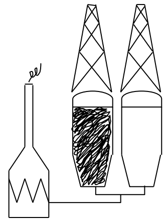
Delayed Coker
Coke Drum Valve Operations Integrity



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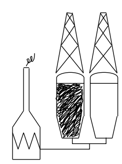
Delayed Coker Valve Operations Integrity



Topics:

(1) XOM History Review
  => Systems on 6 cokers, with 7th in progress

(2) The Probabilities & Risks

(3) Alternate Systems & Procedures
  => LOTO, Trapped key, IntelaTrac, Guiding Light, Hard-wired

(4) ExxonMobil's Power-Actuated design with PLC oversight
  => Control of Defeat
  => Automatic monitoring systems

(5) Motor Actuator Types & Role in reliability of overall system
  => Review of past incidents at XOM

(6) Maintenance of MOV – PLC Interlock Systems

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XOM History:

1993, an operator was on the wrong drum pair and switched feed to an open drum, resulting in a fire and serious injury (this proceeded a more serious fire in the same year)

=> Checklist, Lock-Out-Tag-Out (LOTO) and console radio confirmation was in place; the field operator (qualified, but < 2yr experience) verbally was on the correct drum, but actually on the wrong drum pair

As a result, refinery management decided to create automated valve operations with PLC logic-controlled oversight of all coke drum valve operations

=> The first system was started up 1995 as part of a coker rebuild project

=> The 2 other site cokers received IL's by 1999

The PLC-based system design was done prior to development/implementation of a formal corporate-wide risk assessment process from 2002-2004

The 4th largely-identical system was done as part of a grassroots coker project that started up in 2001.

=> The PLC Logic Matrix is an XOM-proprietary design

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XOM History (cont'd):

2005, XOM upgraded their Venezuelan Upgrader Coker with installation of the 5th PLC-based design and additional valve motor operators

=> Original 1998 design consisted of a simple hard-wired interlock between the feed inlet block valve and the utility header valve (drain, warm-up, steam, quench water)

=> The system was justified based on improved reliability incentives since formal project safety risk assessment and justification techniques were not yet completely implemented

=> The PLC design and logic matrix were XOM-based analogous to previous designs

2007, the Beaumont DCU implemented a complete Safety Upgrade Project

=> This was the first coker interlock system justified by formal safety risk assessment techniques

=> Project Scope – 6th Valve PLC Interlock System, Auto Top and Bottom Deheaders, Enclosed Cutting Shack, Structure Water Deluge

=> Details previously provided in 2008 coking.com presentation

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XOM History (cont'd):

Following Beaumont's Risk Assessment, the other XOM DCU Structure Operations were formally risk assessed

=> Six sites; ten DCU's

The 7th PLC-based Valve Interlock System is being progressed

=> Given the desire to minimize turnaround duration and project cost, the project is installing all wiring during unit operations and is installing MOV's during annual pig decokes

=> This was the first project justified based on quantified risk reduction per unit cost, to allow prioritization with other competing projects

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Approximate Risk Probabilities in Play:

Creating an incorrect valve line-up (can be 2 valves) on the drum structure has a pre-determined base probability

MOV's with PLC Interlock lower the probability two orders of magnitude

A well-controlled and stewarded LOTO program with well-trained and capable operations technicians lowers the probability an order of magnitude

LOTO programs can fluctuate in effectiveness, and they can deteriorate in effectiveness because ultimately they are administrative controls.

Such controls rely on humans to always do the right things

=> be properly trained, have had enough sleep, not be distracted, not be bored by repetitive tasks, know how to deal with all equipment failures, have proper reinforcement on procedures, follow all procedures, not be rushed to meet cycle time deadlines, etc…)

For these reasons it is difficult to view LOTO programs as permanent risk mitigation.

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Examples of Significant Risk Scenarios:

Safety risks that mitigations seek to mitigate:

- Open water over line on coking drum
- Leave blowdown vapor line open for water over step
- Open drain line on live coking drum
- Drain valve left open during coke drum warm-up
- Open vent line on live coking drum
- Open drain line on drum in warm-up mode
- Align feed to open coke drum
- Open overhead vapor line on live coking drum
- Air Free open coke drum

Environmental risks:

- Warm-up condensate line left open to MF
- Open vent line on live coking drum

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LOTO – Lock-Out, Tag-Out

The original goal of Lock-Out, Tag-Out (LOTO) was to prevent maintenance and contract workers from opening a valve that would send auto-ignitable hydrocarbon to an open coke drum

The use of LOTO was subsequently expanded to help reduce the risk that an operations technician would make a valve operations error.

