Drive & Control Systems for Gates in Civil Engineering Applications

Content
- Overview - Applications & Demands
- Design Principles and regulations
- Project Examples

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Civil Engineering Branch Management
Industrial Manufacturing Equipment
Civil Engineering: Applications

- Dams, weirs & Turbine control
- Navigation locks & canals
- Movable bridges & ferry ramps
- Coastal protection & irrigation systems
Hydro power dam: overview

- Turbine
- Ship Lock
- Ship elevator
- Spillway
- Intake gates
Overview: Hydro-mechanical Equipment

Drive & Control systems for:
- Spillways
  - Radial gates (with flaps)
  - Vertical list gates
  - Roller gates
- Intake gates
  - Wheel gates
- Draft tube gates
  - Slides gates
- Bottom Outlet gates
- Sand Flushing gates
Hydropower Dams - Radial Gates

- Spillway radial gates
  - Providing conveyance from Reservoir to Tail water for all flood discharge
  - Safety feature in case of floods

Brazil: Peixe Angical

Venezuela: Macagua
Radial Gate

- Occasional operation
  (piston rod 99% extended!)
- Corrosive environment
- Deflection/bending due to own weight
Radial gate types

Downstream bearing

With Flap

Upstream bearing
Hydraulic cylinders for water turbines

La Yesca, Mexico

Scope:
- Radial Gates
- Bottom Outlet
- Ring Gate
- Turbine Control
Intake Gates

- Long stroke, slender cylinder, vertical gate
- Maximum availability / reliability
- Outdoor wet environment
- Normal position ‘Open’ during plant operation
- Emergency high speed closing due to self weight
Bottom outlets

- High forces, pulling and pushing
- Maximum availability / reliability
- Outdoor wet environment
- Normal position ‘Closed’ during plant operation (piston rod extended)
- Piston rod under water (stuffing box)
Münster, Germany

Bypass wheel gates

Gate closing: 80 mm/sec
Creep speed: 5 mm/sec

Hydraulic Cylinder:
- 140/80-3000mm
- Pulling Force: 200kN
- Pushing Force: 108kN

Hydraulic Power Unit:
- redundant Motor Pump
- double return filter
- stainless steel tank
Overflow flap gate is used to regulate water level of reservoir => cylinder piston rod most of the time not in fully retracted position => good protection needed, especially exposed part of rod!

Exposed part of piston rod (good protection needed!)

Water flow over flap gate

Water splash zone
Radial gate

Water flow under radial gate (when open)

Exposed part of cylinder piston rod

Gate normally closed => cylinder piston rod most of the time in extended position => good protection needed, especially exposed part of rod!
DIN 19704 design principles

- DIN Standard Part 1: Criteria for design and calculation
- DIN Standard Part 2: Design and manufacturing
- DIN Standard Part 3: Electrical equipment

- Considering their function, hydraulic steel structures must be designed \textit{simple, robust and operationally safe}.
- For steel structures a service life of 70 years has to be assumed.
- For machine elements, including their electrical equipment for 35 years. This does \textit{not} refer to wear parts

- Two load cases are relevant for the calculation and rating of the drives
  - Case 1: \textit{Moving} = 250 bar
  - Case 2: \textit{Static} = 300 bar
Hydraulic Power Units – Design Criteria

- Tank size
- Vertical pump arrangement (minimum 2 pcs.)
- Optical pressure gauges: DN100
- Valves with LED indicators and manual override buttons
- Filter: minimum 4x max. system oil flow & max. 20µm
- Design Temperature: -25°C to +60°C
- Air De-Humidifier
- Oil-flow in piping: max. 3m/s
Overview: Hydro-electrical Equipment

Drive & Control systems for:
- Turbine governors
  - Kaplan: Runner & Wicket gate
  - Francis: Wicket gates
  - Pelton: Injection Needles

