Rotary Drive Alternatives for Dredge Machinery

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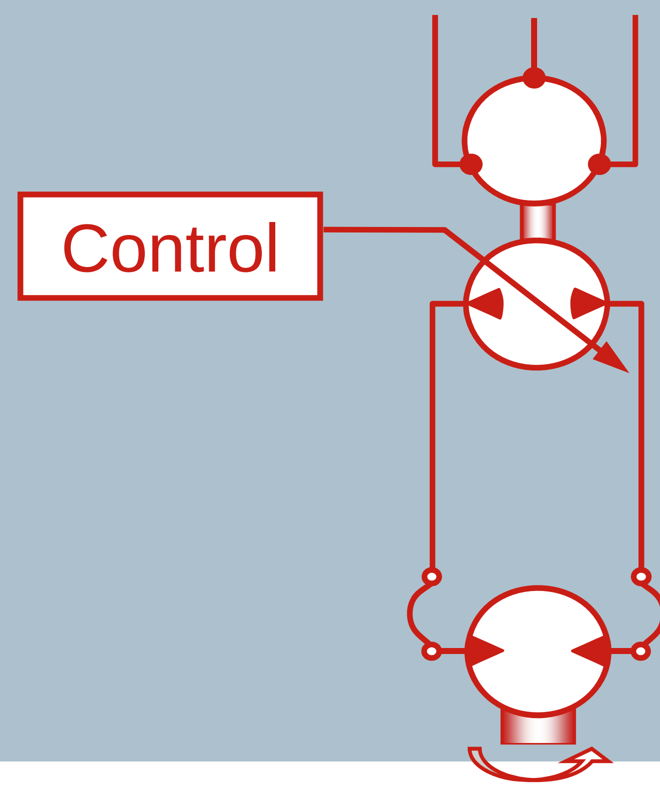
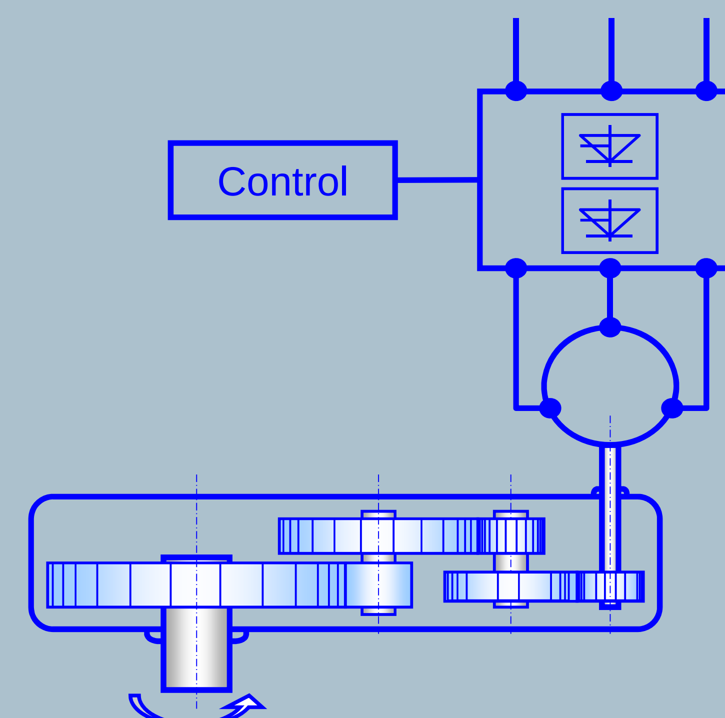
Agenda

- Overview of Main Drive Technologies
- Describe Rotary Actuators in Dredge Machinery
- Selecting Drive Technologies – Factors to Consider
- Drive Alternatives; Pros and Cons
- Comparative Overview
- Q&A

Overview

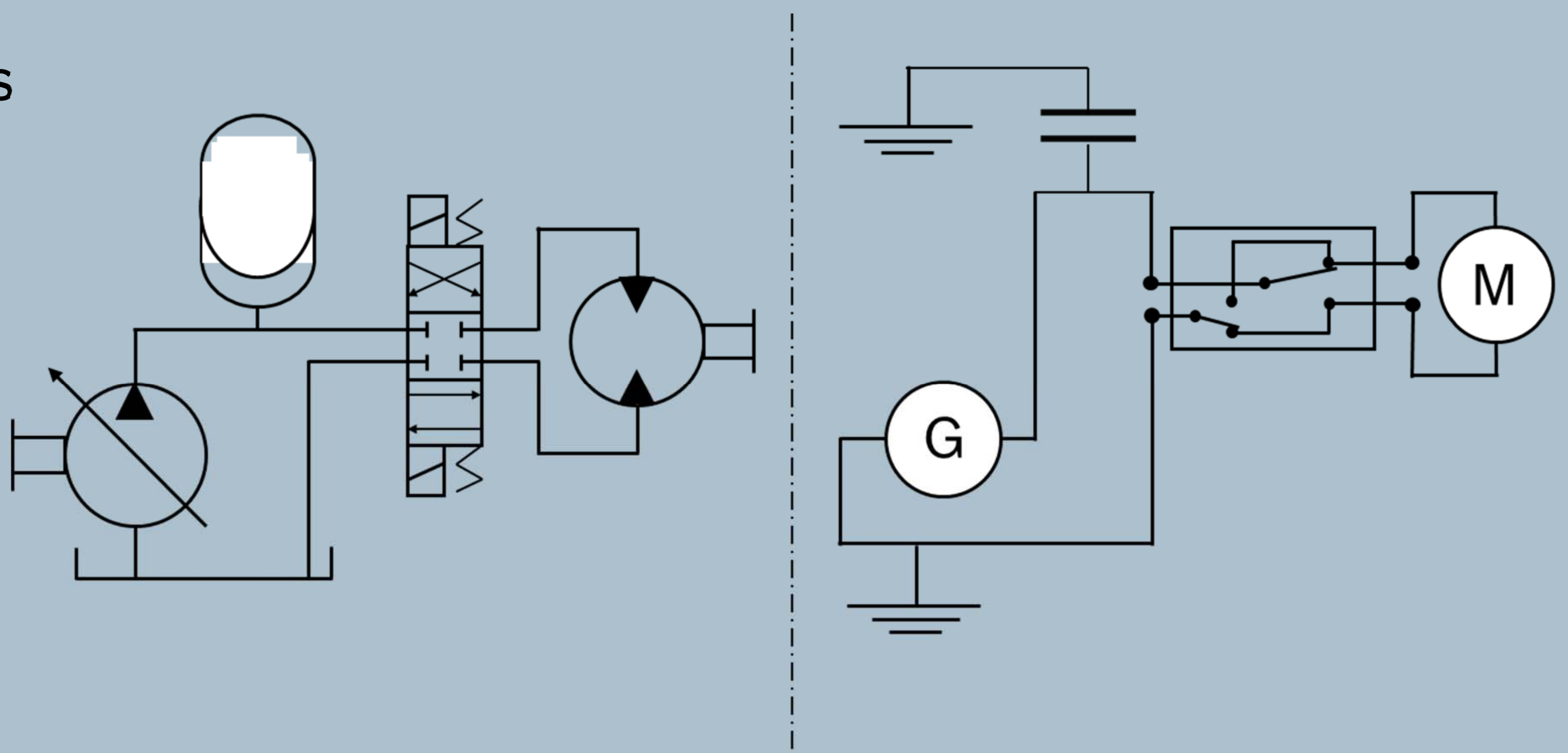
- Electric and hydraulic circuits are similar in principle
- Pressure difference p is equivalent to voltage U
- Flow Q is equivalent to current I





Hydraulics vs Electrics

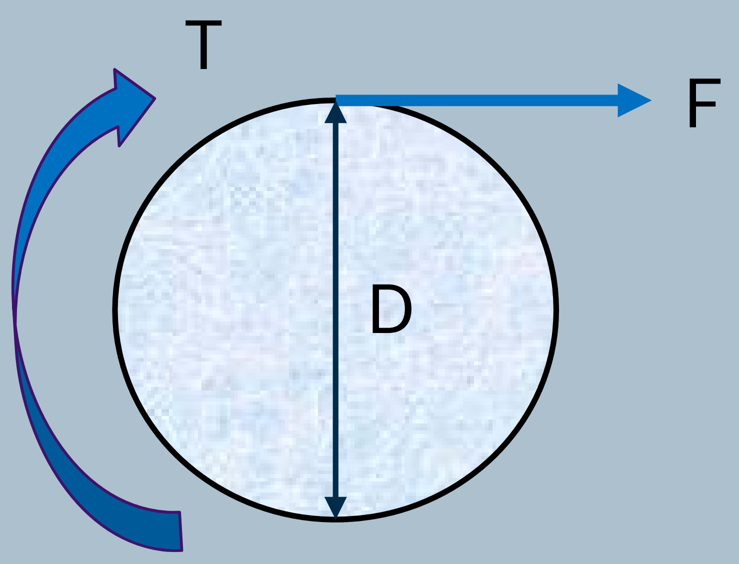
- Hydraulic system components have electric counterparts
  - Pumps are equivalent to Generators
  - Cylinders are equivalent to Linear Actuators
  - Hydraulic Motors are equivalent to Electric Motors
  - Accumulators are equivalent to Batteries and Capacitors
  - Valves are equivalent to Switches and Resistors



Relationship between Power, Torque and Speed

Torque (T) explained

- A twisting force, expressed in Newton meters (Nm)
- Arises when a force (F) rotates a shaft whose diameter (D) is expressed in meters
- **T = F * $\frac{D}{2}$ (Nm)**
- An important factor used in:
  - Dimensioning gearboxes and motors
  - Choosing shaft and winch drum diameters
  - Calculating power

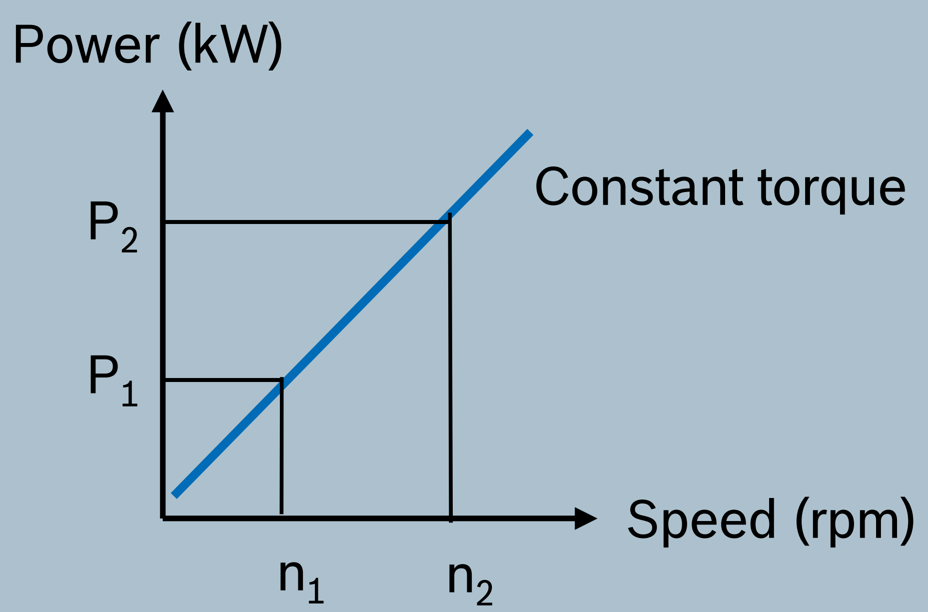


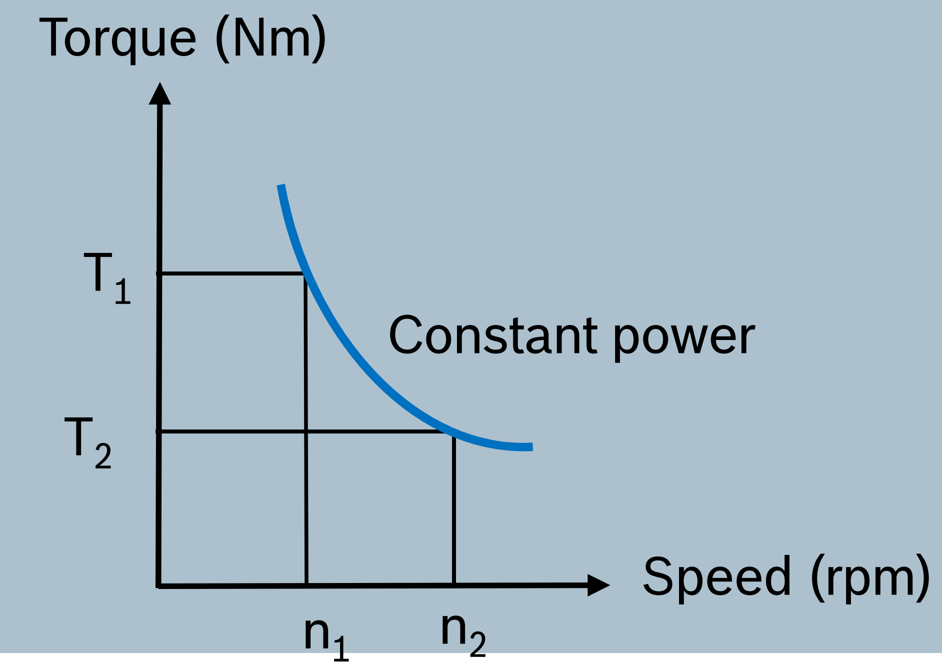
Relationship between Power, Torque and Speed