Main Risks:
- Technician on wrong drum pair
- Technician omits a valve closure step
- Technician on wrong drum out of sequence

Features added:
- Paper checklist (has evolved to electronic via IntelaTrac)
- Enhanced Signage
- Dual Verification (2nd field technician and/or console supervisor)
- Frequent Training Refreshers
- Frequent Audits

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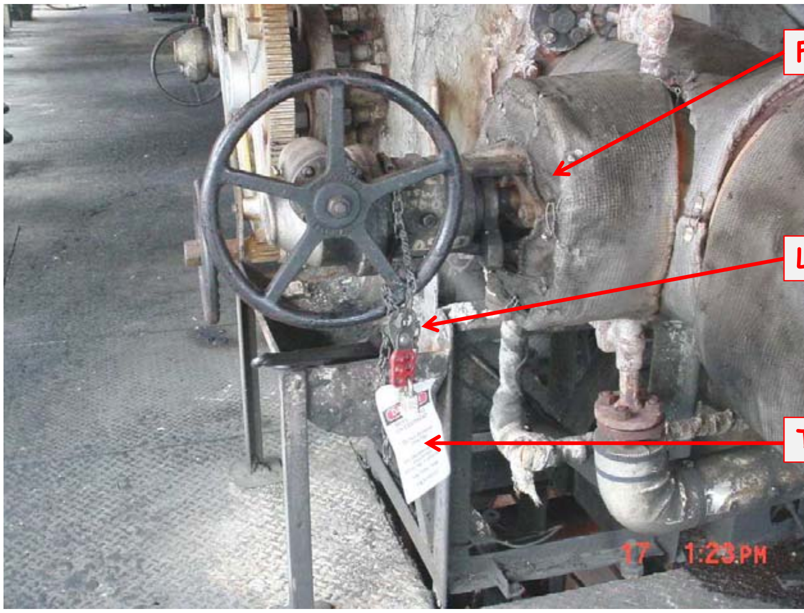
LOTO – Lock-Out, Tag-Out



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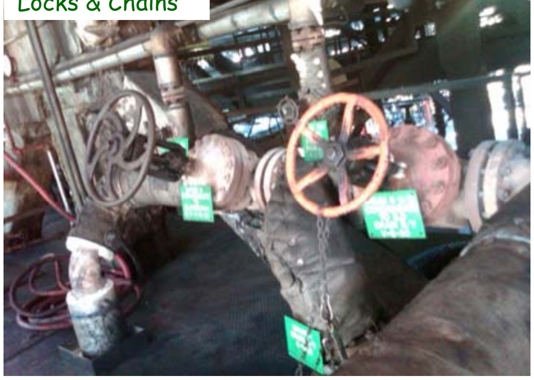
Advanced LOTO – Lock-Out, Tag-Out

Locks and chains are placed on valves to prevent any other person from opening a valve by mistake and cause loss of containment. This applies to drums being decoked and drums in coking service.

Utilizes lock boxes, where each operator locks valves open or closed and places his key in a box. The locks can only be opened by obtaining the key in the lock box, which can be done using that operator's key or a master key ("Tech Lock") held by an Operations Supervisor.

Locks & Chains



Technician Lock Boxes

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LOTO – Lock-Out, Tag-Out Upgrade

One Site's LOTO program was upgraded in 2009 to include "Live Drum" LOTO. This meant that valves on the live drum were added to the chain and lock list. Previously only valves on the open coke drum were LOTO'd.

A live drum is defined as "in hydrocarbon service beginning prior to the Heat Up and during Coking and Blowdown cycle." The following valves were added to LOTO list:

- Top Vent Upstream Isolation Block Valve located on the Top head deck.
- Top Water Downstream Isolation Block Valve located on the Top Head Deck.
- Water Over Wedge Plug Valve located on the Switch Deck.
- Upstream Drain Line Isolation Gate Valve located on the Bottom Head Deck.

Lock Inventory Back-up

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Trapped Key

- Requires that one key be used to allow opening or closing a valve and to obtain another key so that valves can only be opened and closed in a prescribed order
- The intent is to prevent the uncontrolled opening or closing of safety critical valves, which could result in fatal injury to operating personnel, damage to plant and equipment, loss of product and/or pollution of the environment
- Intended primarily for less frequently used valve arrangements. Concept works well for dual-PRV's or redundant emergency valves requiring testing.
- **Disadvantages as part of coke drum structure valve operations**:

  (1) Because of the need to move so many valves in different order at different times, it is not possible to set up sequential interlocks for all valve steps.
  (2) It is not possible to require that all related valves be in the correct position prior to opening or closing a given valve.
  (3) It requires a great deal of keys which can be lost or confused, which can cause delays or confusion in operation.
  (4) Use of trapped keys for so many valves is confusing.

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IntelaTrac, Guiding Light, Hard-Wired Relays

IntelaTrac – Utilization of RFID's (Radio Frequency IDentification tags) to provide additional verification that technicians are on the correct valve and that previous valves have been placed in proper position

Guiding Light – **Red** / **Green** Lights are provided at each valve to indicate to the field technician that the valve is safe to operate.

=> Typically the console enters what coke drum cycle step has been completed, which corresponds to a given light arrangement on the drum structure

=> Relies on human to input correct step number and requires the field operator to understand in which sequence to operate the valves

=> Could use limited hard-wired panel lights with limit switches (cumbersome to use and can be easily defeated or become unreliable)

Hard-Wired Relays – Utilize valve position from either external magnetic proximity switches or motor actuator position switches to circuit relay positions

=> Can be used to address local high-risk valve positions. Such as feed inlet and utility header valve(s).