Shut-Off valves
- Spherical valves
- Butterfly valves
- Ring gates

Lubrification and cooling units
Hydraulic governing systems for hydro turbines

Turbine governing demands

- By control of the water discharge, the governing system enables a
  - Frequency and load regulation
  - Start and stop sequence control
  - Disconnection, load rejection
  - Load limitation
  - Compensation of water disturbances

- Safety demands for governing system
  - Trip (rapid shut down)
  - Emergency shutdown
  - Overspeed safety device
  - Interlocking
Ertüchtigung des Guri-Damms - Venezuela

Verstellzylinder für Leitschaufelen

\[ \begin{align*}
\varnothing_{\text{Kolben}} & : 950 \text{ mm.} \\
\varnothing_{\text{Stange}} & : 360 \text{ mm.} \\
\text{Hub} & : 960 \text{ mm.} \\
F_{\text{Druck/Zug}} & : 3570/3100 \text{ kN}
\end{align*} \]

Zylindergewicht: 23.400 Kg.
Navigation – Ship Locks

Function
- To facilitate the navigation of ships and other vessels across a water barrier
- Raising and lowering of the water level
- Passing of Ice and Debris
Drive & Control Systems in Civil Engineering Applications

Mitre gate

Three Gorges, China
Sector gate

St. Malo, France
Rising sector gate

Fankel, Germany
Drive & Control Systems in Civil Engineering Applications

Vertical Lift gate (synchronised)

Emsworth, USA
Why is synchronization necessary?

1. Operational force is be shared by multiple actuators to reduce drive system size
2. Mechanical structure is not be stiff enough
3. Moving parts are not be connected with each other

- Moving multiple actuator together requires an equal oil flow to each actuator
- Oil leakages, pump slip, changing workloads and varying friction loads could effect oil delivery among other factors
- In civil engineering applications, uneven loadings must be expected and can be a regular situation during operations
Mechanical coupling

Both cylinders are mechanically linked via a rigid structure and will therefore see an equal force (=pressure level).

Equal travel for dual cylinders can be attained with fluid lines of equal length, size, and fittings to both cylinders.
Application: Swing Bridge

Where multiple cylinders are utilized on a rigid structure, there will be the need for a pressure equalization of the actuators!
Variable displacement pumps

Gate structure
Application: Vertical Lift gate

With the gate being more than 60 m wide, the position of both ends need to be synchronized due to the flexibility of the gate structure.
Drive & Control Systems in Civil Engineering Applications

Application: Sluice gates
Experiences from Reference Installations
Refurbishment of the Guri Dam

Intake gate cylinders

Drive & Control System:
Hydraulic Power Unit & Local Control Panels

Installation & Commissioning (option)

Water Turbine Control Cylinder
Wicket Gate Regulation Cylinder, 8 units

Ø_Piston : 950 mm.
Ø_Rod : 360 mm.
Stroke : 960 mm.
F_Pushing/Pulling : 3570/3100 kN

Cylinder Weight: 23.400 Kg. (without Oil)
The Deriner Dam in Turkey

ORIFICE SPILLWAY

OVERFLOW FLAP GATE

720 m

249 m
The Deriner Dam in Turkey

The Orifice Gate Drives
The Deriner Dam in Turkey

Orifice Spillway Gates

Gate no. 2, 3 + 4; R + L

Service gate

Gate no. 1 R + L

Guard gate

Service gate
The Deriner Dam in Turkey

Orifice Spillway Gates Opened
The Deriner Dam in Turkey

Drive System

- Pulling and pushing force: 12,000 kN
- Stroke: 6,000 mm, $\Phi_K$: 900 mm; $\Phi_s$: 360 mm
- Speed up/down: 10 mm/sec.
- Max. cylinder weight: 30 tons
The Overflow Flap Gates

Concept:

- Cost-effective solution
- Simplified assembly
- Hyd. cylinder in vertical position
- Easy to service
Panama Canal – 3rd lane with water saving basins

