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CVN Valve Actuator Network Design Deficiencies

Abstract

Valve actuators have been utilized in the US Navy for decades for the purpose of reducing manpower, reducing reaction time to a material condition, and providing centralized situational awareness of a complex shipboard machinery control system. Recently, ship builders have implemented new technologies in valve actuators on the CVN platform that have produced an increase in complexity, maintenance requirements, cost expenditures as well as degraded system operability.

Certain aspects of the actuator and associated network design must be reevaluated in that they are not conducive to a US Navy ship board environment. These designs include physical media, network topology, and the core technology of implementing smart functionality on devices that have simplistic control and feedback requirements.

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or any military department thereof.

I. Introduction

The Nimitz class aircraft carriers have hundreds of butterfly, ball, globe, and gate valves as part of their auxiliary and fueling systems. These valves require remote monitoring and control and are associated with sub-systems including JP5, firemain, list control, drainage, and ballast. On board the carriers, the use of electric valve actuators has met this requirement. There are a variety of configurations and manufacturers of the actuators on board the CVN class. The two main types of valve actuators are quarter turn and multi-turn. The quarter turn actuators are used on butterfly and ball valves, where the multi-turn actuators are used on rising stem valves such as gate or globe valves.

The CVN class utilizes valve actuators containing AC induction motors and typically a clutching mechanism that allows the valve to be operated locally via a hand wheel. For the remote operation, in most cases, the valve actuators are integrated into a distributed control system, known as a machinery control system or MCS. System operators use a PC or console, known as a Human Machine Interface, or HMI, to issue commands and receive feedback from the actuators to transfer fuel, segregate and activate firemain, transfer seawater for list control, and to purify and transfer fuel to aircraft.

The remote control and feedback has been done in most cases by hard-wired contacts that are tied to the MCS remote Input/Output drops, or I/O drops. There are typically four signals associated with a ship board valve: two - 120VAC discrete contacts for open and close indication; and two - 120VAC relay contacts for open and close commands. The typical remote valve operation using MCS is described in the following example scenario: An I/O drop provides the 120VAC feedback circuits out to the valve by three wires: an open indication, a common, and a closed indication. The shut valve has a closed contact that sends the 120VAC back to the "valve shut" input in the I/O drop. The MCS programmable logic controller, or PLC, reads this "valve shut" input and translates the value to a state tag which the HMI represents by a closed icon. If neither the open nor closed inputs are being read from the PLC, the HMI would display a faulted state, sometimes red, white, or showing both open and closed.

When the operator wants to open the valve, they select the valve icon and select the open option. The I/O drop output relay module closes a contact, which sends 120VAC to the open command contact on the valve. The valve begins to open. While the valve is opening, the "valve shut" contact and the associated input de-energize. The PLC changes the state of the tag and the HMI represents the valve as opening by displaying a flashing open icon on the valve. Once the valve fully opens, the "valve open" contact closure provides 120VAC to the "valve open" input in the MCS I/O drop. This is represented by the solid valve open icon. If the valve does not fully open in a preset amount of time, the HMI would again display a faulted state.

This is how the majority of valves operate on board the CVNs.

II. Deployment of Network Actuators
Due to the harsh environment, including seawater, humidity, and industrial work being performed during overhauls and availabilities, these devices have become maintenance intensive. Valves may be seized, over-torqued, and may blow fuses when commanded to operate from MCS. These valves usually require corrective maintenance to bring them back to optimal performance.

Shipbuilders began to explore ways to ease maintenance requirements by introducing network interfaced valve actuators. Network connected valve actuators have a reduced number of connections and the ability to provide additional diagnostic information.

Frequently referred to as "smart" actuators, these devices contain additional circuitry and processors which translate a network message into the open and close commands as well as package the position feedback into the message and send back to the MCS PLC or HMI over the industrial network protocol. This message can also include diagnostic information such as torque settings, torque required to open/close, cycle times, amount of cycles, temperature, current of the motor, as well as detailed component fault information.

The following table of fault data is part of a profibus message structure for a valve actuator. This data illustrates the beneficial information that can be derived from a network interface.

Ch350_ DI_ACTUATOR_FAULTS	Value
Thermal Overload	0x01
Phase Error	0x02
Valve Jammed	0x04
Manual Moved	0x08
Open Torque Switch Fault	0x10
Close Torque Switch Fault	0x20
Thermal Overload + Manual Moved	0x09
Thermal Overload + Phase Error	0x03
Thermal Overload + Valve Jammed	0x05
Open Torque Switch Fault + Manual Moved	0x18
Close Torque Switch Fault + Manual Moved	0x28

On one carrier, the shipbuilder established a requirement for two port fiber-optic Profibus decentralized periphery (DP) valve actuators. The shipbuilder designed profibus fiber rings for their MCS I/O Drop networks, and decided on connecting the more than 600 valves in the same fashion.

Profibus DP is an industry standard communication protocol used the world over. The physical layer of the OSI model lists the media as both RS-485 and optical, although, in most cases the copper profibus (RS-485 type) cabling has been deployed in far more instances.

Profibus works at speeds between 9.6KBps and 12MBps and operates in a master/slave deterministic relationship. When designing a copper profibus network, there are many options on how to tie the slave devices together. There are T-junction connectors, screw-down connections, or DB9 with an integrated termination resistor. You can have up to 124 profibus slave devices per network, although if using copper, a repeater is required after 32 slave devices. Depending on the network speed, there are length limitations on the copper bus network. The length limitation is where the optical media becomes advantageous.