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XOM PLC-Based Automatic Valve Interlock System

System Design Basis Criteria –

=> Reliable Valve Position Indication to PLC (availability $\geq$ 99% of time)

=> PLC Oversight Availability $\geq$ 99% of time

=> Safety Criticality applied to Operational & Maintenance Oversight to maintain $\geq$ 99% Availability

Valve Position Reliability

=> No external magnetic proximity switches

=> Majority of valves (>98%) are motor-operated with internal position switches; air or hydraulic valves can be used if they have enclosed, integral electronic position switches

PLC Logic

=> The logic matrix relies on unique valve position relationships that must always be true; no sequencing of steps or process data input needed

=> Opening or closing a valve requires at least two other valve line-ups be validated by the PLC

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XOM PLC-Based Automatic Valve IL System (cont'd)

Safety Criticality Applied to Operational Oversight

=> Reliable Valve Position Indication to PLC (availability ≥ 99% of time)

=> PLC Oversight Availability ≥ 99% of time

=> Safety Criticality applied to Operational & Maintenance Oversight to maintain ≥ 99% Availability

Control of Defeat Procedures

=> "Any deactivation or non-standard operation of safety critical equipment or systems must be documented and approved …"

=> First signature approvals are Area Operations Lead and Shift Supervisor

=> If the deviation lasts more than 24 hrs, signature must be obtained from the next highest management level, continually progressing with time

DCS Valve Bypass Monitoring (to highlight bad actors)

=> PLC oversight of individual valves can be bypassed with a key with automatic reset after a certain amount of time (due to various failures of the MOV, typically limit switches, relays or circuits)

=> DCS Program counts the bypasses and displays on Interlock Master Screen

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MOV Types

MOV's are NOT the Same (by any stretch)

=> XOM Sites use (or have used) Limitorque, EIM and Rotork

=> Type-I - multi-turn valves (Gate, Globe, ..) with torque ranges up to 250 ft/lbs

=> Type-II – 1/4 -turn valves (Ball, Plug, …) with torque ranges up to 4100 ft/lbs

=> Service Class II – Explosion-Proof

Limitorque

=> Acceptable experience

=> Most complicated design from a component standpoint

=> Sensitive to vibrations

EIM

=> Good experience

=> Require proactive relay replacements

Rotork

=> Circuit Board based design with smart IQ actuation

=> Circuit Boards can be damaged by heat and steam

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MOV Motors

- **High rated starting torque**
  - Sized to provide the torque required by the valve
  - Delivers this torque over a relatively short time period
- **Short duty cycle**
  - For ac – 15 minutes
  - For dc – 5 minutes
- **Totally enclosed non-ventilated** (TENV)

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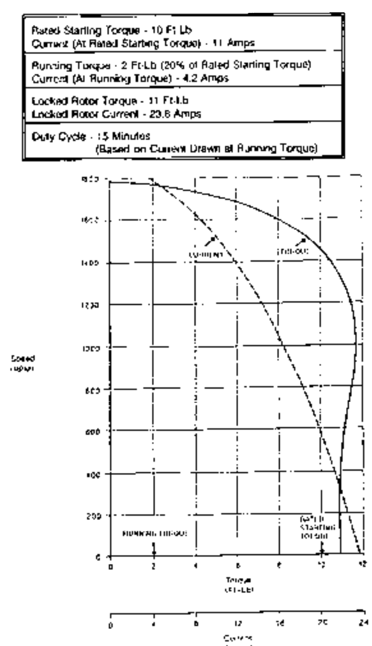
MOV Motors

- Three phase, 230/460 VAC, squirrel cage induction motors
- Factory lubricated sealed bearings
- Three insulation classes
  - Class B – 125°C, mild environment
  - Class RH – 175°C, harsh environment
  - Class LR – 250°C, very high temperature, harsh environments
- Three speeds – 900, 1800, 3600 rpm



Speed vs. Torque and Current for Typical 1800 RPM, 60 HZ, 3-Phase, 230 VAC Motor

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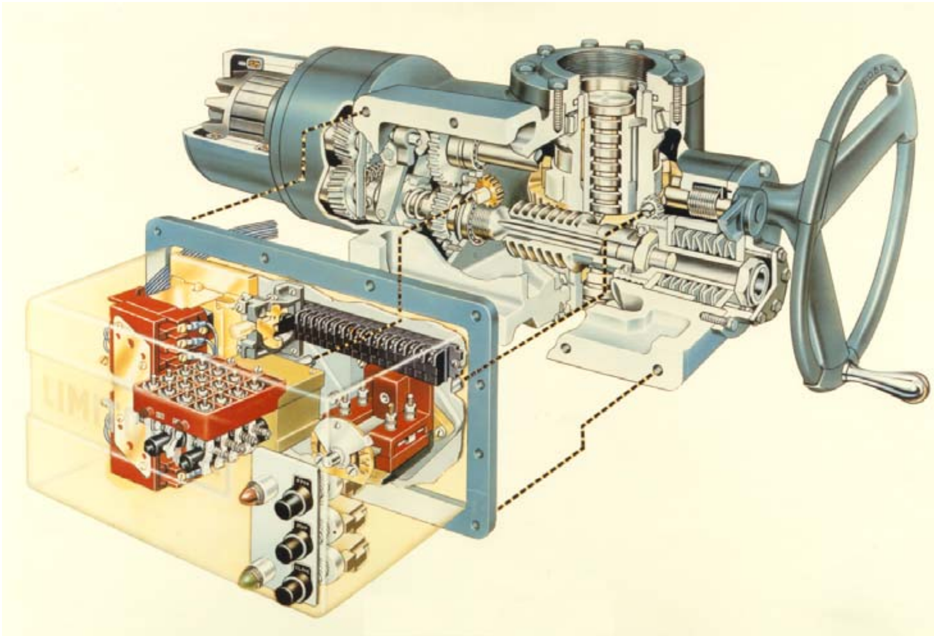
Limitorque



