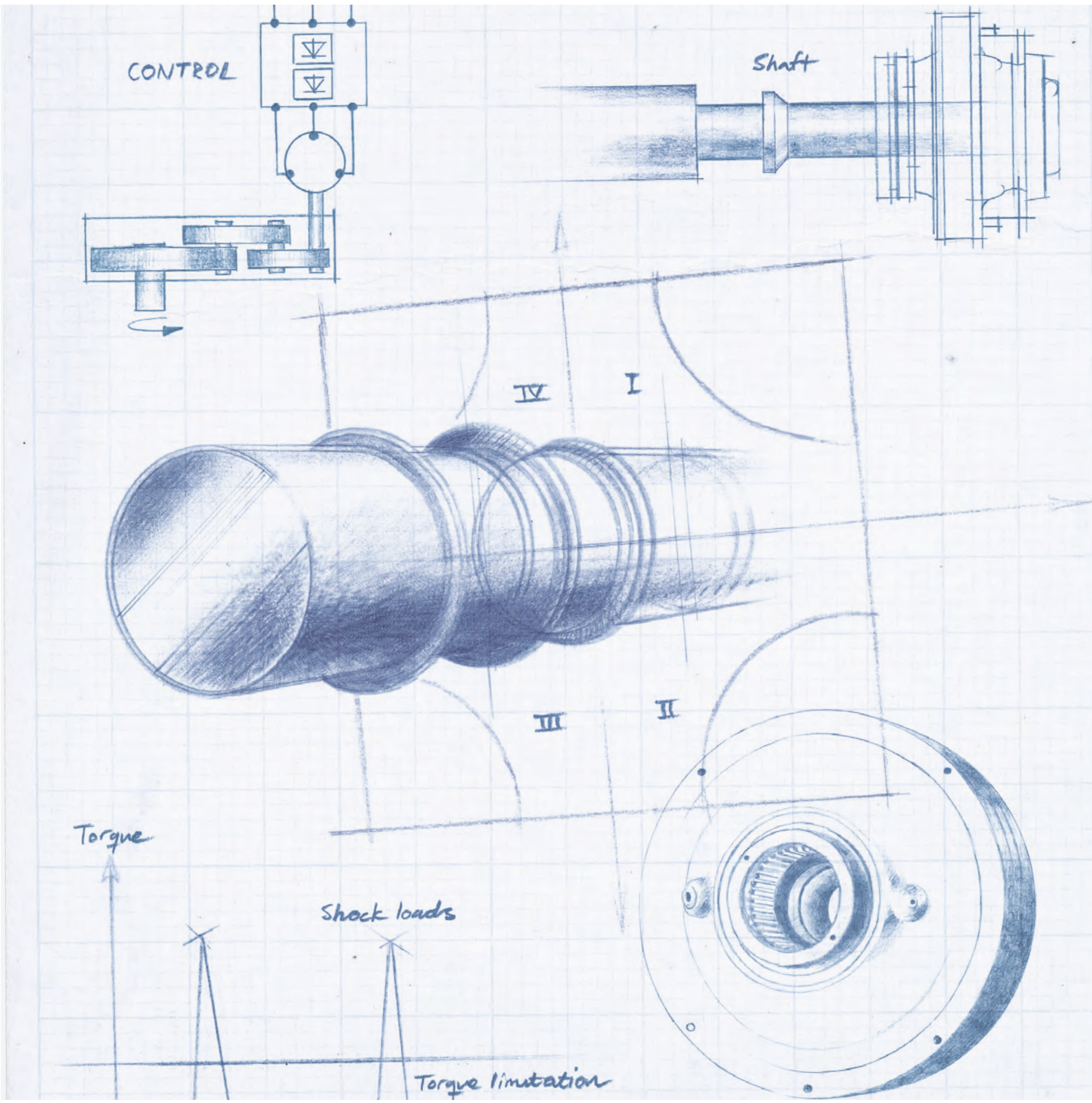
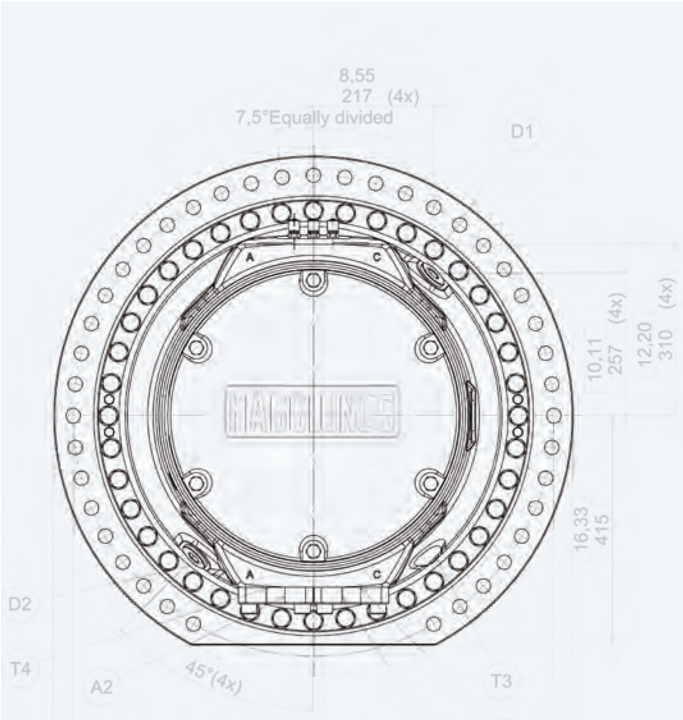
The Drive & Control Company