Power (P) explained

- The amount of work done per unit of time, expressed in kilowatts (kW)
- At constant torque, power is proportional to speed (n)
- At constant power, torque is inversely proportional to speed (n)
- **Power P =** $\frac{T * n}{9549}$ **(kW)**
- **Torque T =** $\frac{P * 9549}{n}$ **(Nm)**

  Note: 9549 is a mathematical constant

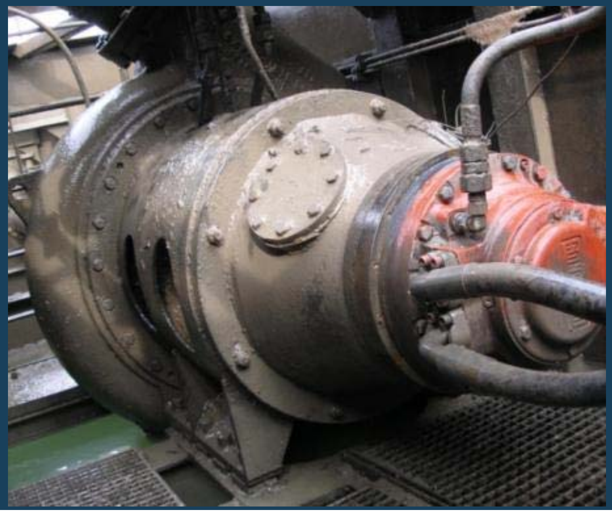




Rotary Actuators in Dredges

- Winch drives
- Cutter Suction head
- Dredge (Sand) pump
- Slew drives

Courtesy of Royal IHC



Courtesy of Royal IHC

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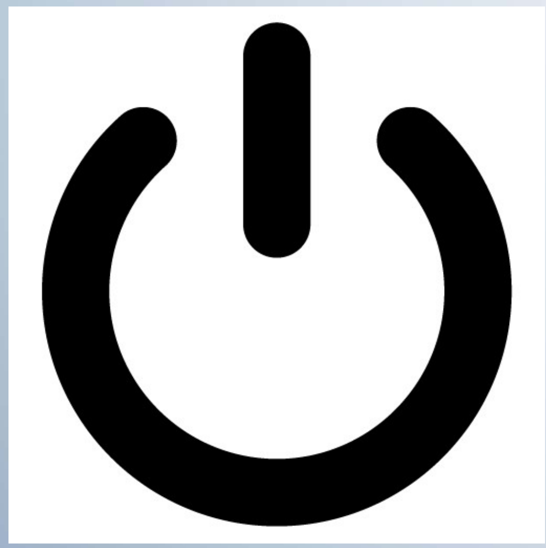
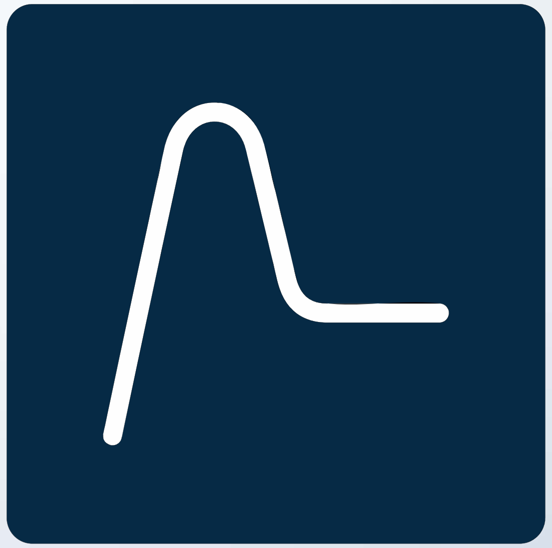
Selecting the Drive Technology



Power Source

Power Demand

Equipment



Energy Management

Environmental

- ❖ As applicable to new builds
- ❖ Ignoring existing technology know-how and legacy products

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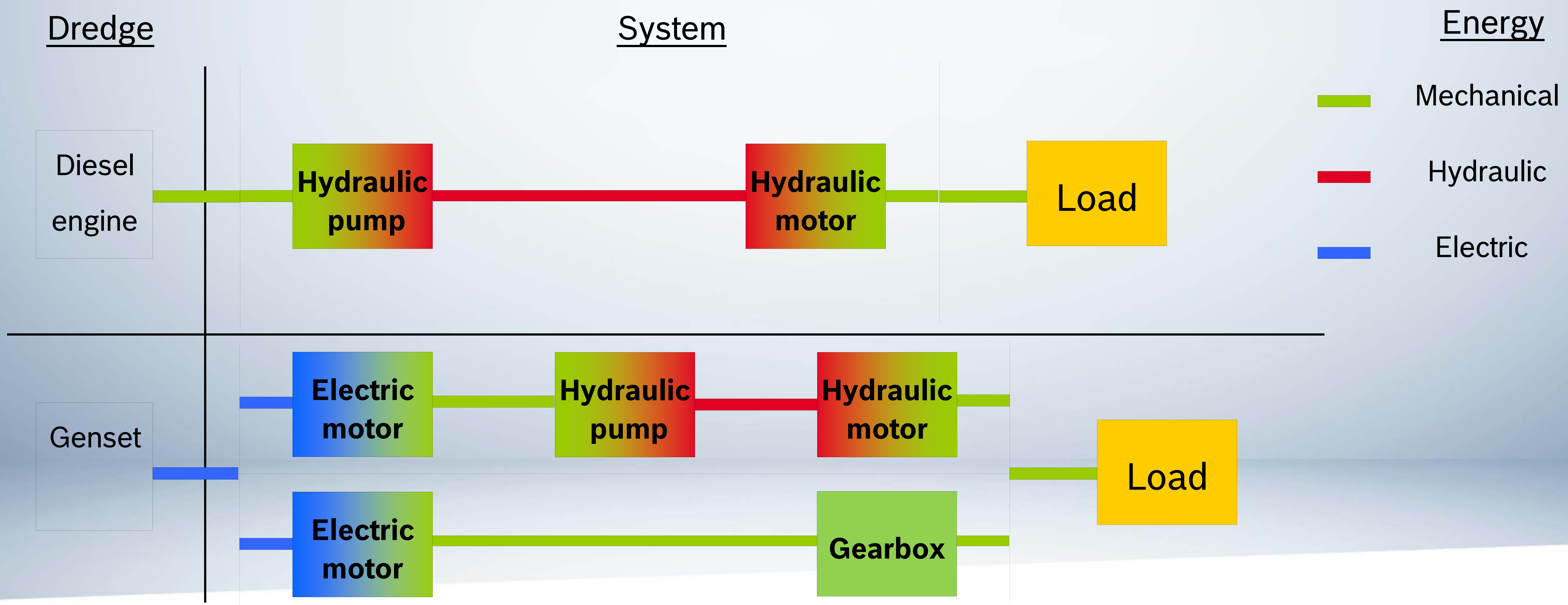
Selecting the Drive Technology

Power Source

- What type of power source available?



Selecting the Drive Technology

Power Demand

- How large are the loads on the system?

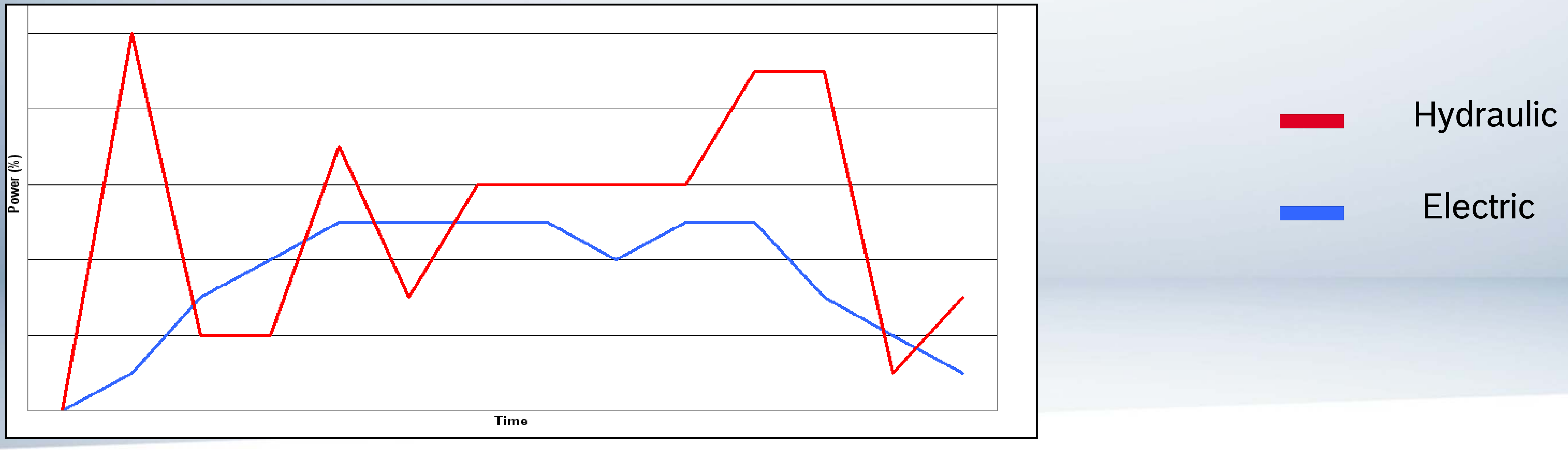
__Hydraulic__ systems can handle larger loads than equivalent electric systems

- Is the power output required constant or are there peaks and troughs?

__Hydraulics__ are capable of handling peaks more efficiently

➢ *Natural shock absorbers*

➢ *Safety devices i.e. Relief valves less complex than dV/dT filters*



Selecting the Drive Technology

Energy Management

- Losses and efficiency

__Electric systems__ have less losses than hydraulic equivalents

__Hydraulic direct drive actuators__ have more flexibility than electric equivalent e.g. starts & stops

- Installed power

__Electric__ systems require less auxiliary power to use components

__Hydraulic direct drive actuators__ have less starting torque and inertia

- Is the loading cyclic and can energy be recovered?