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Limitorque - Components

- **Power Supply** – supply the energy required to operate the MOV
- **Motor** – Converts electrical power to mechanical power. Reversing any two leads will reverse the direction of motor rotation.
- **Overload Heater Coils** (Thermal Overload Relays) – protect the motor in the event of excessive motor current.
- **Reversing Starter** – Two separate functions:
  - Interchange power leads which change the direction of motor rotation
  - Provide mechanical and electrical interlocks that prevent the contacts for both directions being closed at the same time
- **Control Transformer** – reduce the control voltage to a lower and safer level
- **Stop Pushbutton** – breaks the control circuit, causing starter dropout and halting actuator function
- **Open and Close Pushbuttons** – initiate operation of the control circuit, which results in energizing the actuator motor
- **Seal-in Contacts** – allows the pushbuttons to be released without having the actuator stop
- **Remote/Local Switch** – determines the location of control for the actuator, either local or remote

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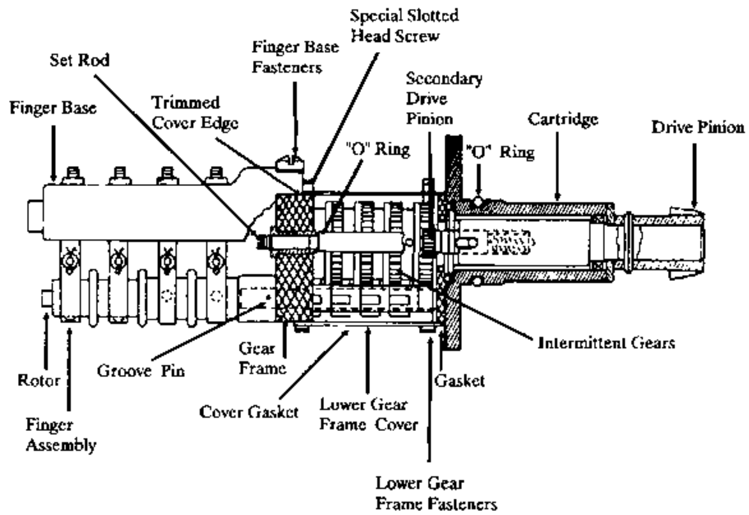
Limitorque Geared Limited Switch

The geared limit switch counts the rotation of the drive sleeve or worm shaft in order to keep track of valve position.

- Shut off power to the actuator motor at the proper stroke position
- Turn indicating lights on and off and the proper stroke position
- Provide electrical interlocks and bypasses as required

- Each rotor set separately for particular valve stroke position
- The valve must be moved to the desired stroke position and then the limit switch rotor set.



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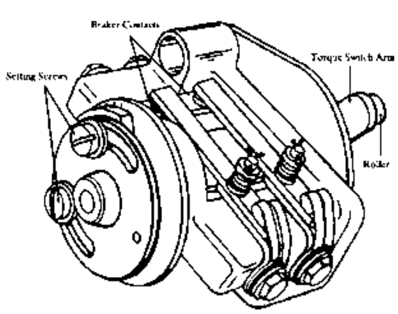
Limitorque Torque Switches

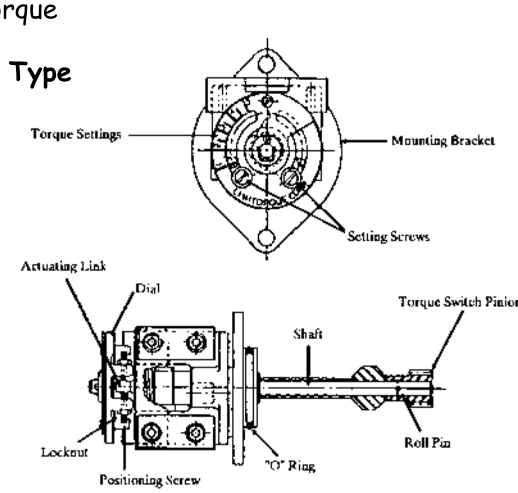
The torque switch has two possible functions

- On torque controlled valves, it is used to ensure that the valve has sufficient torque applied to the valve stem to guarantee seating
- On limit controlled valves, it is used to ensure that the actuator and valve are protected from possible excessive torque