Profibus Fiber Ring Design

The design decision to use profibus fiber rings on the valve actuators may have come from the position that rings are more survivable than bus networks. An introduction to networking source states a disadvantage to a bus network, "Because all systems on the network connect to a single backbone, a break in the cable will prevent all systems from accessing the network." [1] The potential of broken cabling may be the reasoning behind this design decision.

There are Commercial Off the Shelf (COTS) devices that are used to convert the profibus copper into a fiber optic ring network. These devices, known as optical link modules, or OLMs, are specialized media converters/repeaters whose function is to convert the media from profibus copper to two channels of multimode fiber and repeat the profibus signal over either a single or dual fiber ports. The OLM device can create tree, bus, star, or ring topologies. There are variations of these devices from multiple manufacturers and may be known as OLMs, OZDs, or PSIs, but they can all perform the same function.

There is, however, a caveat to devices functionality. Each of the manufacturers states their respective device cannot function with other manufacturer's devices in a ring topology. While there are no issues integrating these devices together in a bus, star, or tree topology, the ring network requires a way to determine when a link fails and when to switch communication paths. Each device manufacturer maintains proprietary rights to the firmware of the OLM's timing and message structure of the heartbeat, or keep-alive probe signal these devices send out on the unused network path, allowing the devices to switch the path when a link failure occurs. There are also specific network configuration parameters that need to be set in the profibus master when using this profibus fiber ring topology. These parameters must be adjusted based on the amount of slave devices on the ring, the total length of fiber, and the network speed. The Original Equipment Manufacturer (OEM) of the dual fiber profibus valve actuator integrated an OLM into their electronics. The OLM internal to the delivered valve actuator requires power to continue the fiber signal through the two channels making the ring. When one of these actuators loses power, it severs the ring.

Shipboard Performance of the Fiber Ring

Onboard the ship, these rings have been difficult to diagnose, troubleshoot and correct. These issues stem from frequent power interruptions. Due to maintenance requirements, troubleshooting efforts, and a ship's electrical safety procedures, power is often secured to electronics enclosures, power panels, breaker panels, load centers, and node rooms. This routine powering down of circuits has had a detrimental effect on the delivered valve actuators connected to the profibus fiber ring. In many instances, when power is lost on two actuators, or there is a mix of power loss and internal OLM failures of the actuator, all actuators between the faulted two lose communication. Due to the design of up to twenty actuators per ring, there have been instances where up to 18 adjacent actuators lost communication, remote control, and monitoring. These occurrences are out of scope of the single point of failure requirement, yet do happen frequently.

This would not occur with a profibus copper bus network. If configured properly, profibus slave devices powered down will not interrupt communications with the actuators further down the bus. The dilemma identified here is the single point of failure requirement. With a profibus bus network, there is a single point of failure, being the cable break. However, the multiple devices being powered down or faulted simultaneously occurs frequently.

Another obstacle ship's force must deal with is the troubleshooting and repair of the fiber itself. This fiber is located in a very harsh environment which gets hot, dirty, and is prone to mechanically-induced vibration. These three characteristics are not conducive for fiber optic cable installation. The fiber does degrade, and unfortunately, the installation of these actuators used standard ST connections outside of the actuator housing. When troubleshooting does occur, sailors disconnect and bypass a powered down actuator. This frequent disconnecting and reconnecting of the ST fiber connections degrades the fiber. The cost associated with the specialized training and tools required to diagnose and repair faulty fiber is significant. A formal training class is required to repair shipboard fiber, whereas the crew can become proficient in repairing profibus copper with on the job training (OJT). Copper can also be repaired using simple tools such as wire cutters, wire strippers, and screwdrivers.

III. Conclusion

Although the legacy, simplified discrete and analog interfaces to valve actuators has proven reliable in the past, the cost associated with corrective and preventative maintenance does prompt the exploration of networked actuators for the benefit of enhanced diagnostics. When deciding on profibus network solutions, the position of this paper is that a copper bus is a more robust solution than the use of a fiber optic ring. Research should be done on existing shipboard control networks prior to conducting failure analysis. The failure analysis should also include "multiple point of failure" parameters. This would highlight the current deficiencies in the shipboard valve actuator ring networks. The fiber network cabling should only be used when either cable length exceeds the transmission capability or if electromagnetic interference is a concern.

Network protocols other than profibus should be explored, including Profinet, Ethernet/IP, Modbus, 4to20mA HART (Highway Addressable Remote Transducer), and DeviceNet. In addition to the protocols, different topologies should also be explored. The star topology is more robust than the bus or ring networks, in that there is no chance that an individual fiber or copper cable break will affect any other device outside of the single connection.

[1] Harwood, Mike; Bird, Drew. Network + Exam Cram 2, p.7, Que publishing, 2005.

Brian Gradel has been an employee of Complete Automation Controls for five years and provides direct support to NSWCCD-SSES Code 967, Carrier Network, Navigation and Steering Control systems branch. He previously supported SSES Code 956, Carrier Machinery Controls branch for eight years as an In Service Engineering Agent for the DDCN systems and their associated profibus networks.