Energy recovery is much simpler and cost effective in __hydraulic systems__

Accumulators currently performing better than batteries and capacitors

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Selecting the Drive Technology

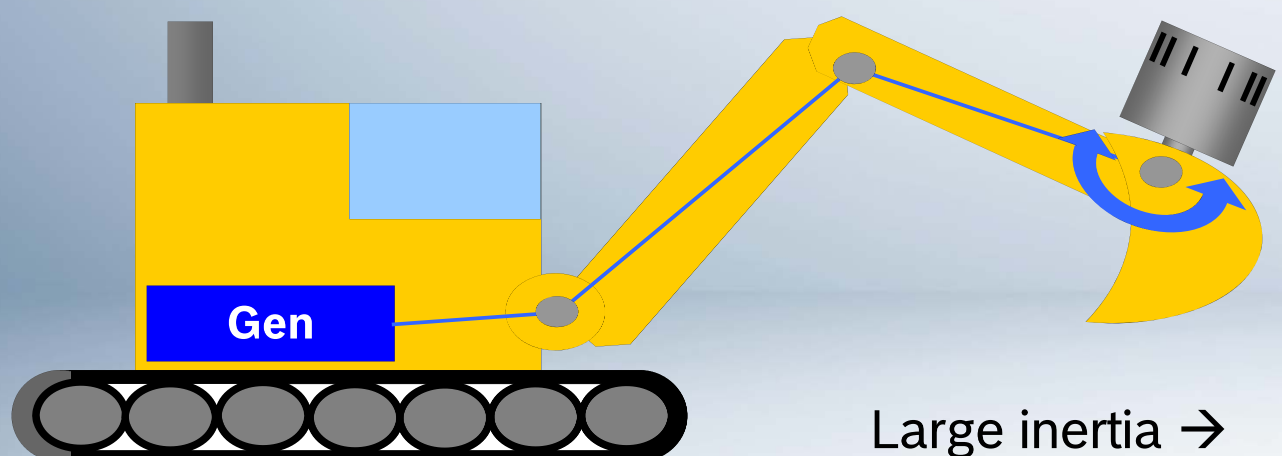
Equipment

- Amount of equipment

  Electric *systems require less equipment than an hydraulic system*

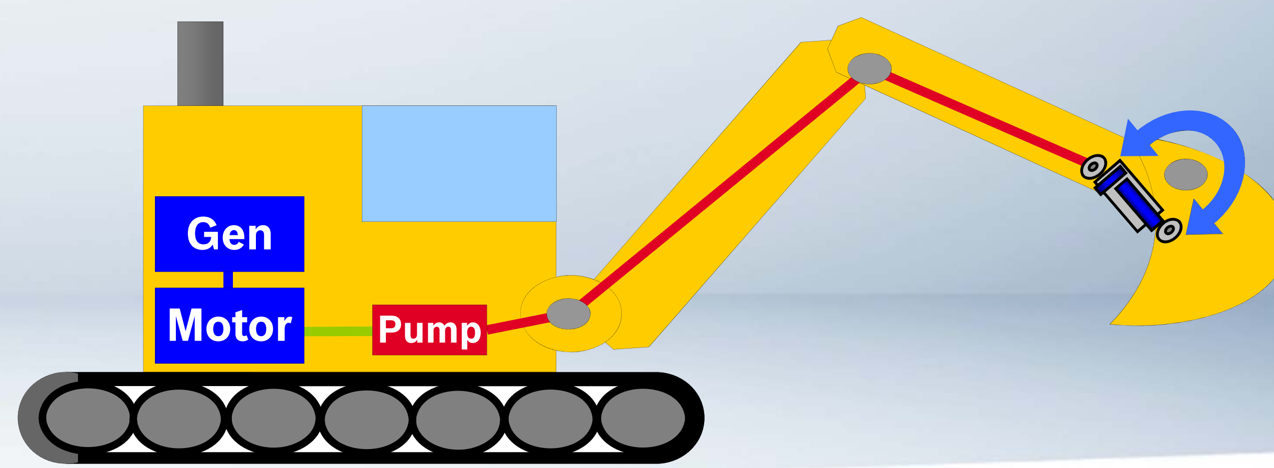
- Weight distribution

  Hydraulic actuators *are more compact than electric actuators*



Large inertia → More power required

Heavier system, better distribution → Less power required



Selecting the Drive Technology

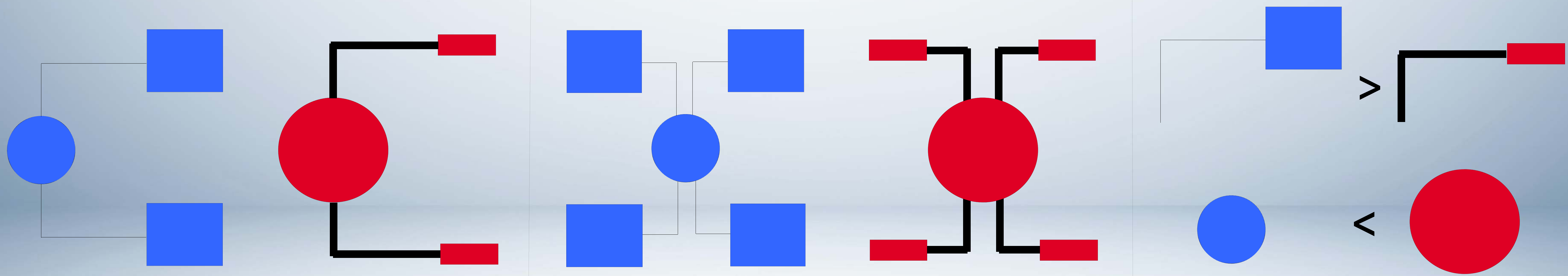
Equipment

- Multiple users with a single power pack

If there are multiple users which do not all operate simultaneously, the compactness of a ***hydraulic*** *actuators will give an overall lighter system*

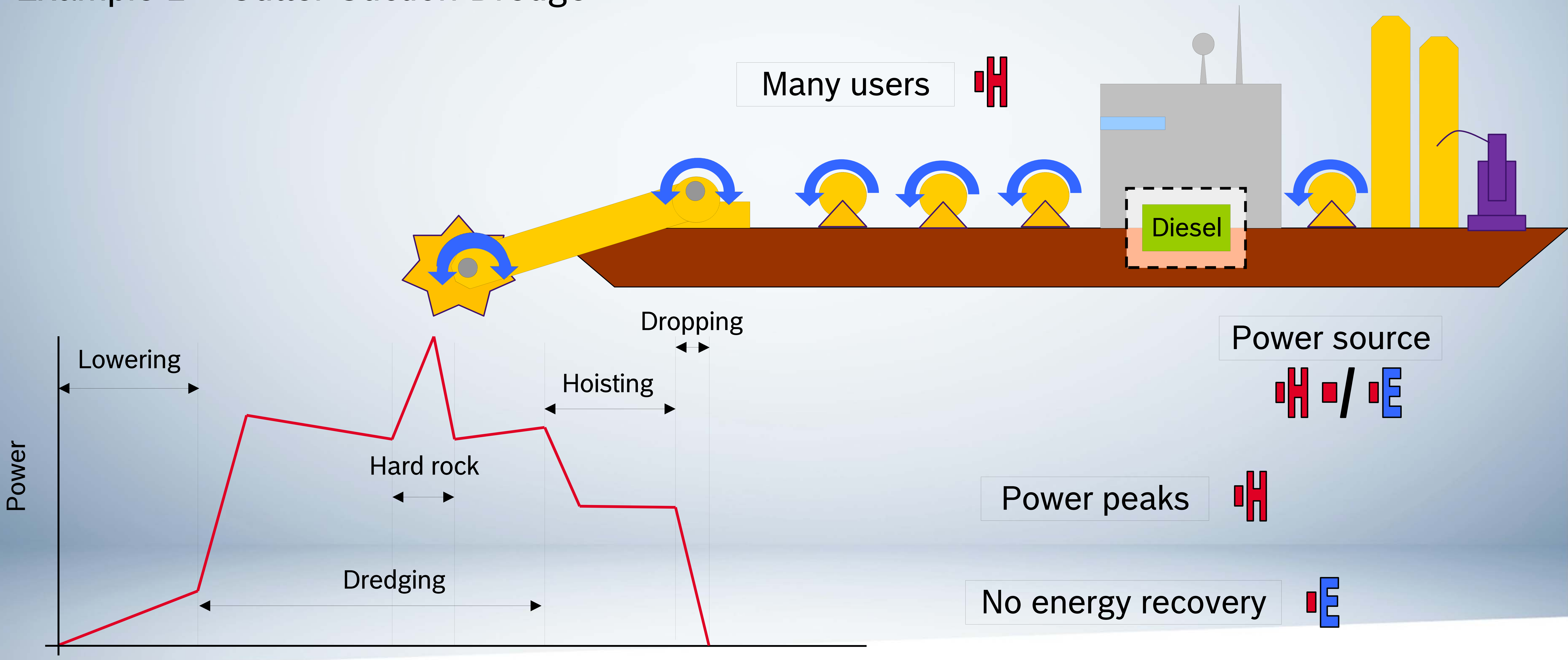
Few users → ***Electric***

Many users → ***Hydraulic***



Selecting the Drive Technology

Example 1 – Cutter Suction Dredge



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Selecting the Drive Technology

Example 1 – Cutter Suction Dredge

- No electric generator
  - Both electric and hydraulic systems will require additional equipment. **Hydraulics** can mount direct on diesel engine
- Power peaks
  - A **hydraulic** system will deal with the power demand more efficiently i.e. Cutter head
- Many users
  - A **hydraulic** system will be lighter and more compact if there are many users

A **hydraulic** system is more appropriate

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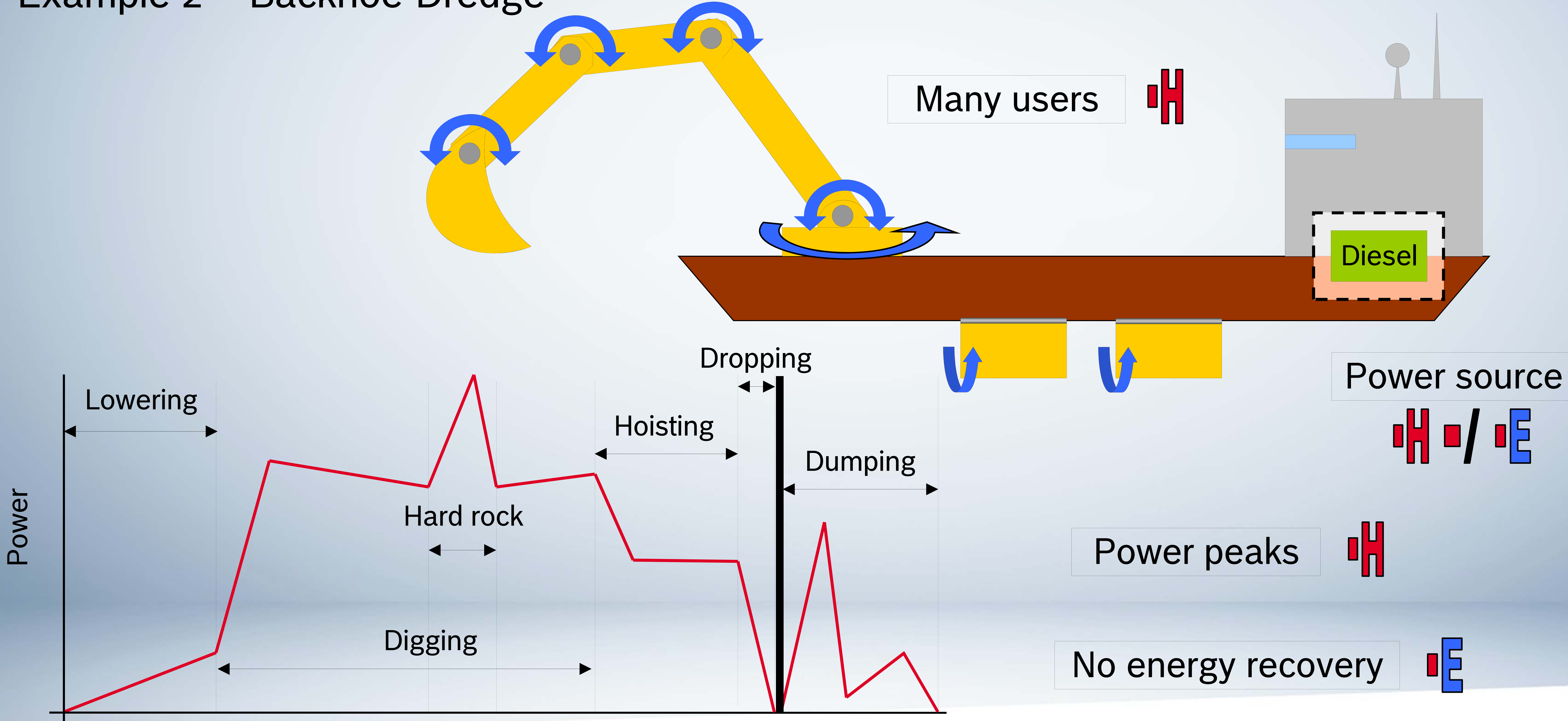
Selecting the Drive Technology

Example 2 – Backhoe Dredge



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Selecting the Drive Technology