Bosch Rexroth China: Cylinder Production
Hydraulic drives design: environmental considerations by civil engineering applications
Hydraulic drives design: environmental considerations by civil engineering application

Hydraulic drive design

Specification

- \[T \]^\circ\ C\]
  - \(-20\) \(^\circ\ C\)
  - \(+50\) \(^\circ\ C\)

- Water
  - Rain
  - Humidity
  - Seawater
  - Immersion
  - Ice

- Chemicals
  - Pollution
  - Liquids
  - Smokes

- Dirt
  - Sand
  - Dust

- Earthquake

- Mechanical impacts

- Aggressive ambient

- Costs
  - Owner costs

- Legals

- Quality
  - Materials
  - Certificates
  - Long life cycle

- Norms, Safety
  - DIN 19704
  - Country specific norms

- Natural

- Non-Natural
Hydraulic drives design: environmental considerations by civil engineering application

Is really protection necessary?

Hartelkering - Netherlands
Balstijsk - Russia
Saint Laurens Seaway - Canada
Tocoma - Venezuela
Deriner dam - Turkey
Marina Barrage - Singapore

Why we need protection?
Because we can’t change the environment

Why we need protection?

Because we can’t change the environment
Hydraulic drives design: environmental considerations by civil engineering application

Hydraulic drive

Bosch Rexroth System

Power unit

Piping

Actuator (Motor or cylinder)

What is the ambient condition?

- Temperature ($t^\circ$)
- Humidity
- Corrosive environment
- Moisture
- Mechanical impact
- Protective enclosure
Ambient zone classes for civil engineering applications

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>Indoor</td>
<td>Outdoor</td>
<td>Marine, high corrosive zone, submerged</td>
</tr>
<tr>
<td>Non-corrosive environment</td>
<td>Indoor protected</td>
<td>Corrosive environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate corrosive</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Images of various civil engineering structures]
Hydraulic drives design: environmental considerations by civil engineering application

Cylinders design

- Piston rod surface technology
- Painting System
- Stainless Steel piping
- Seals system
Influences on cylinder:

- Salt water
- Temperature
- Chemicals
- Abrasive material
- Mechanical impacts
Piston rod surface technology in the market

- Carbon steel + hard chrome layer
- Carbon steel + nickel + hard chrome layer
- Stainless Steel + hard chrome 2 layers

Coatings developed by Bosch Group:

- Carbon steel base + Enduroq 2000 / 2200 (HVOF)
- Carbon steel base + Enduroq 3000 / 3200 (Overlay welding)

Offshore applications
Piston rod surface technology

Enduroq 2000 / 2200

Single / Dual Layer Thermal Sprayed Surface Technology (HVOF)

Characteristics:
- High corrosion protection
- Extreme high wear resistance
- Significant layer thickness
- Extremely low porosity level (<1%)
- Zero permeability

Benefits:
- Longer lifetimes
- Minimum downtime
# Hydraulic drives design: environmental considerations by civil engineering application

## Ambient conditions – Zone Class

<table>
<thead>
<tr>
<th>Piston rod base material</th>
<th>Surface technology</th>
<th>C1: Indoor Non-corrosive environment</th>
<th>C2: Indoor/Outdoor protected Moderate corrosive</th>
<th>C3: Outdoor Corrosive environment</th>
<th>C4: Marine, high corrosive zone, submerged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>Chromium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon steel</td>
<td>Nickel / Chromium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless steel</td>
<td>Chromium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon steel</td>
<td>Enduroq 2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon steel</td>
<td>Enduroq 2200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For each application particular conditions have to be taken into consideration.
Painting system specification

- Temperature resistant
- UV resistance
- Adherence
- Scratch resistance
- Environment compatibility
- Compatibility with fluids

Partnership with painting fabricants

Rexroth painting system
Painting system Application Examples

Turbine regulation power unit

- Hydraulic Power unit
- Piping stainless steel
- Air dehumidifier
Painting system Application Examples