Driving factors




HÄGGLUNDS



Control of speed and torque.

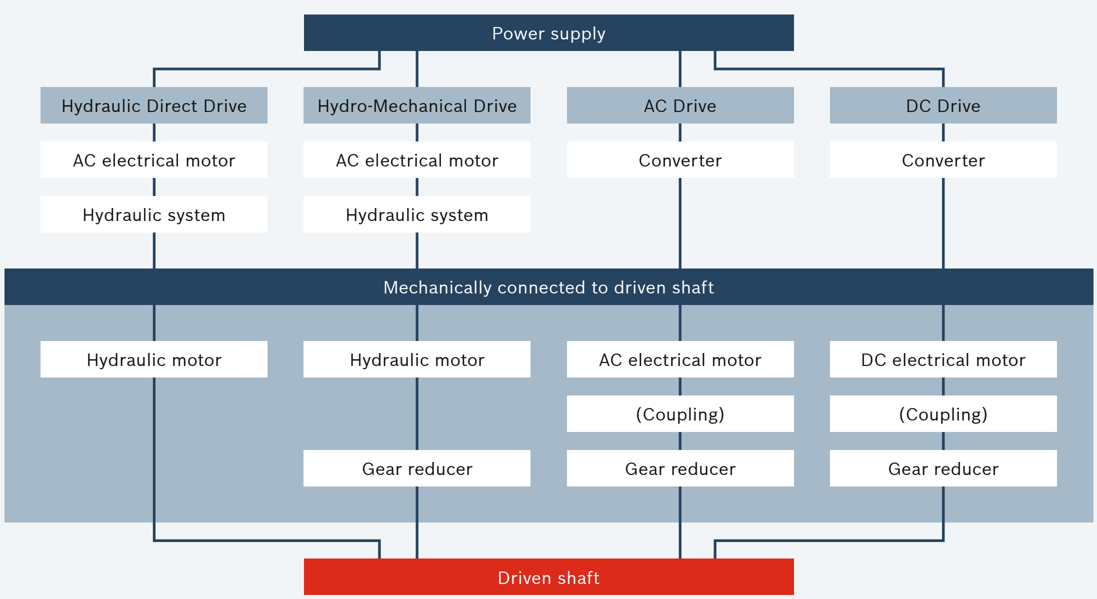
The need to produce better material at an ever-increasing pace puts industrial drives in the spotlight. For processes to be at their most productive, the control of speed and torque in relation to the process is essential, as it has a strong impact on quality, efficiency and reliability.

Comparing drives with variable low speed and high torque

A number of different solutions exist for achieving this control, and the best one is chosen according to the requirements of the application and environment. In this booklet, we discuss some of the criteria and evaluate the main contenders.

- The variable-speed AC Drive (ACD), which is connected to a gear reducer
- The variable-speed DC Drive (DCD), which is connected to a gear reducer
- The variable-speed Hydro-Mechanical Drive (HMD), which is connected to a gear reducer
- The variable-speed Hydraulic Direct Drive (HDD), which needs no gear reducer

