplies Pulse Width Modulation (PWM) signaling to the Motor Drive Amplifier in response to position and velocity commands. Current, velocity and position sensors provide the necessary feedback to the control system to dynamically adjust the PWM signals so the motor tracks the commands. The sensor feedback is also used to time the PWM for proper motor commutation.

The valve itself will have a position sensor, such as an LVDT and/or limit switches, for valve position feedback. This allows for precise control of the valve according to velocity and position profiles customized to a specific valve application.

3.2 Motor Drive Amplifier

The motor drive amplifier uses the PWM signaling from the motor controller to control power supply switching to the actuator. The in-line valve motor driven actuator would employ a 3-phase DC brushless motor of low fractional HP size. This amplifier is available as a module, which comes in various configurations depending on voltage and current requirements. This makes the Intelligent Fluid Controller scalable from small to large motors, and in turn, small to large valves.



The Intelligent Fluid Controller is designed to be flexible.

3.3 Sensor Data Acquisition Interfaces

The Intelligent Fluid Controller provides interfaces for most any sensor. Analog signal conditioning and data acquisition, AC sensor excitation (if applicable) and digital I/O is used to gather inputs from aforementioned sensors. The sensor baseline is as follows:

- Voltage and Current Monitoring
- Limit Switch
- LVDT
- Pressure
- Temperature
- Flow

3.4 Network Interface Adapter Options

The Intelligent Fluid Controller is designed to be flexible regarding the communications interface to the user's network. This is why the network interface is referred to as an adapter. At present, it is uncertain what type of communications interface and protocol will be used in a particular application—there are a number of candidates from both the industrial and office automation worlds. The link and physical layer of the network adapter will be modular. The controller software is similarly modular in adapting the communications protocol (sometimes referred to the "protocol stack" above the hardware "layers").

There are many options for implementing a "fieldbus" or a local area network for control of devices. Table 3.4 provides a matrix of information on some of the fieldbus major players.

A study of the various cited standards suggests that a broad number can be supported at the physical layer lever using serial (RS 422/485) and Ethernet (IEEE 802.3) interfaces. More recently industrial strength Ethernet standards have emerged and today's new ships will likely move in that direction. The Intelligent Fluid Controller will support a minimum of these interfaces. The I/O structure of the controller will still be flexible to accommodate other I/O types, including discrete I/O and parallel buses.

Item	Profibus	AS-Interface	Interbus-S	Modbus	Ethernet	DeviceNet	LonWorks
General	Communication Protocol	Low cost two wire system and protocol	Hardware master & protocol	Communication protocol, Layer 7 over TCP/IP	Hardware & low level protocols	Controller Area Network Protocol, aka CAN	Hardware & protocols
Standards	DIN 19245, EN 13321/1, (FMS), EN 50254/2, EN 50170/2, IEC 61158 Type 3, SEMI E54.(DP)	EN 50295, IEC 62026/2, IEC 947	DIN 19258, EN 50254/1, IEC 61158 Type 8	A proposed standard has been submitted to IETF	IEEE 802.3	ISO 11898 & 11519	Echelon defined
Physical Media	Twisted pair, fiber	Two wire cable	Twisted pair, fiber	CAT5, coax, fiber, twisted pair	CAT5, coax, fiber	Twisted pair	Twisted pair, fiber, power line
Topology	Line, star, ring	Bus, ring, tree, star	Segmented with "T" drops	Linear	Bus, star, daisy chain	Trunkline or dropline w/ branching	Bus, ring, loop, star
Transport	Master/slave or peer-to-peer	Master/slave with cyclic polling	Master/slave w/ time division multiplexed transfer	Server/client, peer-to-peer	Server/client, peer-to-peer	Master/slave, multi-master, peer-to-peer	Master/slave or peer-to-peer
Relative Performance	Medium	Low	High	High	High	Medium	High
Web Site	www.profibus.com	www.as-interface.net	www.ibsclub.com	www.modbus.org/default.htm	grouper.ieee.org/groups/802/3/	www.odva.org	www.lonworks.com

Figure 3.4—
Options for Control of Devices

3.5 Back-up Power Control Logic and Charging Circuit

When the system depends on electromotive actuation, loss of power becomes a system reliability and survivability issue. Marotta has addressed this concern by developing backup capability, which allows the actuation as well as the system communication function to continue. Enough energy is stored to allow a set number of full range actuations to occur, enough to provide the main system with the ability to adjust and stabilize to a damage control event.