Guri Dam - Venezuela

- Stainless steel piping
- Orkot TLM marine bushes
- Special coating for underwater
Painting system Application Examples

Shiplock Münster - Germany

- Cylinder
- Hydraulic tank
- Motor pump unit
- Stainless steel piping
Hydraulic drives design: environmental considerations by civil engineering application

Housing Application Examples

Tocoma Dam - Venezuela

Protection house
Electrical control
Hydraulic power unit
Stainless steel piping
Hydraulic drives design: environmental considerations by civil engineering application

Environment safeguarding

Cylinders seals / tribology optimization
Easy maintenance design
Long life cycle
Efficient system design
One hand complete system
Hoses
Drip tray construction
Environment friendly hydraulic fluid

It's bio-oil isn't it?

NOT ACCEPTED
Environment safeguarding

- Environment friendly oil
- Biodegradable fluid
- Biological-oil
- Low toxicity oil

There are no statutory / legal definition for biodegradable hydraulic oils.

Definition: readily biodegradable / low eco-toxicity effects on humans + environment

Technical requirements for bio-hydraulic oils: ISO 15380

Bio-oil are not carefree handling by contamination have to be properly disposed.
Environment safeguarding

Oil from the power unit

Drip tray complete tank volume

Drip tray in concrete
Hydraulic drives design: environmental considerations by civil engineering application

Environmental influences

Bosch Rexroth Fulfillments

- Extremely robust equipments
- Reliability and availability
- Powerful
- Safety
- Long life service
- Long experience and references
- High Know How
- Low maintenance
- Long term cost reduction
- Standards and regulations

Dedicated solutions – In house production – One partner
Modernization of existing mechanical drive systems
Types of Drive systems: Mechanical vs. Hydraulic
Comparison of Mechanical and Hydraulic Drives

- Manual emergency drive
- El. motor for slow speed
- El. motor for normal speed
- Planetary gear
- Gear without casing
- Synchronisation shaft
- Driving pinion
- Mech. drive for flap gate
Mech. Gear Drive vs. Hydraulic Cylinder Drive

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mechanical Drive</th>
<th>Hydraulic Cylinder Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting torque / force</td>
<td>$\eta$ Electric-Motor $\times$ $\eta$ Gear</td>
<td>$\eta$ CYL (high)</td>
</tr>
<tr>
<td>Ac- &amp; Deceleration Synchronization</td>
<td>Less controllable</td>
<td>Smooth, controllable</td>
</tr>
<tr>
<td>Installation</td>
<td>Limited due to mech. drive train</td>
<td>Unlimited (direct linear drive)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Lubrification</td>
<td>Minor service, reliable after years</td>
</tr>
<tr>
<td>Environment</td>
<td>grease from mech. Parts</td>
<td>clean if properly installed</td>
</tr>
<tr>
<td>Structural vibrations</td>
<td>critical at stiff structures (slack gear)</td>
<td>not sensitive to vibration</td>
</tr>
<tr>
<td>Position measuring system</td>
<td>External</td>
<td>internal, integrated in cylinder option)</td>
</tr>
<tr>
<td>Corrosion</td>
<td>metallic parts (shafts)</td>
<td>piston rod surface technologies</td>
</tr>
</tbody>
</table>
Upgrade Project: (total 80 Systems)

- Design, supply and installation of complete system to operate the Mitre Gates under all operating conditions.
- Complete Local Control Systems
- All upper level controls for Control Towers
- Data Logging and Diagnostic Control System

Engineering:

- Complete HPU with redundant Pump/motors
- Hydraulic Cylinders with control Manifolds and position feedback system
- Local/ Central Control Panels
- Installation and Commissioning
Panama Canal

Mechanical Drive

Hydraulic Drive
Drive & Control Systems in Civil Engineering Applications

Panama Canal

Mechanical Drive

Hydraulic Drive
Panama Kanal

- Rising stem valve drives

Original Solution: Needs several gear boxes, axes, screws and bearings for moving the gate.