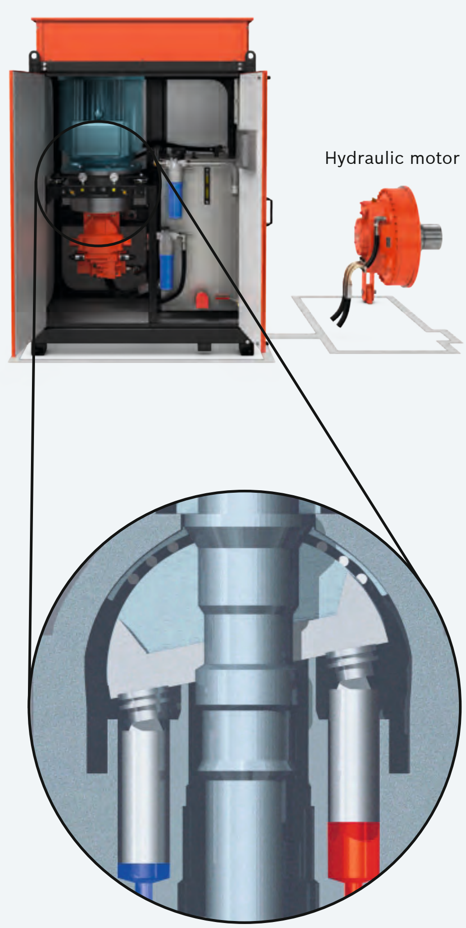
The basic components and characteristics of these drives can be seen in the diagrams on the following pages. While the ACD is the drive solution most commonly chosen today, the unique advantages of the HDD have become increasingly popular in heavy/process industries. This brochure will explore some of the reasons why, as well as highlighting the key issues an engineer should consider when choosing a drive system.



▲ **Figure 1: Alternative types of variable-speed drives.**

The Hägglunds solution

Although still less common than other drive alternatives, the Hydraulic Direct Drive is making steady gains as industrial demands increase. Developed by Hägglunds, the Hydraulic Direct Drive is particularly effective in harsh environments and difficult or demanding operating situations. It is simple, versatile and user-friendly.



▲ **Figure 2: A Hydraulic Direct Drive.**

The Hydraulic Direct Drive (HDD)

An HDD is a closed system with a low-speed hydraulic motor at its heart. Notable for its ability to sustain high torque even at minimum speed, the hydraulic motor is mounted directly on the driven shaft using a mechanical shrink-disc coupling or splines. No foundation is required and there is no need for a gear reducer, belts, chains or sprockets.

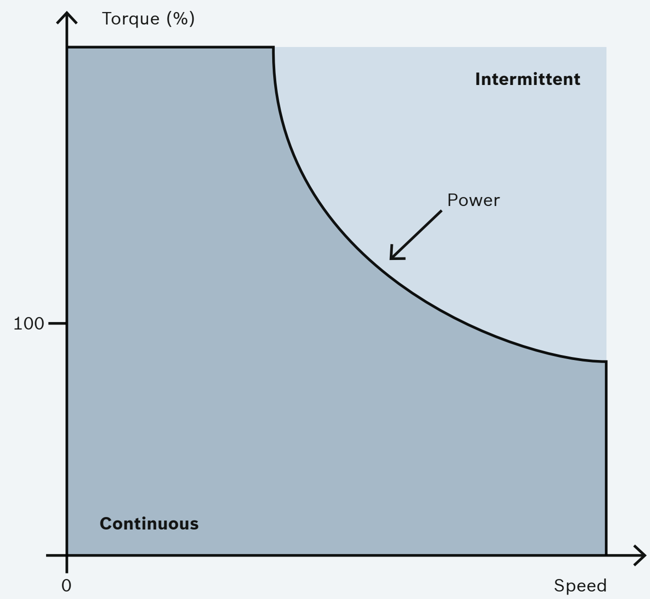
Power is supplied to the hydraulic motor by a separate drive unit, which can be positioned almost anywhere in relation to the installation. The drive unit contains at least one standard AC induction motor, which runs at a fixed speed and drives a variable-displacement axial piston pump.

It is the variable flow of oil from the pump that determines the speed and direction of the drive. As a result, speed and directional control are not compromised by the limitations of the electric motor. Oil flow is controlled by adjusting the angle of the swash plate against which the pistons act. When the swash plate is moved over centre, the direction of flow is reversed, which in turn reverses the direction of the drive. Due to the hydraulic motor's low moment of inertia, the response is almost instantaneous.

An HDD can operate continuously throughout its power range up to its rated torque, from zero to full speed. It can maintain full shaft torque continuously at zero or low speed, and since the electric motor is unaffected, no time restriction applies. (See figure 3.)

In addition, an HDD can operate intermittently above its installed power rating with the same limitations that apply to any fixed-speed electric motor with an equivalent service factor. It is the operating torque and the desired service life that determine the size of the hydraulic motor.