Leaf Type



New Knee Type



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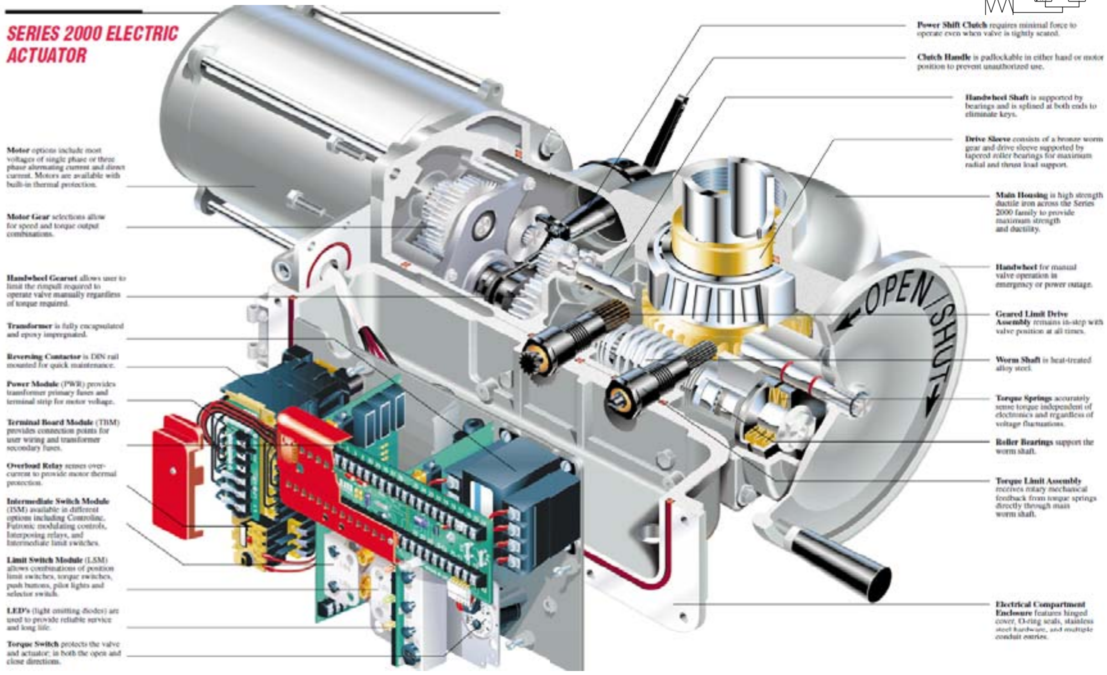
EIM



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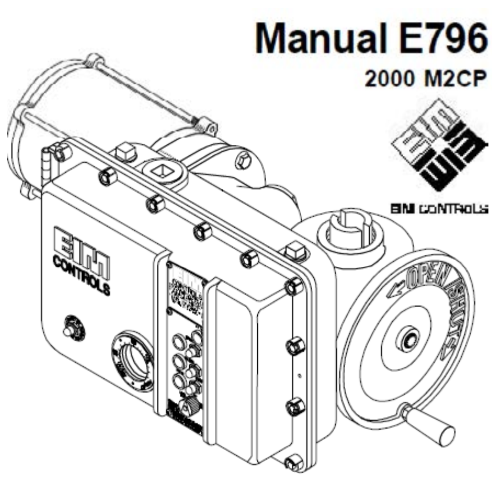
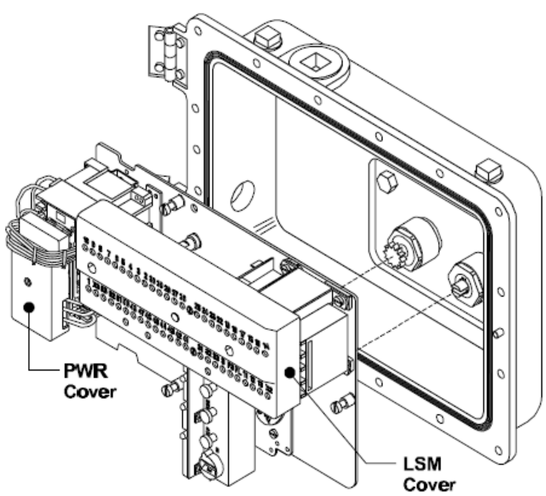
EIM

"A" Actuator





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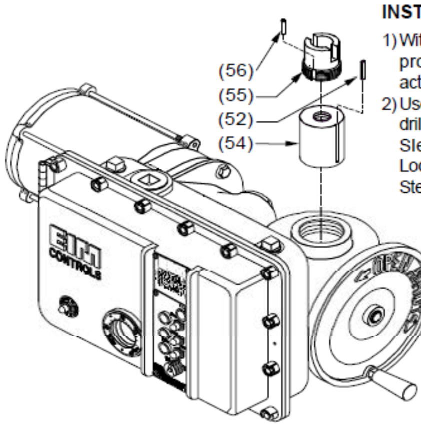
EIM

ASSEMBLY TO VALVES - Threaded Valve Stem



LOCKNUT LOCKPIN INSTALLATION

1) With actuator in place on valve, ensure proper flange mating and valve actuator orientation.
2) Use a number 30 (.1285) drill bit to drill a hole 3/4 inch deep into the Drive Sleeve assembly threads for the Locknut Lockpin (56) using groove in Stem Nut Locknut as drill guide.
3) Install Locknut Lockpin (56) into drilled hole to prevent Stem Nut Locknut from working loose and turning.

Note: When installing, the Locknut Lockpin - it should extend 1/4 inch above the Drive Sleeve assembly to allow for future removal.

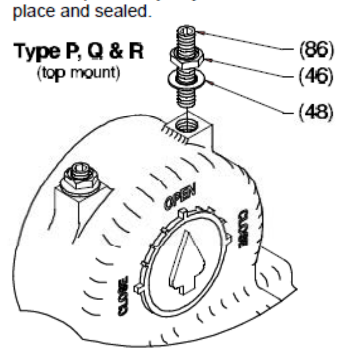
THRUST SPOOL

Quarter-Turn Valve

STOP SETTING PROCEDURE

Built-in mechanical stops are provided to prevent handwheel operation beyond total valve travel (90 ± 6°). End of travel stops are independently adjusted, locked in place and sealed.