Marotta has applied super capacitor technology to provide for backup power. Super capacitors have the capacity and energy density thousands of times larger than electrolytic capacitors. When compared to Li-ion batteries, super capacitors have lower energy density but can be cycled tens of thousands of times, making them much more powerful. They also possess faster charge and discharge characteristics than batteries and don't have hazard and maintenance concerns of batteries. Super capacitors are available from a number of manufacturers in many different combinations of voltages and capacitance values.

An overview of this technology is provided at http://www.maxwell.com/ultracapacitors.

The Intelligent Fluid Controller will feature power management functions in managing the backup power supply, such as load shedding and processor standby. The constant current charging circuit is regulated and monitored. Status of the backup supply is provided as part of the built-in-test.

If power is lost, the Intelligent Fluid Controller can operate autonomously to achieve a pre-determined state.

In testing that Marotta has performed on DC brush version of the actuator, with no power management optimization of the controller, power is available for up to about one hour, which will vary with the number of open/close actuations performed. Up to 20 open/close actuation (uni-directional) cycles have been performed prior to power depletion.

It is expected that with a more efficient DC brushless motor and power management techniques applied to the electronics, the time of power availability will improve to about an hour or more.

3.6 Built-in-Test (BIT) and Status Feedback

A key feature of the Intelligent Fluid Controller is the ability to provide feedback to the command system the status of the valve unit. Status includes health, updated readings of any sensors, and actuator position and velocity. The BIT feature can also have system initiated self-test sequences, such as a profiled actuation to determine health of entire mechanical assembly.

Other information that can be returned to the command system is run time and fault history. By virtue of non-volatile memory, the Intelligent Fluid Controller can keep a log of activity. A more advanced feature being envisioned is a wear indicator based on sensor feedback of the actuation system and valve body. By examining the noise signature of the signals against those of known wear patterns, a flag can be set

Life cycle cost is reduced with Built-In -Test as part of the overall system design.

to indicate repair or replacement of the device. Such flags are part of the data stream sent to the command system as a result of the BIT.

With BIT as part of the overall system design, life cycle cost is reduced since the Intelligent Fluid Controller informs system command of the faults, wear and run time. Such data collection can be automated and the valve is serviced only when necessary. Fluid system debugging is greatly simplified. More importantly, during tactical situations, the command system can react quickly to a valve fault and make the necessary adjustments without sending personnel to check the system out.

There are three modes of BIT and a suite of tests for each. These are discussed in the paragraphs below.

3.6.1 Power on BIT

Power on BIT is performed at system power up, after internal initialization of subsystems. The suite of tests will be comprehensive. The tests and reading can include the following:

- Input power voltage
- Input power current
- Regulated power
- Backup power status (low, charging, ready)
- Sensor reasonableness (by disturbance of excitation and read back)
- Sensor readings
- Actuator jog to assess the servo drive and sensor feedback
- CPU test
- ROM test
- RAM test
- NVRAM test
- Data acquisition test
- Communications wrap-around test
- Run time log
- Fault log
- Firmware version

3.6.2 Continuous BIT

Continuous BIT is performed continuously during normal operation. The suite of tests includes those that are non intrusive to normal operation. The tests and readings can include the following:

- Input power voltage
- Input power current
- Regulated power
- Backup power status (low, charging, ready)
- Sensor readings
- ROM test
- Limited RAM test
- NVRAM test
- Reduced data acquisition test
- Communications wrap-around test

3.6.3. Initiated BIT

Initiated BIT is performed on demand when commanded by the host system. The tests and readings can include the following:

- Input power voltage
- Input power current
- Regulated power
- Backup power status (low, charging, ready)
- Sensor reasonableness (by disturbance of excitation and read back)
- Sensor readings
- Actuator jog to assess the servo drive and sensor feedback
- Data acquisition test
- Run time log
- Fault log
- Firmware version

The actuator jog test can be modified to perform a full open/close cycle, or any other desired profile.

4. Other Features

An electronically controlled valve can have other features as well:

- On valve electrical or mechanical status indicators
  - Power
  - Charge
  - Valve position
  - Network status
  - Go-Nogo status
- External power/charge via man-pack
- External network port to control via man-pack
- Manual actuation

5. Summary of Benefits

Remote and autonomous operation reduces manpower requirements.

This section describes the benefits of Intelligent Fluid Control technology vs. current legacy valves and particularly, valve which do not provide two-way communication, backup power, or power and size reduction.

5.1 Reduced Manning

It is the stated goal to reduce manpower requirements, as on DDX for example, where reduced manning is cited as a key objective of the program. In order to reduce the number of "touches" of the valves during operations, the valves need some level of inherent intelligence. As part of a command network, the valve can operate autonomously or by remote top-level commands. The built in test feature allows monitoring of the valve at any time from a remote command and control post. The remote post can similarly be automated, or it could be manned so that during operations there is no reason to "visit" the valve. More importantly, overall operation during adverse emergency situations can be accomplished with reduced personnel since the values van operate by remote command or autonomously according to pre-programmed intelligence.

5.2 Enhanced Survivability

The fact that Marotta Intelligent Fluid Controls are network enabled allows them to be employed in re-configurable technology. Whether the network is master/slave, peer to peer, or some combination of the two, intelligence can be imparted in the valve and in other distributed intelligence such that reconfiguration (automatic or manual) is possible should breaks in the network occur. Please see Figure 5.2 for an illustration of this concept.

Valve intelligence and power backup provides a powerful fail safe in the event of complete power and network disconnect from the valve. If the unit senses this, it can autonomously operate the valve to a predetermined state. That state could be a static position or it can modulate to control a pressure or flow. The valve contin-

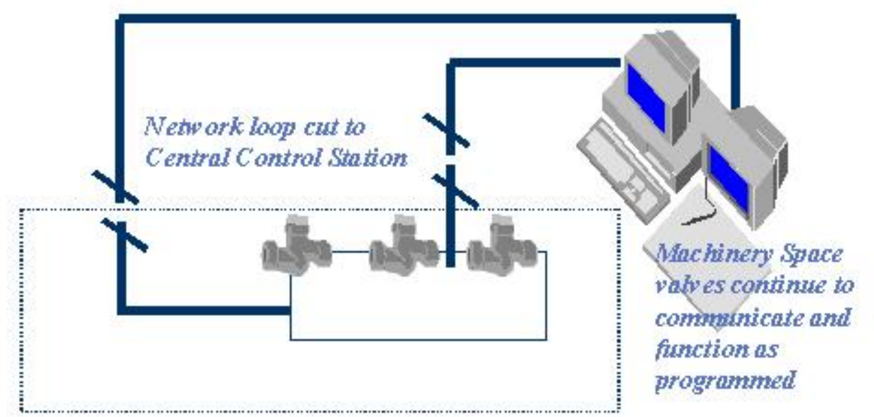


Figure 5.3—Master/Slave Topology

ues to operate until the power backup supply is depleted, as described in the Power Backup section.

5.3 Network Control Schemes

As a node in machinery network, the Intelligent Fluid Controller can participate in the network as a slave or peer device. The network topology would depend on the survivability strategies of a fluid supply system.