Among the drive's key operating advantages is its pre-set pressure-limiting function, which prevents maximum torque from being exceeded by de-stroking the pump as necessary during lengthy acceleration cycles and in overload conditions. Another is the fact that the drive can operate in all four quadrants (driving and braking, forward and reverse) without the need for special accessories. (For more on drive operation, see pages 16-17.)



▲ **Figure 3: The operating characteristics of a hydraulic Direct Drive.**

Geared solutions

The traditional way of thinking when it comes to industrial drives is to use a medium- or high-speed drive motor, which can be either hydro-mechanical or electro-mechanical. In such a solution, the application speed is achieved by means of a gear reducer, which adds to the drive's bulk and moment of inertia.

The Hydro-Mechanical Drive (HMD)

An HMD makes use of a medium- or high-speed hydraulic motor and is not connected directly to the driven shaft, except in low-torque applications. The addition of a gear reducer, usually of the planetary type, increases the size of the drive in the axial direction.

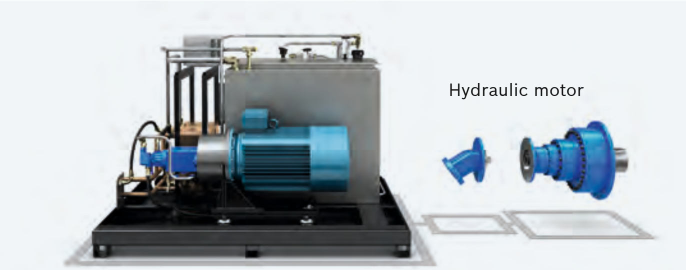
While the basic torque and speed characteristics of an HMD are similar to those of an HDD, the introduction of a gear reducer creates mechanical losses that reduce the output torque. Exactly how much torque is lost depends on the type of gear reducer used, the number of gear stages it has and the factor by which it has been over-dimensioned. (For more on over-dimensioning, see pages 14-15.)

In addition, the introduction of a gear reducer creates a moment of inertia that may be up to 100 times higher than that of an HDD. In the event of a sudden shock load or stop, a substantial amount of additional torque is placed on the driven shaft, which may lead to stress-related wear or fatigue within the drive system and application.

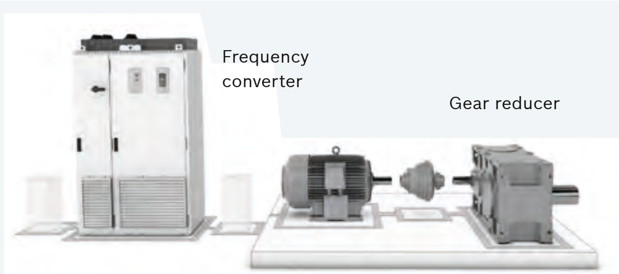
The variable-speed AC Drive (ACD)

An ACD combines a converter and a high-speed AC induction motor. Like an HMD, it requires a gear reducer to achieve a low running speed, and in many cases a fluid coupling must be installed between the motor and gear reducer. These components, together with the motor's own moment of inertia, create a total moment of inertia that may be up to 1.000 times higher than that of an HDD.

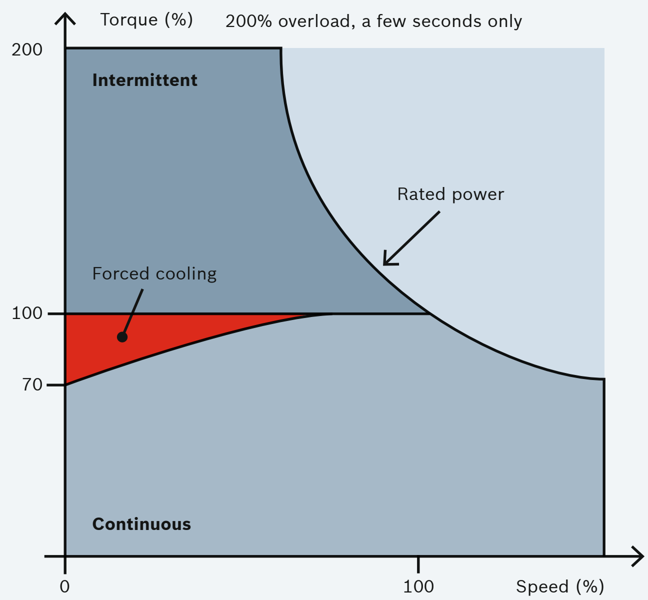
There are several different methods of controlling an ACD. These methods usually allow a controllable speed range from 0 to 100 Hz in heavy-duty applications. When running at the rated frequency of 50/60 Hz, the drive can operate



▲ **Figure 4: A Hydro-Mechanical Drive.**



▲ **Figure 5: A variable-speed AC Drive with gear reducer.**



▲ **Figure 6: The operating characteristics of a variable-speed AC Drive.**

continuously at 100% of the motor's rated torque. (See figure 6.)