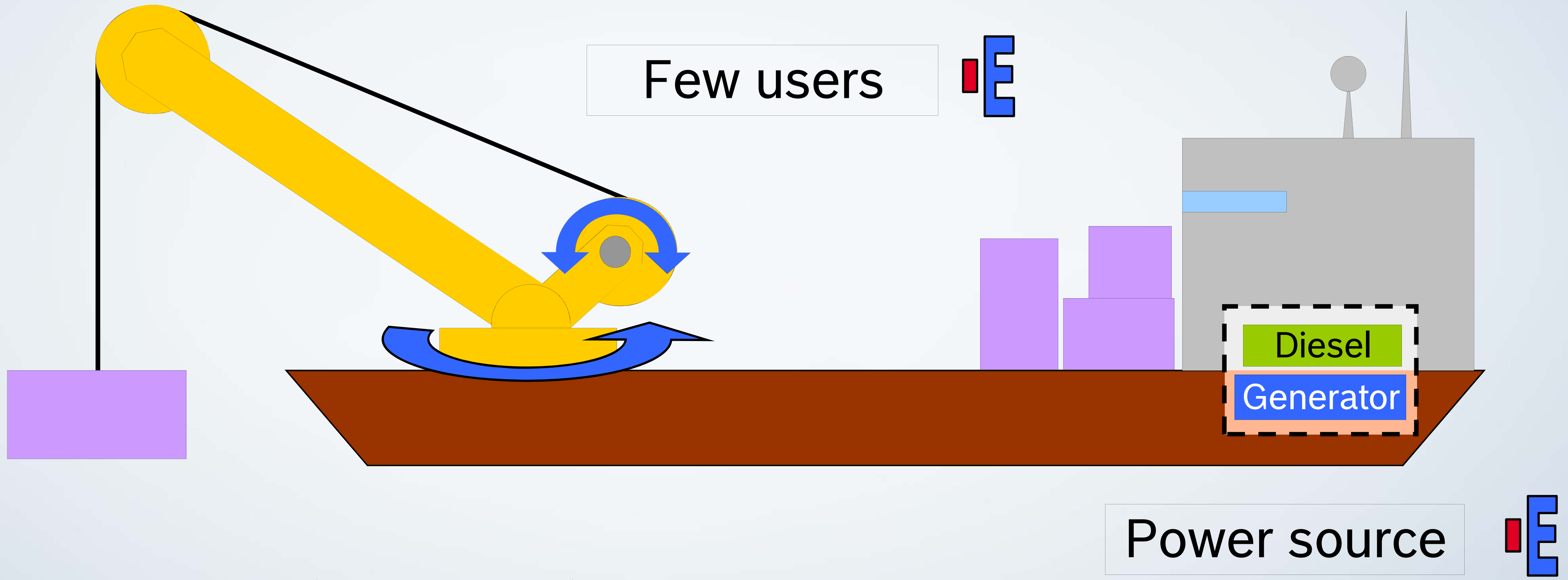
Example 2 – Backhoe Dredge

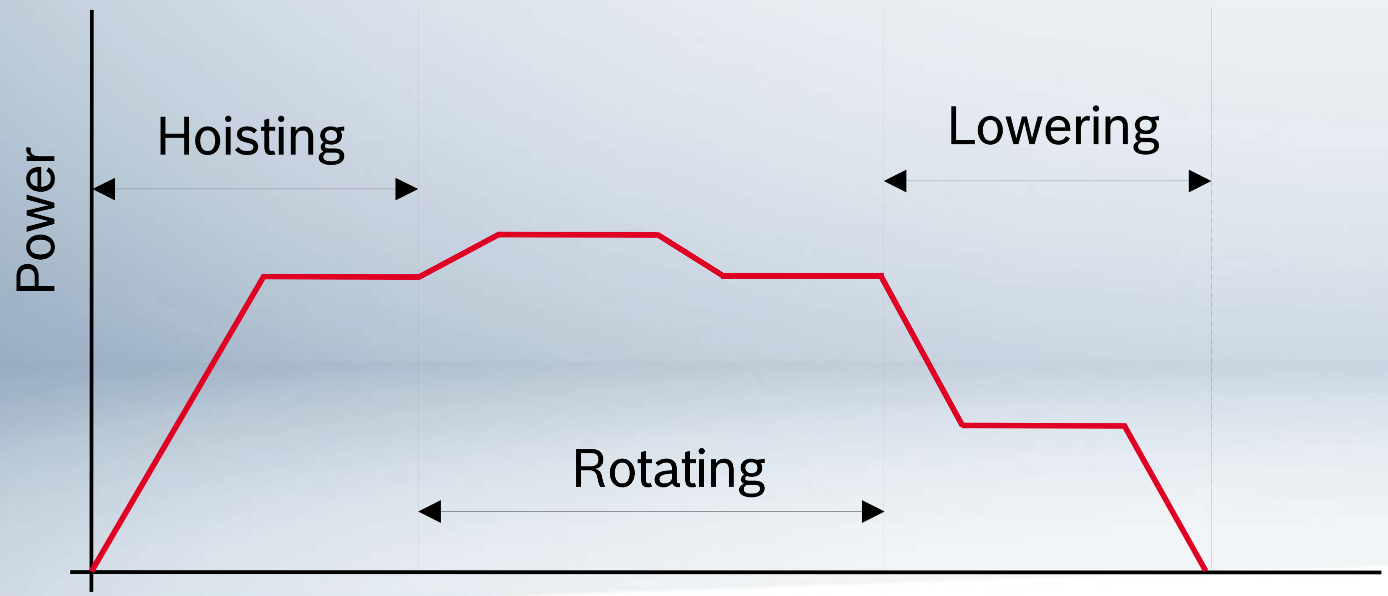
- No electric generator
  - Both **electric** and **hydraulic** systems will require additional equipment
- Power peaks
  - A **hydraulic** system will deal with the power demand more efficiently
- Many users
  - A **hydraulic** system will be lighter and more compact if there are many users

A **hydraulic** system is more appropriate

Selecting the Drive Technology

Example 3 – Transport Ship Loading





No power peaks

No energy recovery

Selecting the Drive Technology

Example 3 – Transport Ship Loading

- Readily available generator on ship
  - An **electric** system will require less auxiliary systems than a hydraulic one

- No power peaks
  - An **electric** system can deal with the given power demand efficiently

- Few users
  - An **electric** system will be lighter if there are few users

- Energy recovery
  - A **hydraulic** system will have higher efficiency and more cost effective if there is energy recovery

An **electric** system is more appropriate

Selecting the Drive Technology

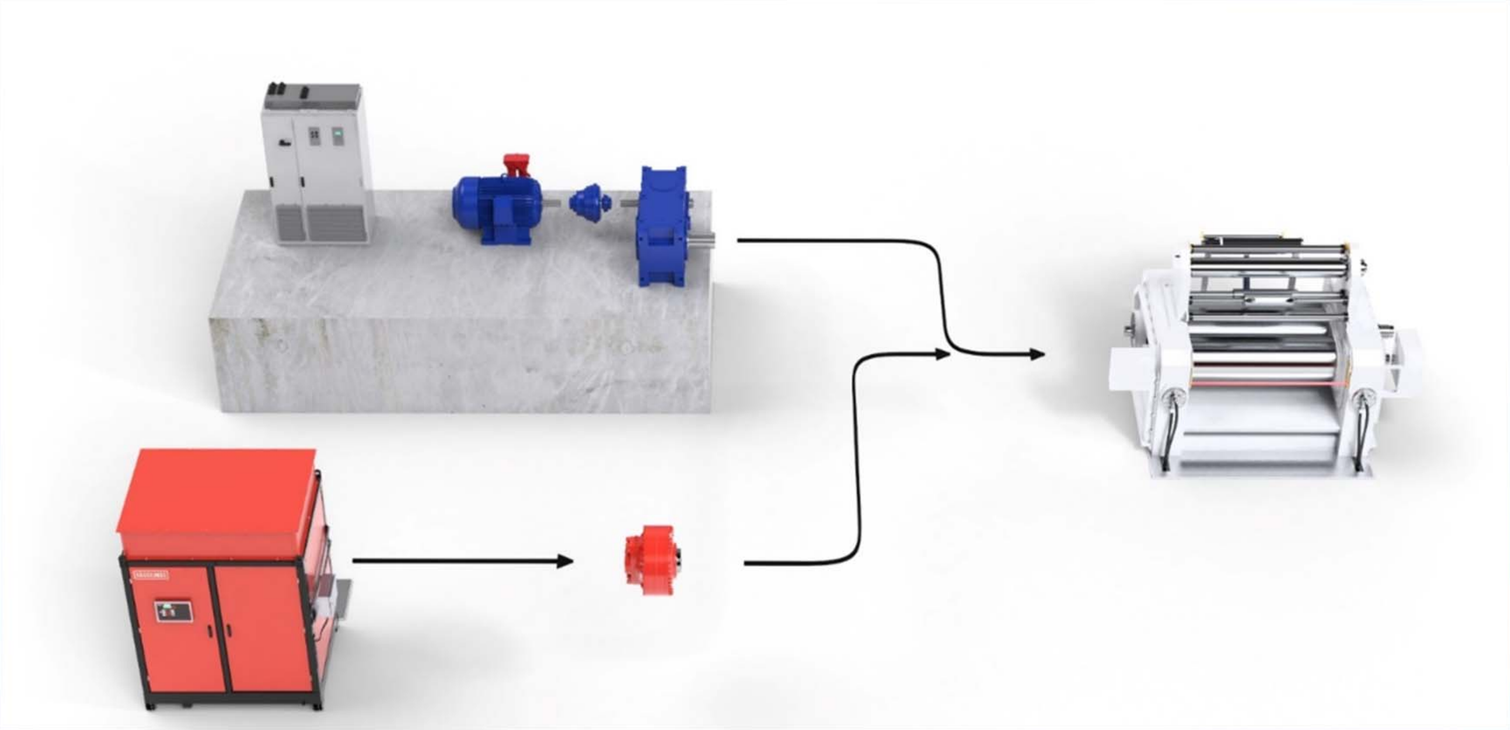
Environmental Impact

- Both **hydraulics** and **electric actuators** can use Environmental acceptable lubricants (EAL)
- Closed loop hydraulic systems use significantly less oil volume than traditional open loop systems
- Environmental impact mitigation
  - Biodegradable oil
  - Design and material selection
  - Tex-sleeves

Drive alternatives

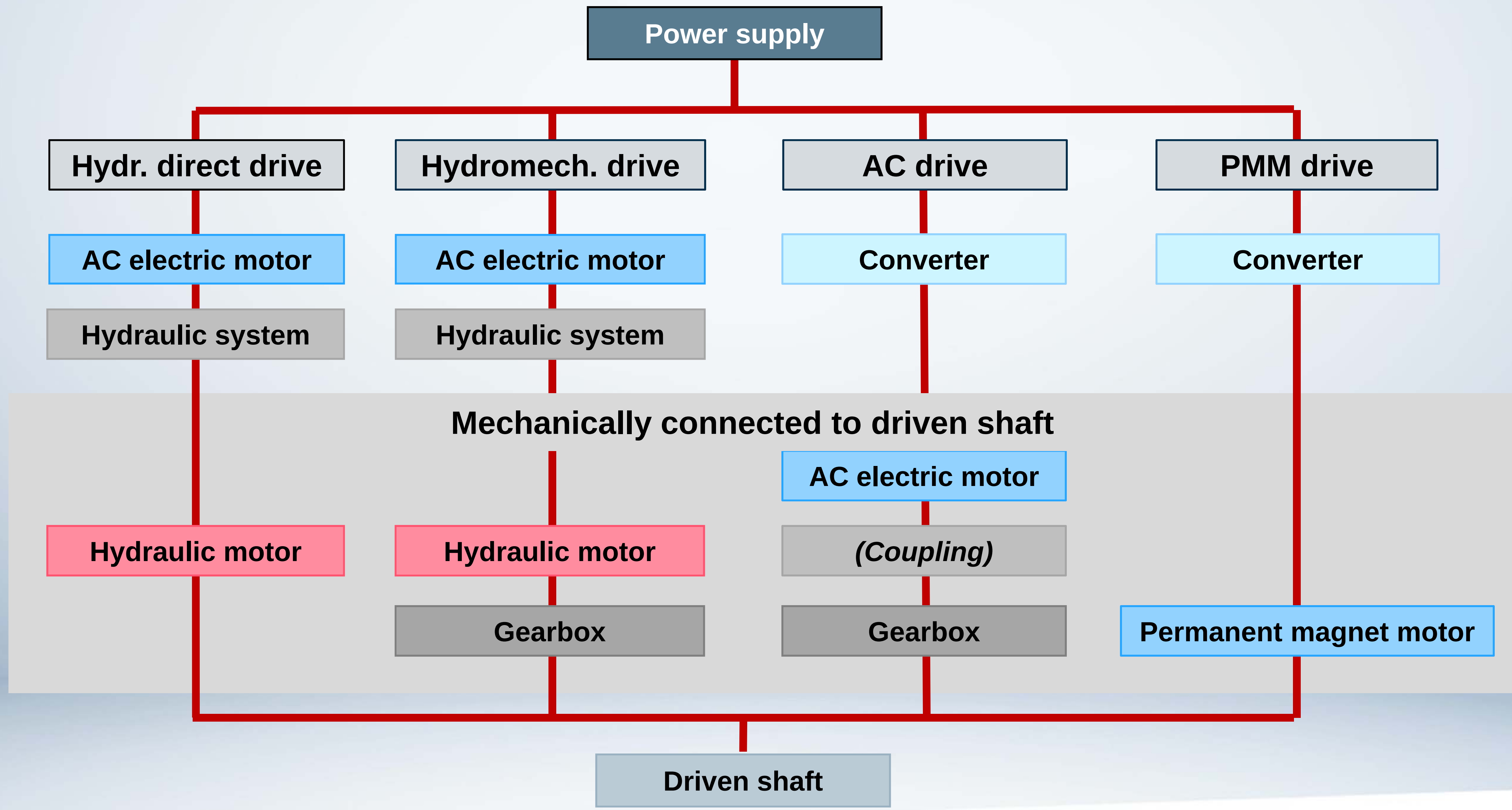
Purpose

- Compare three drive types in low speed, high torque applications:
  - Hydraulic direct drive (HDD)
  - Hydromechanical drive (HMD)
  - Electromechanical drive (ACD)