Type P, Q & R
(top mount)



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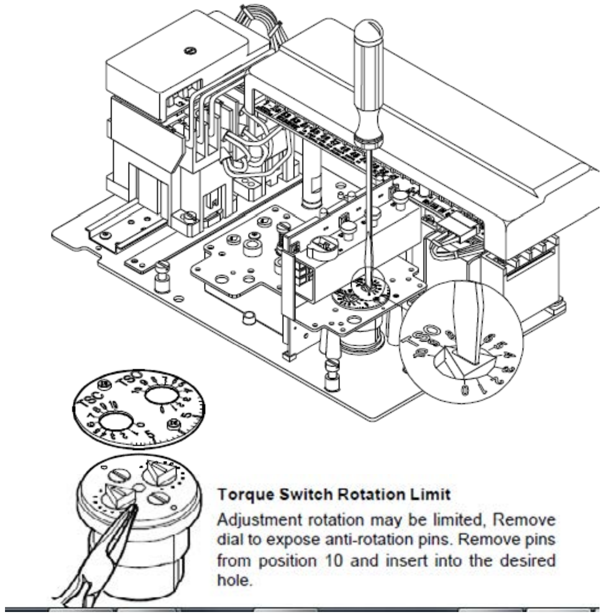
EIM

Torque Switches



Torque Switch Rotation Limit

Adjustment rotation may be limited, Remove dial to expose anti-rotation pins. Remove pins from position 10 and insert into the desired hole.

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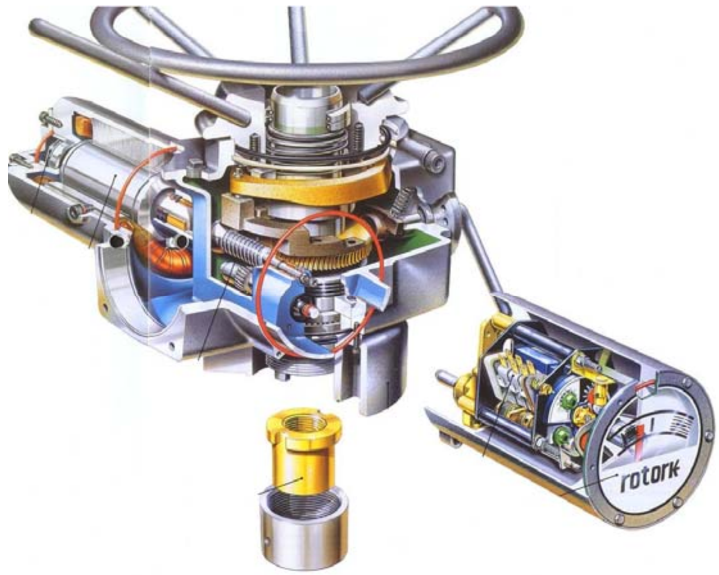
Rotork

"A" Actuator



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Rotork - Components

Motor – Three phase, 220 VAC, squirrel cage induction motors. A winding thermostat is included in the "A" range and "NA-4" actuators for overload protection.

- Class B – 125°C , Class F – 155°C, Class H – 175°C

Starter – Houses mechanically and electrically interlocked reversing contactors

- Two normally open auxiliary contacts
- Opening and closing coils
- Fused control transformer.

Integral Controls – open/stop/close pushbutton with lockable local/off/remote selector switch.

Position Indication – mechanical three-position indicator shows open, intermediate, and closed conditions..

Torque and Limit Switches – open and close torque or position limit switches plus two auxiliary limit switches at each end of travel.

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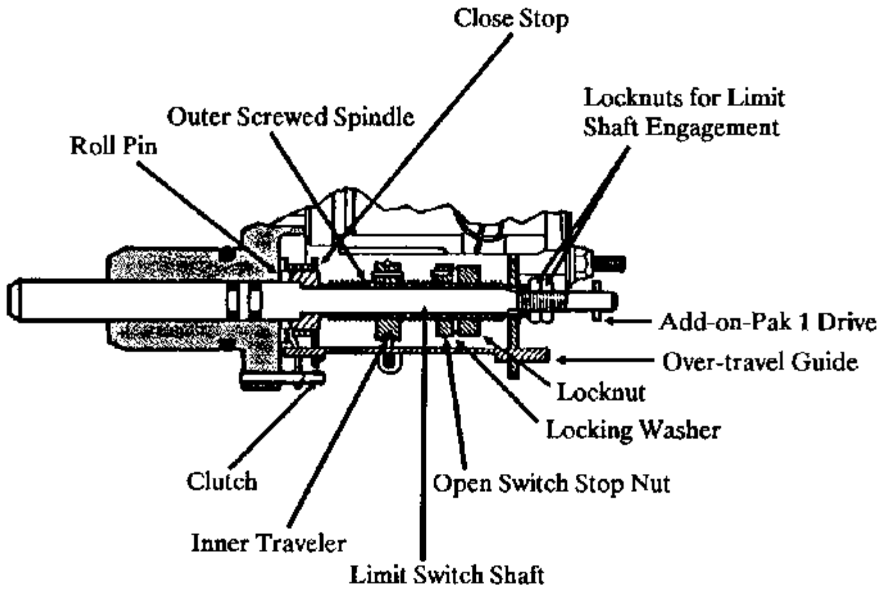
Rotork Limit Switch