At lower speeds, the continuous torque available is reduced. As the speed approaches zero, the continuous torque is limited to approximately 70% of the rated torque, unless the motor's self-ventilation is supplemented by cooling.

Likewise, an ACD can operate intermittently above 100% of its rated torque, but only for a very short period of time. Operation at 150% of the rated torque, for example, can be sustained for only one minute out of ten, while starting torque in the 180-200% range can be sustained for only a few seconds. Because the selection of an ACD must be based on its continuous torque capacity over the required speed range, these limitations, especially at lower speeds, lead to over-dimensioning. (For more on over-dimensioning, see pages 14-15.)

An ACD also creates harmonic distortion that can pollute the power distribution grid. This feedback has the potential to overheat transformers, cables and motors, as well as to damage electrical equipment connected to the mains. Though the installation of a low-harmonic converter or external filters can prevent this, both options add complexity and cost while increasing power consumption.

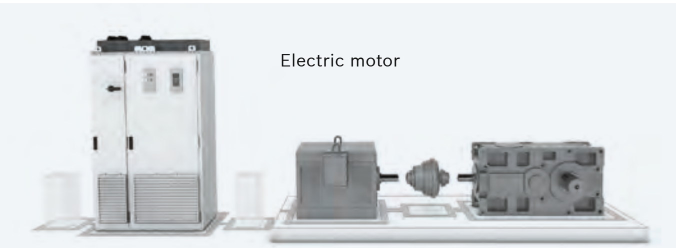
The variable-speed DC Drive (DCD)

A DCD, which combines an AC/DC converter with a DC electric motor, is a less common alternative to an ACD in industrial applications. It too requires a gear reducer to handle low-speed applications, and in most cases a helical or bevel-helical gear reducer is used. In applications that involve shock loads, a fluid coupling may also be needed to protect the gear reducer and the driven machine. This is due to the high moment of inertia, which may be up to 1000 times higher than that of an HDD.

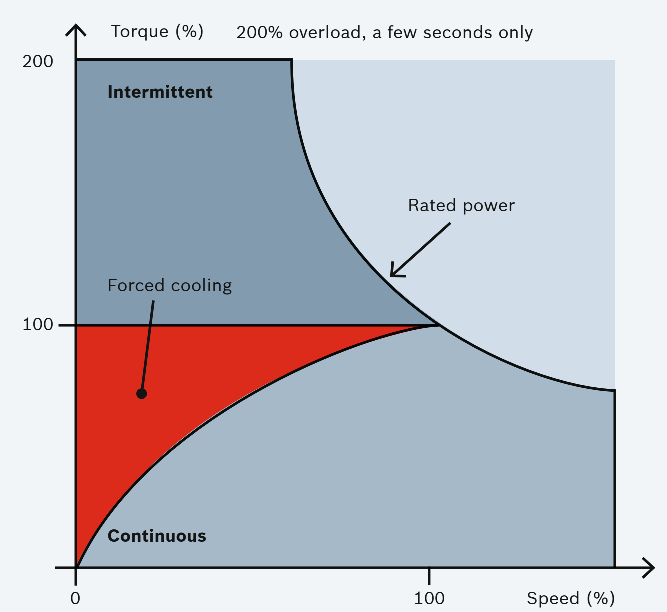
The speed of a DCD is controlled by altering the supply voltage to the DC motor, which is powered by a thyristor rectifier that receives its current from an AC supply. The thyristors are used to alter either the armature voltage or the field voltage.

When running at its rated speed, the drive can operate continuously at 100% of the motor's rated torque. (See figure 8.) At lower speeds, the continuous output torque is reduced due to reduced cooling capacity. Forced cooling is therefore necessary in order to operate with high torque at lower speeds.

A DCD can operate intermittently at more than 100% of its rated torque, but as in the case of an ACD, it can only do so for a limited period of time. A DCD has a starting torque capacity of approximately 200-250%, but this torque can still only be maintained for a few seconds. Because the selection of a DCD must be based on its continuous torque capacity over the required speed range, its limitations at lower speeds lead to over-dimensioning. (For more on over-dimensioning, see pages 14-15.)