Drive alternatives

Variable-speed drive alternatives



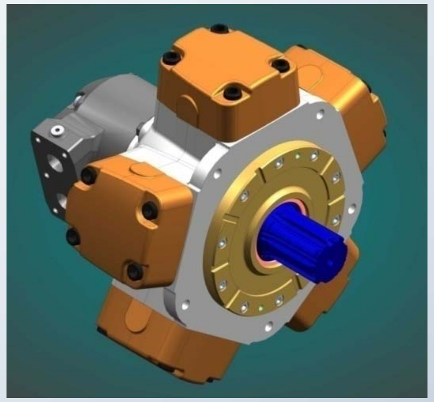
Drive alternatives

Hydraulic motors

Common types in drive systems

- **Axial piston motors – fixed displacement**
  - High-speed motors, combined with a gearbox
  - Motors with variable displacement (not considered here)

- **Excentre motors**
  - Low-/medium-speed motors, used as a direct drive or combined with a gearbox



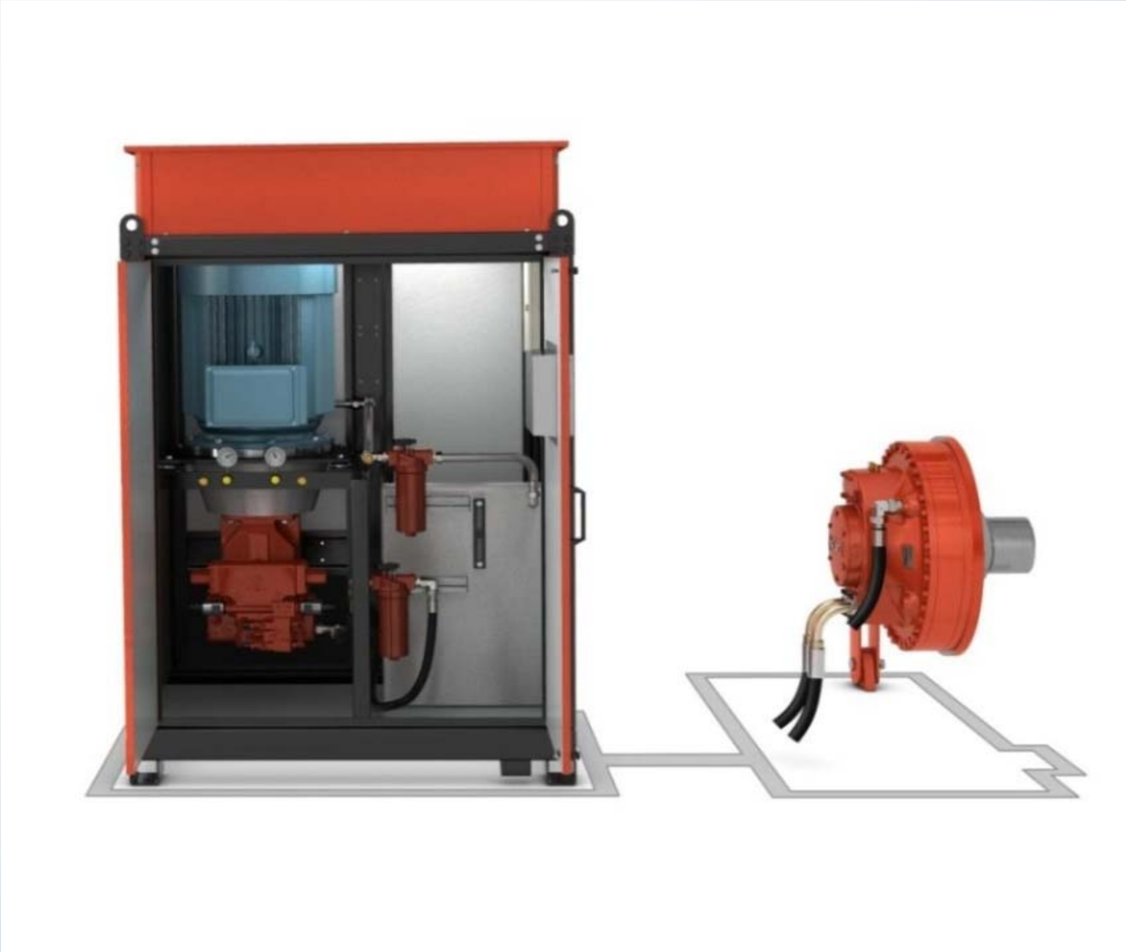
- **Radial piston cam ring motors**
  - Low-speed motors, normally used as a direct drive

Drive alternatives

Hydraulic direct drive (HDD)

Design

- Motor mounted directly on shaft
- Speed adjusted by increasing or decreasing oil flow
- Direction of rotation reversed by changing oil flow direction
- Motor connected to drive unit by pipes or flexible hoses

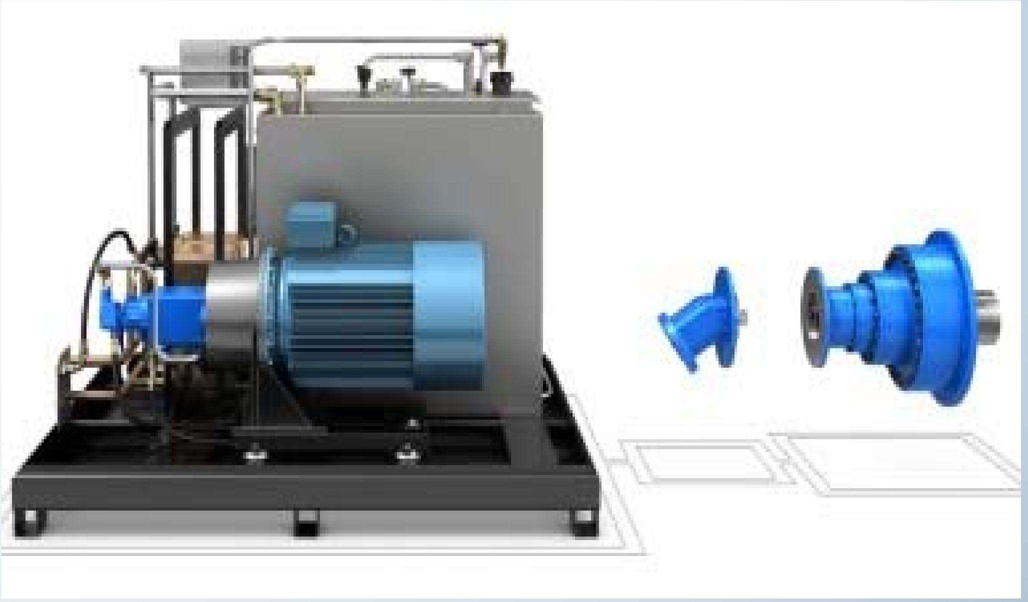


Drive alternatives

Hydromechanical drive (HMD)

Design

- Medium- or high-speed hydraulic motor with fixed displacement
- Connected to drive shaft by means of a gearbox
- Speed adjusted by increasing or decreasing oil flow
- Direction of rotation reversed by changing oil flow direction
- Motor connected to pump by pipes or flexible hoses

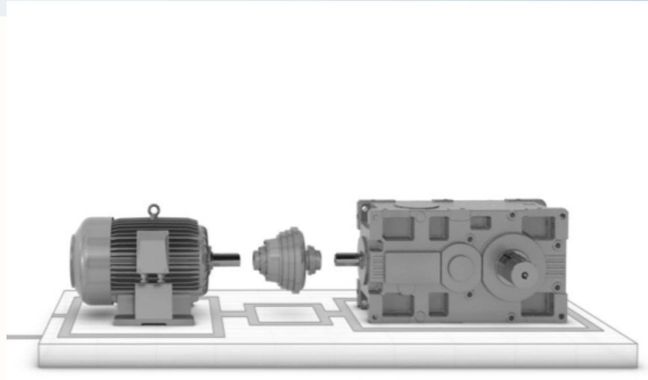


Drive alternatives

Variable-speed electromechanical drive (ACD)

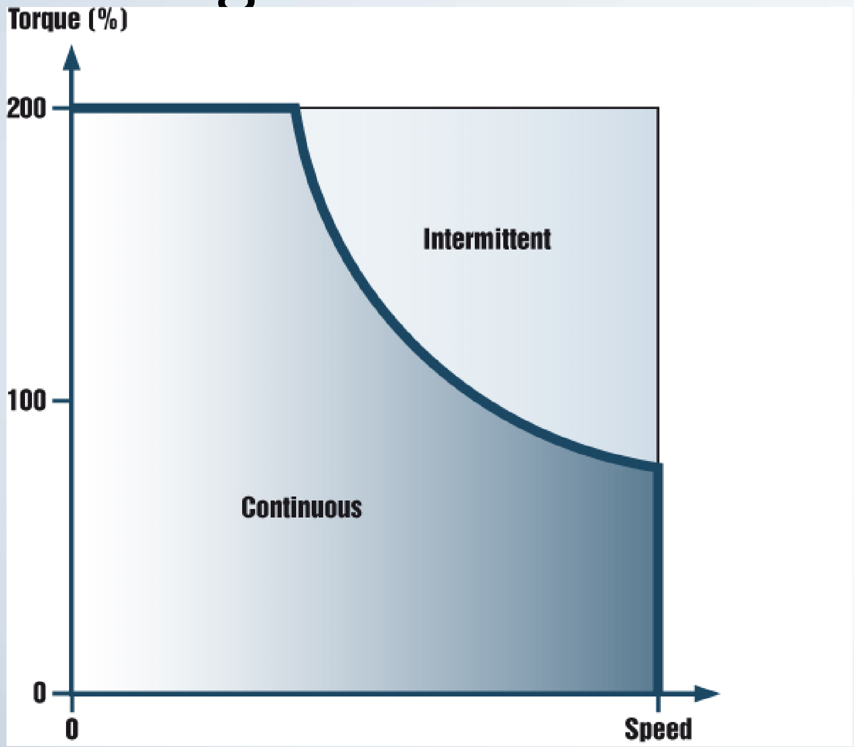
Design

- Combines a frequency converter and an AC induction motor
- Gearbox used to achieve low speed and high torque
- Fluid coupling sometimes required for shock load protection
- Electric motor speed controlled by converter
- Shielded cables between converter and motor