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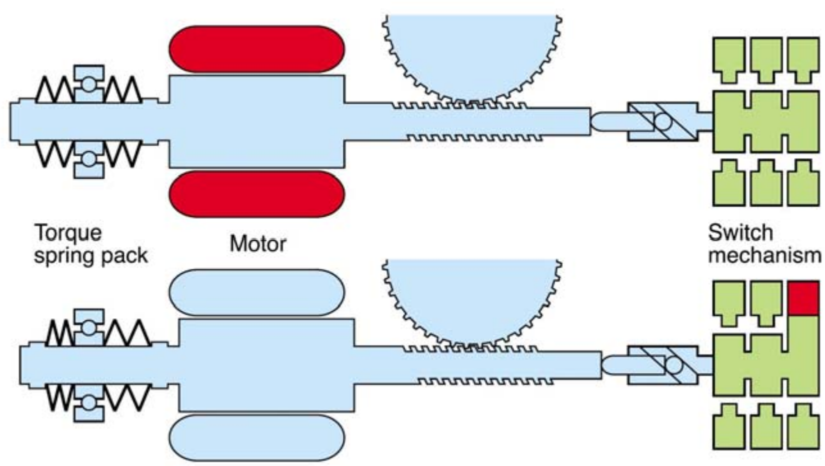
Rotork

Torque Switch Mechanism



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XOM Near Misses

Site-1 Limitorque L120 MOV's w/ PLC Interlock commissioned and started up in 2007

=> No issues except following Ike Hurricane which caused MOV & wiring damage

may-2011 … over two weeks, four different valve movement incidents occurred on one drum pair that violated interlock permissive logic and were not initiated by an operator instructing the valve to move. Two of the movements were the feed inlet block valve opening on drum-5 in the middle of drum-6 coking. The other 2 incidents involved the drum-6 quench water valve opening in the middle of drum-6 coking.

Site-2 2001 EIM MOV's with PLC Interlock Oversight commissioned and started up

=> EIM actuators have slowly been replaced over the years with Limitorque as part of site standardization

=> One issue - an electrician discovered a jumper bypassing the Triconex Interlock logic inside the actuator for quench water MOV, allowing a technician to open quench water because warm-up condensate MOV showed "no status"

may-2011 completely by coincidence Site-2 experienced random valve movements

=> Drum-3 Warm-Up, Drum-4 Inside Drain, Drum-4 Quench Water, Drum-4 Quench Water, Drum-5 Outside Drain, Drum-5 Inside & Outside Ejector

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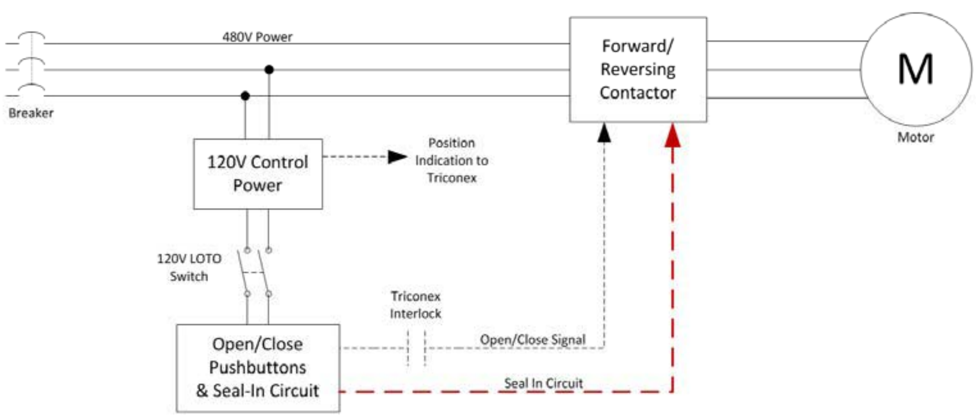
Wiring Schematic



When a technician presses the open or close pushbutton, a signal is sent to the forward/reversing contactor to deliver power to the MOV motor which then moves the valve.

The seal in circuit maintains the forward/reversing contactor status after the technician has removed his hand from the pushbutton and until the valve has reached fully open or closed.

The PLC interlock prevents the open or close signal from reaching the forward/reversing contactor unless several permissives have been met.

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Root Cause

Both sites use electro-mechanical type electric actuators with integral starters.

=> For reliability reasons, solid-state (printed circuit board) actuators were not used due to the extreme radiant heat around these valve installations.

Both Limitorque & EMI brands use a Telemechanique style reversing contactor to control motor rotation.

The random valve movements were linked to **the electro-mechanical contactor inside the MOV actuator being "bounced"** by non-routine periodic excessive line vibration.
- => Water hammer was one culprit
- => The contactors are designed to withstand vibration (expected to be seismic in origin) and should not easily bounce
- => However, when they are exposed to enough shock and vibration, they end up electrically sealing themselves in, causing valve movement and travel.