▲ **Figure 7: The operating characteristics of a variable-speed DC Drive.**



▲ **Figure 8: The operating characteristics of a variable-speed DC Drive.**

Summary

With a geared drive solution, the electric motor, gear reducer and coupling is mechanically connected to the driven shaft, often requiring considerable space around the machine. A direct drive is much more compact.

A geared drive solution will also generate high additional torque in case of sudden speed changes caused by heavy shock loads. Failure to compensate for these can lead to considerable costs from breakdowns and resulting downtime. A direct drive eliminates this risk; the additional load is negligible due to a low moment of inertia and a fast reacting hydraulic system.

With ACD and DCD, the rotation speed is controlled by varying the speed of the electric motor. This means reduced cooling capacity at lower speeds, which reduces the allowable continuous torque at lower rotation speeds. There are no such limitations with HDD and HMD, as the electric motor always rotates at its rated speed, and operating rotation speed is controlled by the pump's oil flow. A hydraulic drive provides full torque at low rpm.


TONS.

Installation

Since space is often limited in industrial applications, the physical size and flexibility of an installation are key factors in selecting a drive system. Thought must be given not only to the drive components themselves, but also to the foundations and other accessories that may be required.

Physical considerations

When using an HMD, ACD or DCD, all of which require a gear reducer between the motor and the driven shaft, a good deal of space must be set aside for the drive transmission. The physical size and weight of the gear reducer can make the installation work difficult and costly, and in the case of a foot-mounted gear reducer, the motor, the gear reducer and the driven shaft must all be carefully aligned. When an ACD or DCD is chosen, a fluid coupling is often required as well.

If the environment is acceptable, all of these components can be installed on the same foundation and close to the driven machine. In a harsh environment or a high-power application, however, the converter of an ACD or DCD must often be installed in an isolated, air-conditioned enclosure. Even the cables between the converter and the electric motor have to be shielded.

Moreover, high-power applications require external cooling and lubrication for the gear reducer. In the case of an ACD or DCD, forced cooling may also be required for the electric motor. In general, such accessories are not included in a drive supplier's quotation, but rather represent additional costs for the end user.

These complications are avoided when an HDD is chosen. The hydraulic motor mounts directly onto the driven shaft, which means that no foundation has to be built and no alignment is needed. There is no gear reducer or fluid coupling, and the drive unit can be installed in any convenient location, which reduces space requirements near the driven machine.

If air/oil cooling is required, the necessary components are included in the scope of supply. Thus, the only additional components needed for an HDD are the steel pipes and flexible hoses, which are necessary for the flow of oil between the drive unit and the hydraulic motor.

Power considerations

A number of additional installation issues are raised by the power connected to the drive system. These relate not only to the electricity coming in, but also to electrical pollution going out.

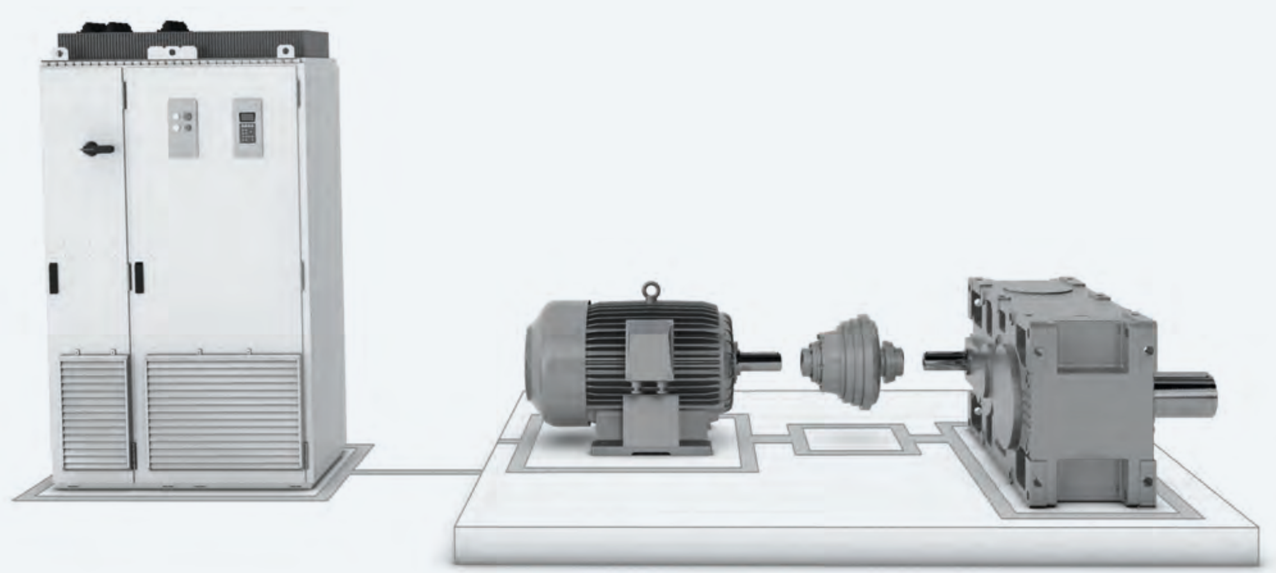
Many low-speed, high-torque drive applications involve low-voltage equipment of up to 690V. But in some installations and locations, medium-voltage equipment is required. In these cases, changes must be made to the drive system in order to accommodate the higher voltage.