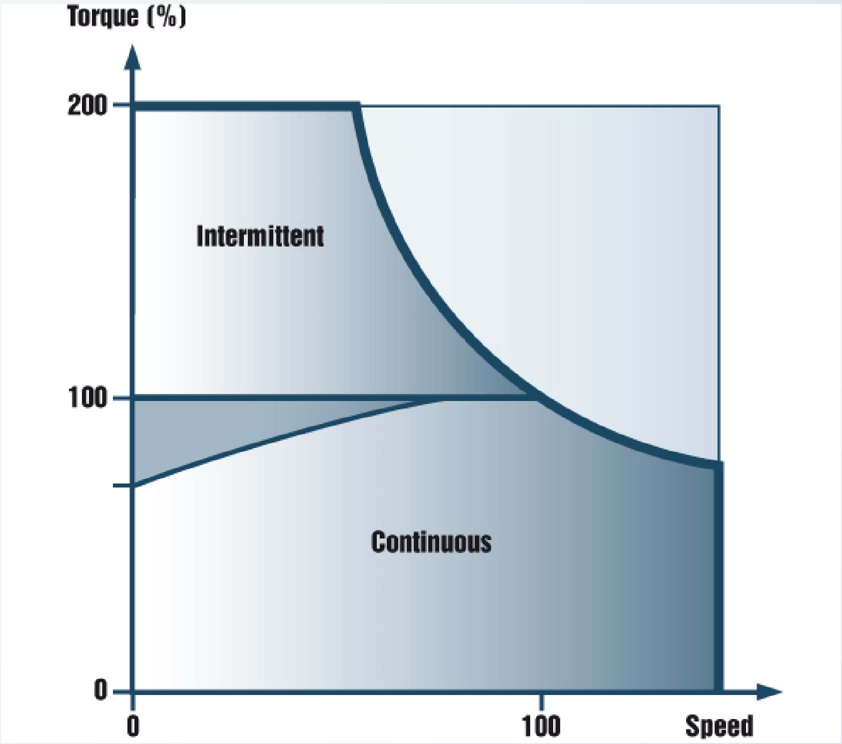
Drive alternatives

Comparing operating characteristics



HDD, HMD

- Full shaft torque at zero speed – no time limit
- Full shaft torque throughout speed range
- Max torque 200–300% of nominal torque – no time limit
- Unlimited starts, stops, and reversals (HDD)– unless limited by gearbox (HMD)
- Max speed and torque depend on motor type and gearbox selection (HMD)



ACD

- Reduced torque (70%) at low speed (self-ventilating motor)
- Forced cooling for 100% torque at low speed
- Torque above 100% is time-restricted
- Max torque up to 200% – a few seconds only
  – Only for certain drives
  – Risk of drive overheating – drive must cool down after

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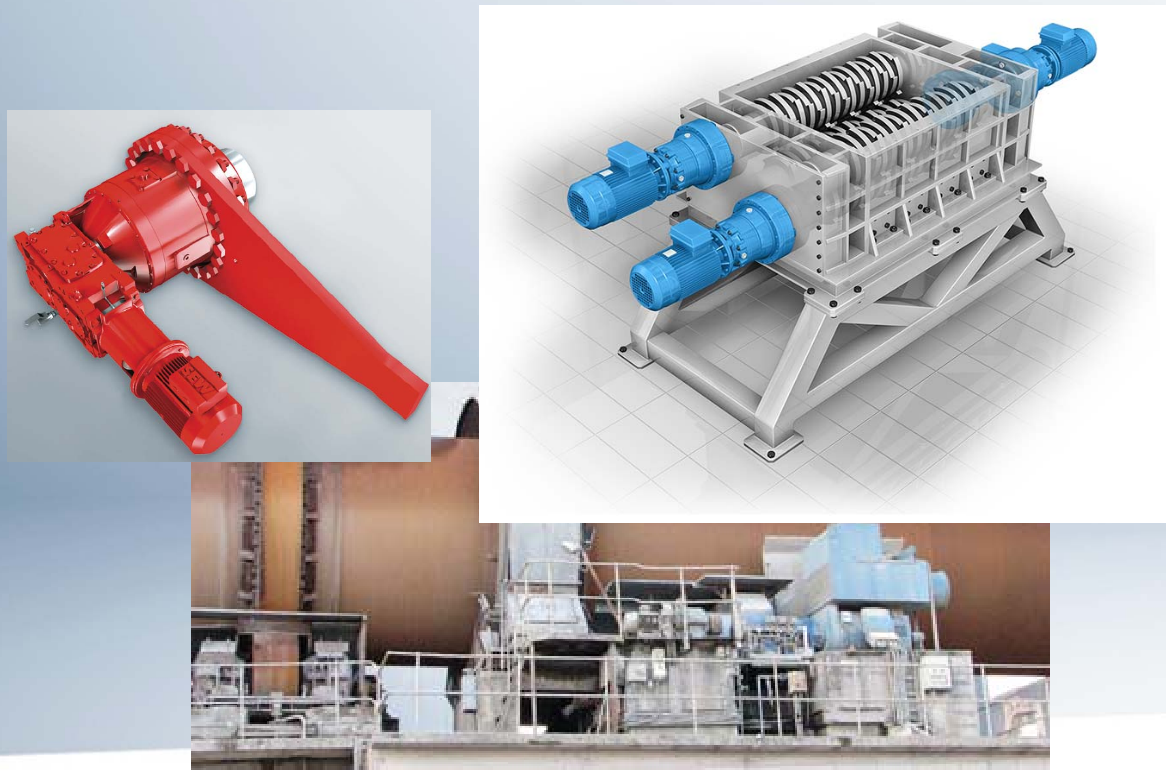
Drive alternatives

Physical considerations

ACD:

- Foundations needed
- Size at shaft (large size and weight)
- Gearbox maintentance & change problematic
- Harsh environments, extreme temperatures or high power -> enclosures and shielding
- Additional cooling & lubrication



HDD:

- No foundations
- Size at shaft (small size and weight)
- Power & torque density is high in relation to weight
- Direct mounted on shaft (coupling or splines)
- Separate drive unit
- Closed loop system – insensitive to harsh environments

HMD

- No foundation
- Size on shaft
  - Gearbox added weight on shaft
  - Long drive assembly
- Extra cooling & lubrication of gearbox

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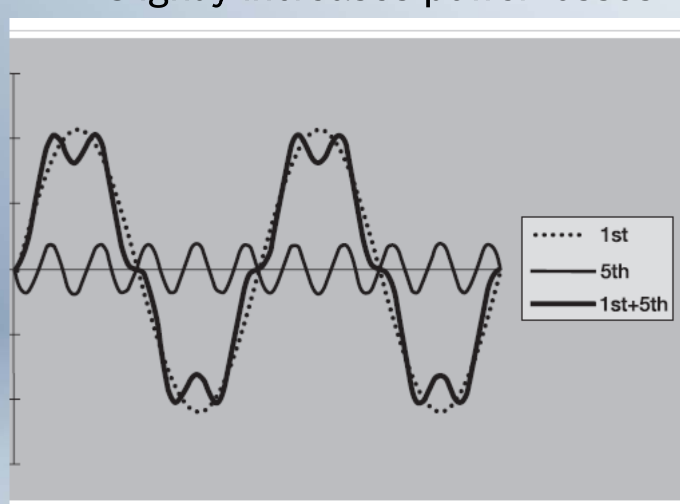
Drive alternatives

Harmonic distortions

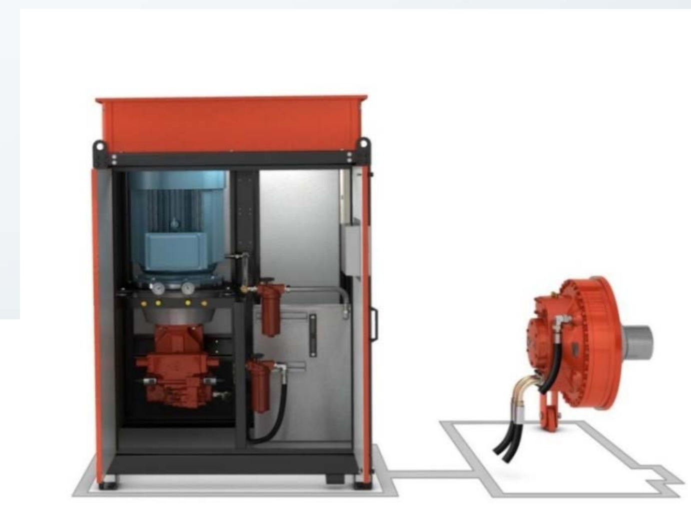
ACD

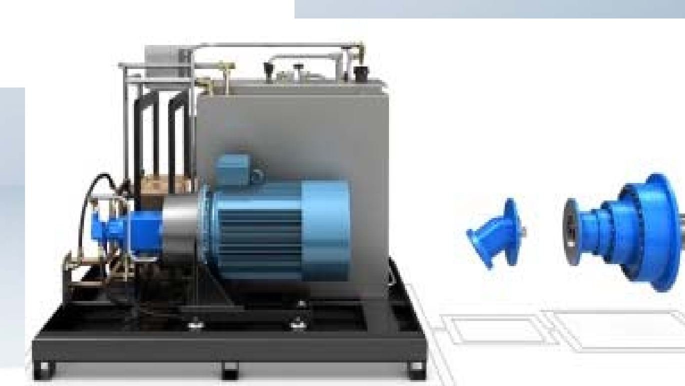
- Harmonic distortions on the grid can damage connected equipment
  - How it arises:
    - ACD speed is adjusted by changing the net frequency
    - To do so, the net frequency is divided into several sine waves
    - Sine waves are combined to create the required frequency
    - The result is not a clear sine wave, leading to harmonic distortion
  - Harmonics can be reduced with low-harmonic converters or external filtering
    - Adds to the drive cost
    - Slightly increases power losses



HDD, HMD

- Electric motor always runs at rated speed
- No harmonic distortion produced
- No additional equipment needed





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Drive alternatives

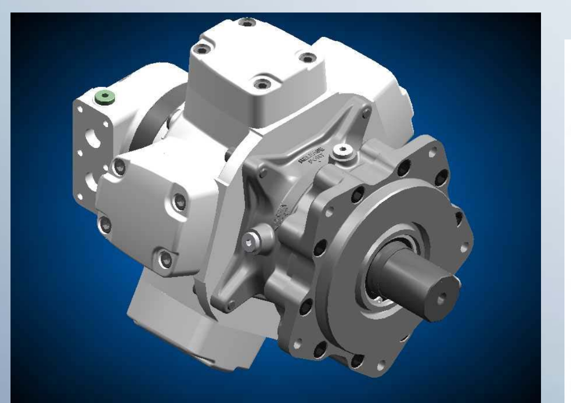
Parking brakes

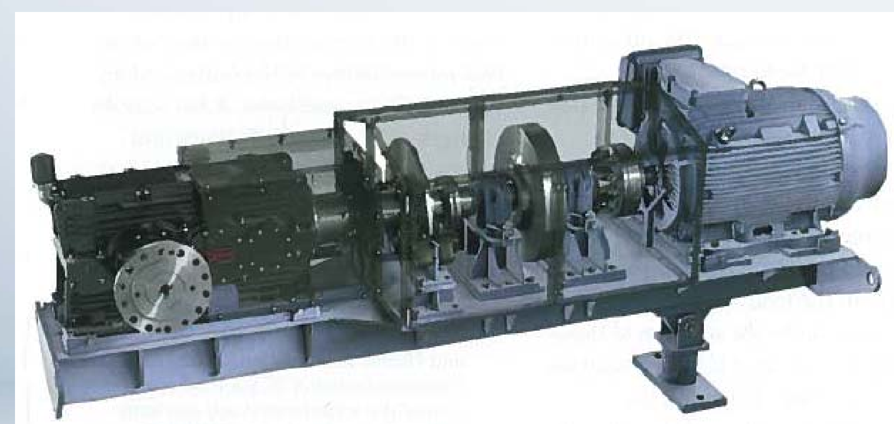
When using an ACD or HMD

- Brakes installed on the gearbox's high-speed shaft
- **Advantage** – low-torque brake, cheap solution
- **Disadvantage** – less safety in the event of a gearbox failure

When using an HDD

- Brakes installed at the front or rear end of the motor
- **Advantage** – greater safety compared to ACD and HMD
- **Disadvantage** – high-torque brake, expensive solution