Updated system: Only one hydraulic power unit and one cylinder. No need of a gear box.
Wire Rope vs. Hydraulic Cylinder Systems

- Comparison with hydraulic cylinder driven systems:
  - Environment:
    - Corrosion protection of wire rope
  - System stability:
    - Synchronization failure due to elongation of wire rope
    - Position control with hydraulic cylinders better
  - Forces:
    - Cylinder offer the ability to induce also pushing forces to the gate, if necessary
  - Price level:
    - Wire rope systems have a lower price level
  - For very small forces and long lifting or displacement paths, e.g. sliding gates in sea locks, mechanical wire rope or chain drives still can have some advantages
Drive & Control Systems in Civil Engineering Applications

Intake Taintor Valves - Old

- **Issues**
  - Maintenance
  - Lubrication
  - Safety
  - Machine Guarding
  - Environmental
Discharge Taintor Valves - Old

- **Issues**
  - Safety
  - Lubrication
  - Maintenance
  - Machine Guarding
  - Environmental
  - High Rehab. Costs
Rope Operated Gate Drives - Issues

- Safety
  - Drives in pits, pit floors always wet and slippery, blocked pit drains
  - Machine guarding

- Maintenance
  - Lubrication of open gears – Environmental Issues
  - Rope replacement every two years
  - Sheave and roller rehabilitation
  - Operation & location Slip clutches for maintenance & adjustments

- Breakdowns and downtime
  - 5 to 8 Operating Rope Failures per Year
  - Approximate Downtime 6 Hours

- High Rehabilitation Costs
Hydraulic Conversion
Intake Valve Drives

- Hydraulic Conversion Project
Hydraulic Intake Valve Drives
Hydraulic Intake Valve Drives
Project Benefits - Operational

- Significantly reduced maintenance requirements
- Virtually no lubrications required
- Significantly reduced breakdowns
- No machine guarding issues
- Eliminated time consuming underwater dive inspections and maintenance
- Reduction of inventory and maintenance sundries
  - Eliminated large cables, gears, bearings, castings etc.
- Improvement is vessel transit times
- Possibility of longer navigation season
Project Benefits – Hydraulic System

- System self monitoring
  - Self diagnostic system
  - Leak detection system

- Very reliable system
  - Increase in the overall reliability index of equipment
  - Improvement in efficiency
  - Compact design

- Enables condition monitoring and predictive maintenance
- Eliminated failures due to overloads or restrictions
- Possibility of remote operation
- Possibility for consolidation of job functions
Project Benefits - Personnel

- Reduction in maintenance personnel and tools, vehicles, etc.
  - From 8 of 4-6 person crews to 4 crews of 4 persons
- Previous crews were task specific
  - There were separate crews for maintenance and operations
- New crews are multi-skilled and cross disciplined
  - There are no longer dedicated maintenance crews
  - Operations personnel now are more skilled to carry out maintenance
- Retraining of staff
  - Local support available by Bosch Rexroth Canada
- Maintenance staff are no longer on standby
Project Benefits - Environmental

- System environmentally friendly
  - No grease in the waterways
  - Biodegradable hydraulic oil in systems adjacent to the lakes
  - Significantly reduced noise levels
Summary – Advantages of hydraulic systems

- Convenient power transfer
  - Few moving parts, which results in little wear and easy maintenance
  - Compact design allows to locate hydraulic elements more efficient

- Flexibility and safety
  - Diversion and distribution of force in multiple directions
  - Can be stored under pressure for long periods
  - Excellent over-load safe drive system. This can easily be achieved by using pressure relief valves.

- Variable control
  - Quick response
  - Limiting and balancing of hydraulic forces are easily performed
  - Hydraulic systems can be moved smoothly and steplessly to any desired position.
Thank you very much for your attention!