With a hydraulic drive system, i.e. an HDD or HMD, such changes are generally limited to replacing the electric motor and the starter. But with an ACD or DCD, the starter, the converter and the drive motor itself must all be upgraded to operate at the higher voltage. The alternative is to install an additional transformer that converts the medium/high voltage to low voltage, but both options involve a substantial increase in the drive's cost.

In addition, there is the problem of harmonic distortion, a type of feedback pollution that occurs when non-linear loads are connected to the power distribution grid. These disturbance in voltage and current, if fed back into the mains supply, can severely damage other electrical equipment connected to the grid. Because they can destroy circuits and overheat transformers, cables and motors, there are usually heavy penalties for exceeding harmonic limits.

ACDs and DCDs frequently cause harmonic distortion, which means precautions must be taken to limit the disturbances if one of these drive types is chosen. Harmonics can be reduced either by structural modification within the drive system itself, or through the use of external filtering.

Hydraulic drives, which use only standard AC motors that operate continuously at the rated speed, do not produce any harmful harmonics. Thus when an HDD or HMD is used, no additional equipment is required.



▲ **Figure 9: Installation of a variable-speed AC or DC Drive.**

Over-dimensioning

To handle the demands of high-torque, low-speed applications, HMD, ACD and DCD systems must all be over-dimensioned. This protects them from the peaks associated with starting torque, shock loads and other operating factors, but it also creates built-in losses within the drive system that reduce efficiency.

Over-dimensioning of gear reducers

HMD, ACD and DCD systems all use gear reducers to achieve the c ombination of high torque and low speed. The size and type of gear reducer used is determined by aspects such as the application, type of prime mover, output torque, speed, number of starts per hour and required service life.

When selecting a gear reducer, the necessary output torque is multiplied by a service factor, thus increasing the drive's ability to handle operating peaks. Such service factors are specified according to application by all major gear reducer manufacturers. (See figure 10.)

For low-speed applications with continuous torque, the gear reducer is normally over-dimensioned by a factor of 1.4-2.5. In tougher applications involving frequent shock loads, however, the required service factor may be higher.

Application	Service factor
Drives with no peak loads	1.25–1.75
Drives with moderate peak loads	1.50–2.00
Drives with heavy peak loads	1.75–2.50

▲ **Figure 10: Examples of service factors.**

Gear reducer losses due to over-dimensioning

Gear reducer efficiency is normally expressed at rated conditions. The efficiency of a helical gear reducer, for example, can be said to fall in the range of 98-99% per gear stage at rated data. A planetary gear reducer has a similar efficiency of 97-98% per gear stage at rated data.

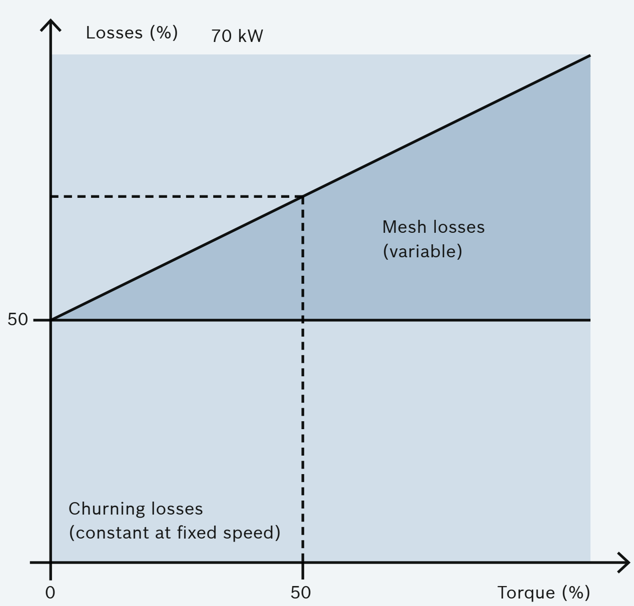
Yet because gear reducers are always over-dimensioned and a certain amount of loss is constant, their efficiency drops during normal operation. If the torque is reduced from 100% to 50% at fixed speed, approximately 75% of the losses remain. (See figure 11.) This means that the overall efficiency for a three-stage helical gear reducer falls in the range of 92-95% when operating at 50% of rated capacity. And for a three-stage planetary gear reducer with a 50% load, the efficiency drops to 88-90%.