Drive alternatives

Overdimensioning

When using an ACD

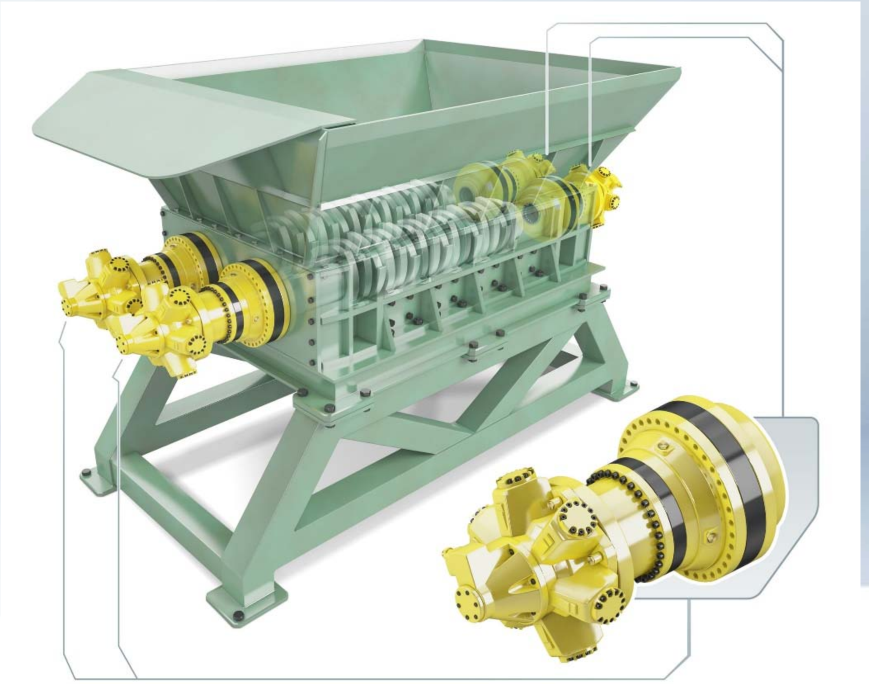
- Converter and motor overdimensioned to handle high starting torque, frequent starts and stops, etc.
- Gearbox overdimensioned to handle application requirements (such as shock loads) and ensure service life
- Built-in losses due to overdimensioning reduce drive efficiency

When using an HMD

- Gearbox oversized in the same way as ACD
- Built-in losses due to overdimensioning reduce drive efficiency

When using an HDD

- No overdimensioning required

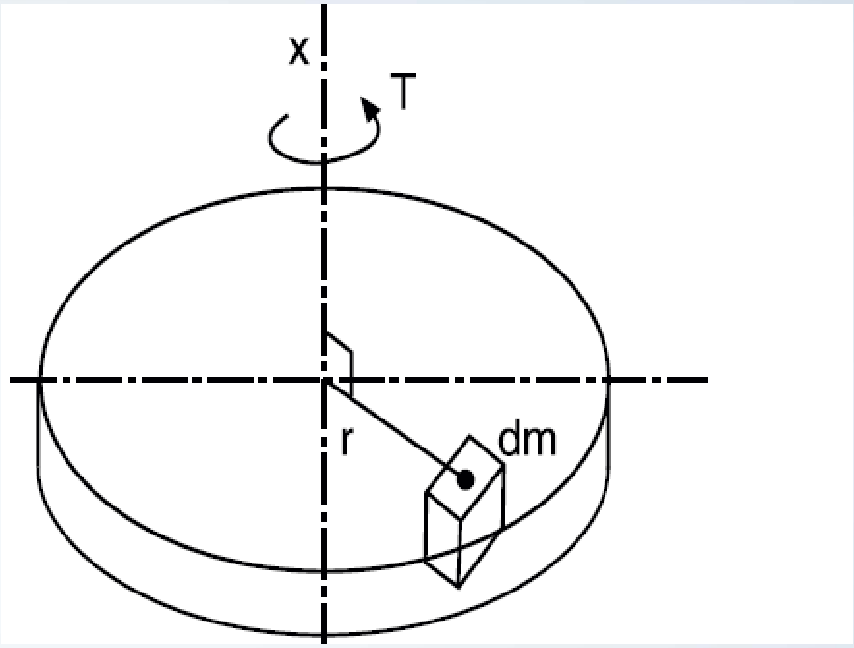


Drive alternatives

Moment of inertia

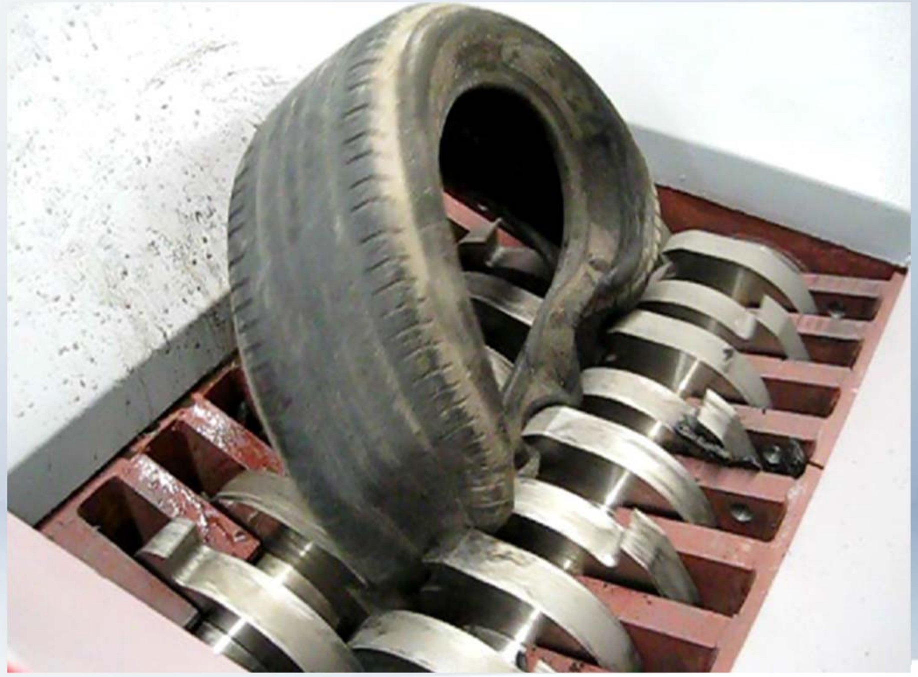
Definition and background

- "The resistance of a body to a variation in velocity"
- A critical factor in many applications
- Can have both a positive and a negative impact
- Torque necessary to overcome the moment of inertia



Moment of inertia and shock loads

- High moment of inertia can create very high additional torque
- Extreme strain may be created during sudden stops
- Higher drive moment of inertia = heavier stresses
- Stresses create significant wear and tear
  – leading to high maintenance costs and reduced productivity
- If the drive and machine are designed for high shock loads, the additional torque can help overcome peak loads



Drive alternatives

Moment of inertia - comparison

- High-speed drive components have a low moment of inertia
- Moment of inertia for high-speed components must be recalculated to the gearbox output shaft
- Components connected to the high-speed shaft contribute most
- Moment of inertia is negligible for the gearbox

$$J_{Total} = J_1 * i^2$$

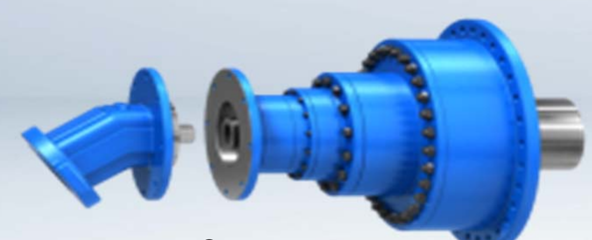
J_{tot} = 15 666 kgm^2

J_1 = 2.9 kgm^2

i = 75.5 : 1

i = 1 : 1

$J_1 = J_{tot}$ = ~20kgm^2



J_{tot} = 1 459 kgm^2

J_1 = 0.27 kgm^2

Drive alternatives

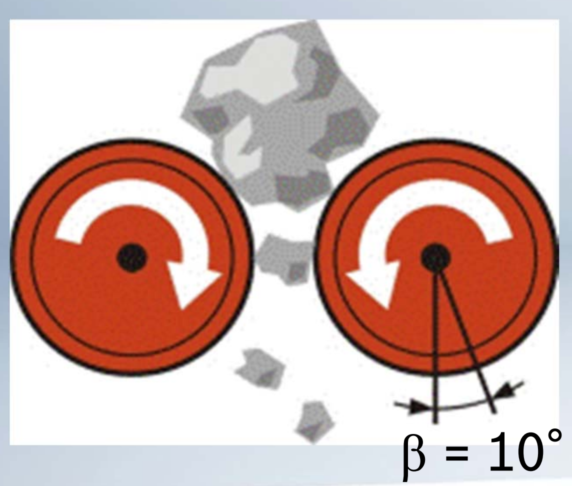
Moment of inertia – additional torque

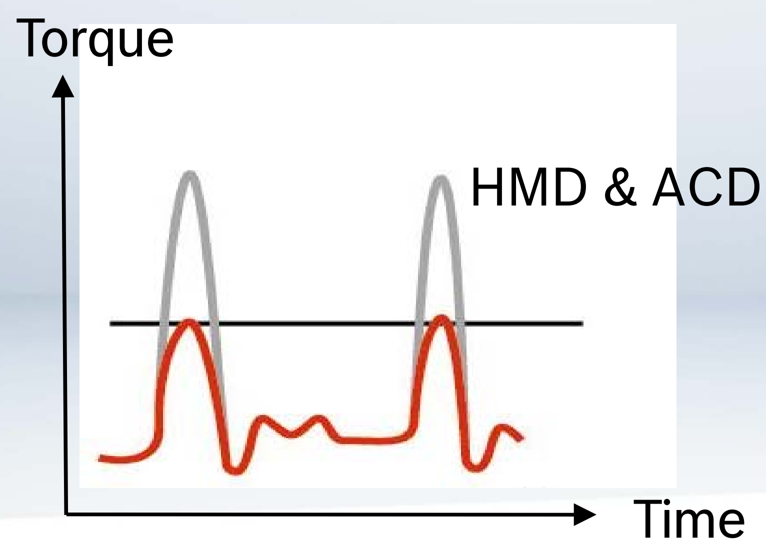
Additional torque

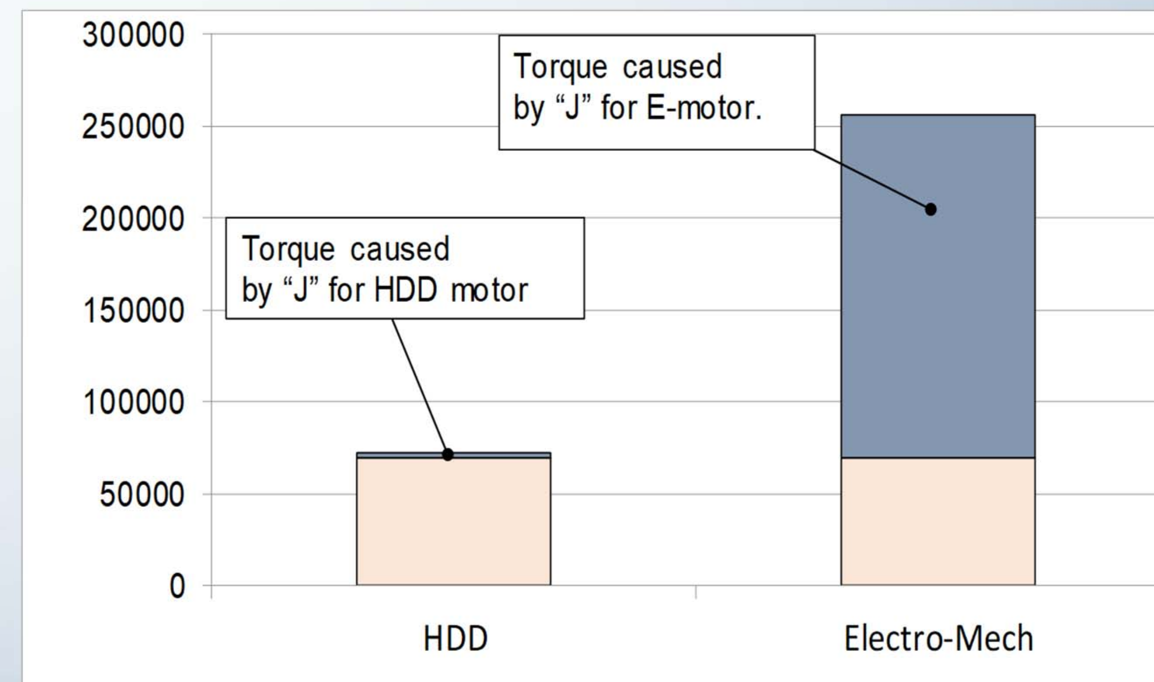
- High moment of inertia cause high additional torque during rapid speed changes

Sensitivity to shock loads

- HMD and ACD drives are sensitive to shock loads
  - Overdimensioning of gearbox required
- HDD drive is unsensitive and creates less torque peeks
  - Longer service life for machine and its components