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Solutions – Short Term

Both sites have manually deenergized the power to the MOV's

Site-1 => individual 480 VAC circuit breakers placed in the OFF position

Site-2 => individual 120 VAC Lock Out Tag Out switch (adjacent to each valve) in the OFF position

No effect on providing continuous valve status info locally or back to the DCS

The XOM sites and the industry were consulted to gauge experience

XOM Site-3 has had EIM actuators for 17 years and have not had any vibration-induced problems

- => HOWEVER, **interlock relays** have become stuck, such that the valve interlock permissive was satisfied, allowing the valve to move. Has happened 2X in last 3 yrs
- => Example – Feed line utility header valve (SP-7) opened while setting up for a drum switch. Coke drum was in service and interlock system should have prevented it

FLS - "Caused by stuck interlock open relay (ILO). As a result, the valve was receiving a permissive to operate when it should not have. The ILO was replaced and issue was resolved."

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Industry Feedback

Preferred DCU grassroots fix is to not have the MOV Contactor seal-in circuit in the MOV Actuator. Rather, it is more desirable to do it back at the Interlock PLC logic. This is the trend on new Coker projects per discussions with Limitorque, which they recommend. One industry site implemented this approach as part of their PLC valve IL project 3 years ago with Valve Systems Controls. Have not seen any problems.

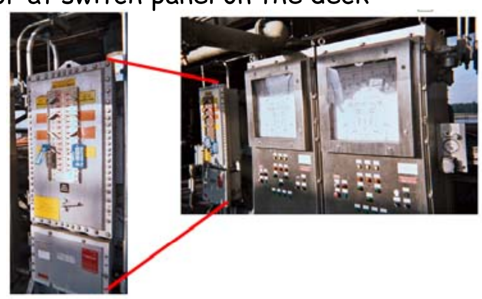
Industry Feedback:

=> Random, uncontrolled MOV movement has occurred on cokers

=> Standard practice to manually shutoff motive power

At MOV

or at switch panel on the deck



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Industry Feedback

Industry Consensus:

=> Many reports of vibration, heat, coke fines and water causing shorts in the electrical power circuit that have resulted in operation of MOV's when not desired

=> Two separate instances of switch valve movement, one resulting in a fire. One was caused by coke drum structure movement.

=> Best solution is to shutoff motive power to the MOV motor via the PLC, while still maintaining power for position indication, “smart” controls and motor heaters

=> Ability to remotely operate the MOV’s during an emergency should also be maintained through the main PLC bypass, such that power is restored to all MOV’s coincident with the PLC bypass.

=> Some IL systems use AOV’s and air needs to be shutoff to them as well

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Site-2 Incident (post short term fix)

Vibrations caused feed inlet block valve to close and coke off furnace

On

Off

- Technician report indicates 120V LOTO switch working intermittently for several months (i.e. sometimes required technician to jiggle switch to turn control power on).
- Testing of the 120V LOTO switch immediately after the event indicated the switch was working properly.
- Noted that 120V LOTO switch could be Locked Out, but power could still be on if not properly used.

Follow-ups => Provide Indication Light, Checklist Procedure & PM Switches

<u>OR</u> Fix System and/or Actuators

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Solutions – Permanent

Site-1 => Using existing wiring to allow physical relocation of the circuit seal-in contacts and switches, that are in parallel with the push-button, to a remote location AND modifying the PLC circuit logic to prevent the motor from receiving a full travel signal

Site-2 => Will install redundant perpendicular contacts and additional circuit seal-in wiring within the existing Limitorque Actuator Box, such that shaking would have to be in two simultaneous 90-degree directions (almost impossible) to provide a full seal-in of the valve movement circuit

Destructive G-Force testing was performed to validate the XOM-specific fix

As part of the testing, it became apparent that the G-Force and frequency rating of the contactors is a component-design variable. Normal Limitorque contactor is rated for 3 G's. Can go to 8G's or more based on my checks.

Delayed Coker Valve Operations Integrity

MOV Maintenance

- Preventive maintenance & proactive replacement of key parts is important as part of MOV / AOV equipment strategy
  - Relays, contacts, contactors etc
- Inspections - Casing grease leaks; Cracked housings; Bent stems or other signs of over-stressing; Stem lubricant; Brass or metal shavings mixed in with grease; Broken strain gages or disconnected gage wires; Missing bolts; Painted-over T-drains
- Lubrication of the actuator internals is critical to the proper and sustained operation of the equipment.
  - Reduces wear
  - Removes heat
  - Resists moisture
- Major wear areas include
  - Bearings - drive sleeve, spring pack, and worm shaft
  - Sliding surfaces – drive sleeve splines, worm shaft splines, worm and worm gear teeth
  - Motor pinion and drive gear

Delayed Coker Valve Operations Integrity

MOV Lubrication

- The physical characteristics of each lubricant change at elevated temperature.
- Operation at elevated temperature can have a significant effect on the stem coefficient of friction.
- Stem friction repeatability depends upon the unique stem, stem nut, and lubricant combination.
- The value and the direction of change in the end of stroke friction behavior is highly dependent on the stem/stem nut and lubricant being tested.

- Exxon Nebula grease production has been discontinued
- Limitorque recommends MOV Long Life as replacement
  - The industry has limited experience with MOV Long Life
  - Licensees need to justify the stem friction and actuator efficiencies for actuators that use MOV Long Life
  - EPRI is performing tests of MOV Long Life; no concerns have been identified (yet)