Fortunately, many of the standardized industrial network architectures can accommodate either one and even multi-master, which can fit well in a survivability scheme. Figure 5.3 illustrates a master/slave topology that becomes peer to peer when the master is cut off. A networking standard should be chosen with this flexibility in mind. The Marotta Intelligent Fluid controller is designed to be flexible in accommodating the leading industrial networking standards.

5.4 Valve Modulation

Use of motorized actuation instead of solenoids or other hard off/on techniques provide the ability to modulate the degree of valve opening. The open and programmable nature of the Intelligent Fluid Control makes this easy to do. There are a number of benefits provided by valve modulation:

- Applying profiles to fluid control. For example, a set position vs. velocity profile can minimize the water hammer effect by decreasing actuator speed as the valve approaches a stop.

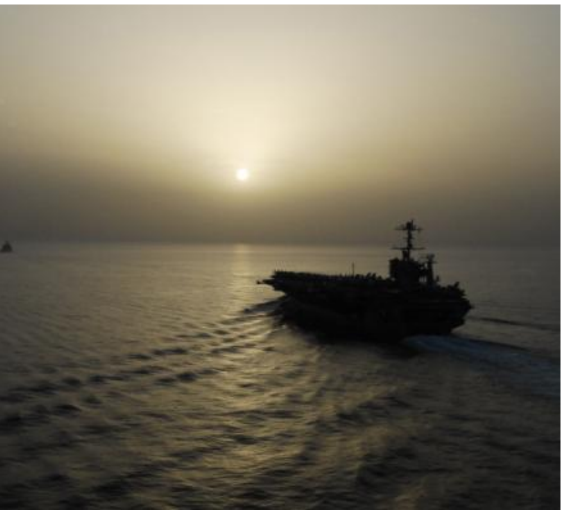
- Modulate valve position as function of other parameters as part of a closed loop system. Using sensors, such as pressure or flow, either within the valve or elsewhere in the piping system, the Intelligent Fluid Controller can modulate the valve to maintain the desired set point.

5.5 Ease of Expansion

As opposed to discrete methods of control, where additional valves or other control devices requires an additional harness and control interfaces downstream, the Intelligent Fluid Controller uses industrial automation network topologies, which are highly scalable without requiring additional control interfacing hardware. In most cases, all that is needed is an available port on the “hub”.

5.6 Minimal Wiring

For the same reason that expansion is eased with respect to control and communication with the Intelligent Fluid Controller, wiring requirements are minimized as well. In an application where wiring is to be minimized, all that is needed is power and a network connection, typically twisted pairs. Consequently, wiring is minimized down the line.



Another possibility is wireless. Marotta has previously demonstrated just such a system of valves, which are networked wirelessly to a control station.

5.7 On Line Condition Assessment

Via status reporting and comprehensive built-in-test, the command system will always be aware of operating conditions at the valve and of any faults that may occur. Status information can be sent autonomously at a regular interval or on demand.

5.8 Weight, Power and Space conservation

It is planned for most valve applications that employ Intelligent Fluid Control technology that DC brush and brushless motors will be used. These motors possess a high energy density, small size and efficiency. As a result, there are considerable weight, power and space savings. For example, in a 3 inch in-line valve application, a small DC Brushless motor measuring 1.3”x2.25” is used versus actuators that are bigger than the valve themselves. Of course, our In-Line balanced valve design significantly contributes to this efficiency achievement as well.

The Intelligent Fluid Controller has many benefits.

For more information contact:

MICHAEL GERMINARIO
Electronic Systems Manager

PETER TARTAGLIA
Director, Business Development
Marine & Land Systems

MICHAEL J. LEAHAN
Vice President & Chief Sales Officer

Marotta Controls, Inc.
78 Boonton Avenue
P.O. Box 427
Montville, NJ USA 07045
+1.973.334.7800
www.marotta.com

Rev 04/09