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Drive alternatives - operation

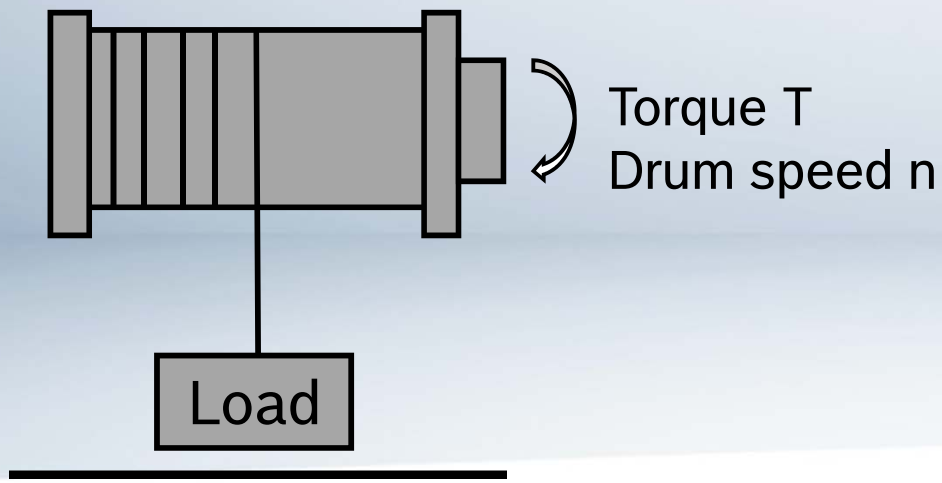
Controllability

Drive requirements

- Smooth acceleration and deceleration
- Accurate positioning

When using an ACD

- Risk of drive overheating at full torque and low/zero speed
  - Overdimensioning or external cooling may be required
- Accurate positioning may be difficult due to gearbox friction
  - Difficulty increases with the number of gear stages
  - New control methods may overcome this



When using an HDD

- Stepless adjustment of oil flow and thereby drive speed
- High hydromechanical efficiency
- Excellent controllability in both directions – very accurate positioning
  - Some changes to the hydraulic system may be required, depending on requirements
- No time restrictions apply

When using an HMD

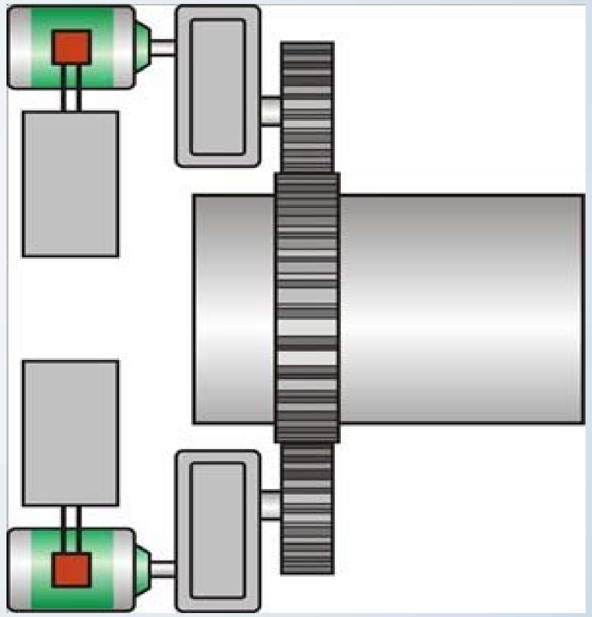
- Same hydraulic performance as HDD
- Accurate positioning may be difficult due to gearbox friction
  - Difficulty increases with the number of gear stages

Drive alternatives - operation

Load sharing

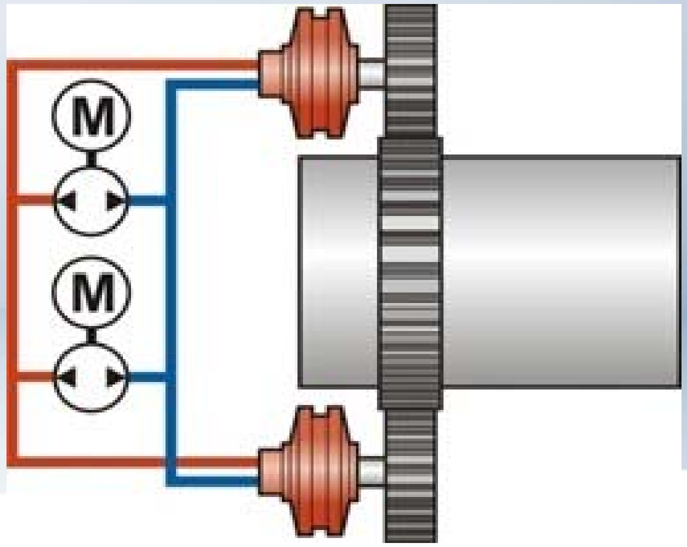
When using an ACD

- Difficulty sharing the load equally
- Risk of vibrations and gearbox fatigue
- Problems may be reduced if one motor is used for position control, the other for torque control



When using an HDD or HMD

- Hydraulic motors connected to a common hydraulic system
- 100% load sharing automatically
- No vibration risk



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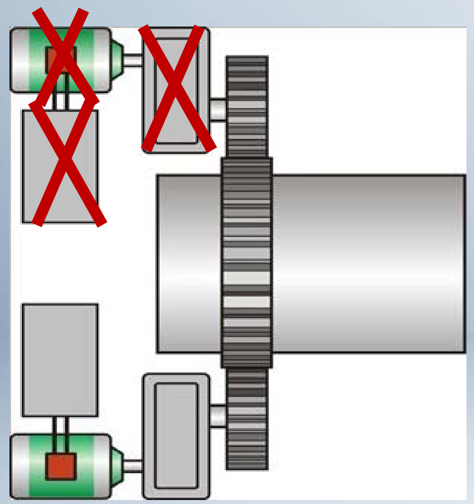
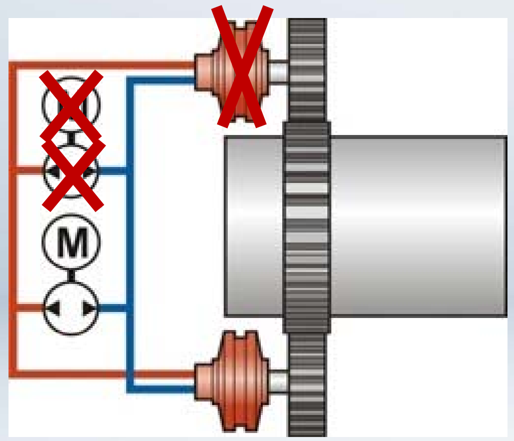
Drive alternatives - operation

Load sharing - redundancy

When using an ACD

- Drive depends on electric power to develop torque
- In the event of a converter, electric motor or gearbox failure:
  - Affected drive system component must shut down
  - Operation at higher power and torque probably not possible with remaining drive
  - Application must shut down or operate at reduced capacity





When using an HDD

- Hydraulic motor failure – operation possible
  - Remaining motor can be run at higher pressure/torque if starting torque not too high
  - Alternatively, the application can be run at reduced load and torque
- Pump failure – operation depends on amount of hydraulic contamination
  - Uncontaminated: pump can be blocked off to run at reduced speed and full torque
  - Contaminated: drive must shut down and the system must be cleaned
- Electric motor failure – operation possible
  - Electric motor and pump can be blocked off to run at reduced speed and full torque

When using an HMD

- Gearbox or hydraulic motor failure – operation probably not possible
  - Remaining gearbox must be able to operate at higher torque
- Electric motor or pump failure – same as for HDD

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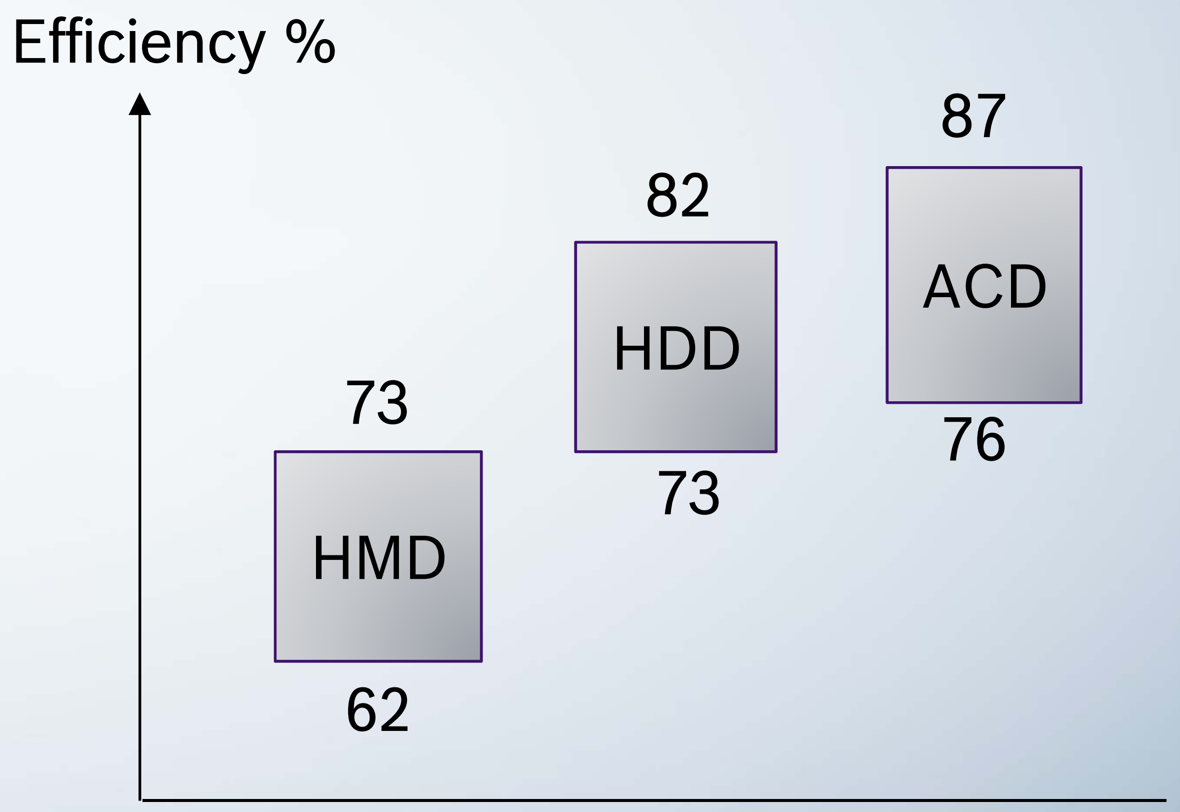
Drive alternatives - Efficiency

Efficiency compared by drive type

- Efficiency ranges shown are indications
- Actual efficiency figures may be higher or lower
- Power consumption and efficiency depend on many factors
- Impossible to say which type of drive is most efficient
- Fair comparison requires study of:
  - The specific application
  - Duty cycle
  - Selected drives



Drive alternatives – comparative overview

Quick comparison table

Characteristics	HDD	HMD	ACD
Starting torque	200–300%	200–300%	200%, time restricted
Standstill time at load	Unlimited	Unlimited	Limited due to overheating
Torque throughout speed range	Full torque	Full torque	Reduced continuous torque at lower speeds
Sensivity to shock loads	Not sensitive	Sensitive	Very sensitive – fluid coupling or overdimensioning required
Rapid stops	Very fast	Fast	Slow
Start/stop frequency	Unlimited	May be limited by gearbox	Limited
Moment of inertia	1	20–100	100–1000

Drive alternatives – comparative overview

Quick comparison table

Characteristics	HDD	HMD	ACD
Gearbox required	No	Yes, in most cases	Yes
Foundation required	No	No	Yes, unless mounted with a torque arm
Weight of units connected to driven shaft	Low	Higher, depends on gearbox size	Higher, depends on drive size
Size at driven shaft	Very compact	Longer axis than direct drive	Bulky, especially at high power
Load sharing	100%	100%	Difficult, load on electric motors must be compared
Redundancy with multiple drives	High	Limited - dependent on remaining gearbox capacity	Very limited, drive dependent on power to develop torque
Sensitivity to harsh environments	Not sensitive	Gearbox may need cooling and flushing	Converter must often be insulated or installed in an air-conditioned room
Harmonic distortion	No	No	Yes, low-harmonic converter or filter required

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Questions?

Thank you!

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