Over-dimensioning of motors for starts and stops

Additional over-dimensioning is needed when an ACD or DCD is chosen for an application with frequent starts and stops. In these drive systems, where the electric motor itself controls the speed, the motor can only be started and stopped a certain number of times without overheating. Over-dimensioning of the motor is therefore needed when stops and starts are frequent, which adds further losses to the system.

Moreover, over-dimensioning is required if an ACD or DCD has to operate at a constant torque over a wide speed range, because these drive types have reduced continuous torque capacity at reduced speed. For the drive system to function under such parameters, more power must be installed or forced cooling of the electric motor must be introduced.

Such over-dimensioning is not necessary with an HDD or HMD, where the electric motor runs continuously and efficiently at the synchronised speed and is never stopped during operation. In a hydraulic system, it is the flow of oil from the variable-displacement pump that determines the speed and direction, and changes in these parameters are made by adjusting the signal to the pump's control unit. Starts and stops of the hydraulic motor are also controlled by the pump stroker, which means that the drive can start and stop as often as required.



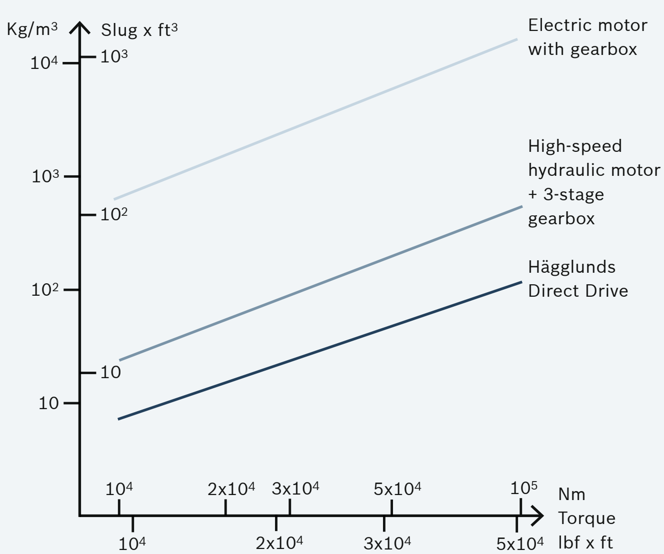
▲ **Figure 11: Sample gear reducer losses at 100 % and 50 % load and fixed speed.**

Operation

A drive's operating characteristics are crucial in meeting the needs of an application. The more demanding and varied the application and environment, the more robust and versatile the drive needs to be. This brings the differences between hydraulic and electro-mechanical systems into focus.

Moment of inertia and shock loads

Moment of inertia is a critical factor in many applications, especially in those involving shock loads. If a sudden stop occurs, the drive's moment of inertia can place extreme additional torque on the driven machine, straining not only the drive transmission but the shafts, couplings and bearings as well. This stress creates significant wear and tear, with high maintenance costs and reduced productivity as a result.



▲ **Figure 12: The moment of inertia for electro-mechanical and hydraulic drives.**

An ACD with its electric motor running at 1480/1760 rpm, for example, places tremendous force on both the gear reducer and the driven machine in the event of a sudden peak load. This stress becomes worse if the machine is forced to stop within a short distance, i.e. within a few degrees of shaft rotation. The moment of inertia at the driven shaft is that of the electric motor plus that of the coupling (if any), multiplied by the gear ratio squared: ^{J}driven shaft = (^{J}motor + ^{J}coupling) x gear ratio^{2}. Added to this is the moment of inertia of the gear reducer.

Both HMD and HDD systems have a far lower moment of inertia than an ACD or DCD system, but the fact that an HDD has no gear reducer gives it the greatest protection when it comes to shock loads. (See figure 12.) In fact, the moment of inertia of an HDD can be up to 1000 times lower than that of an ACD or DCD. Its maximum torque can be set at any desired level, thus protecting the drive and the driven machine from shock loads and limiting the stress on machine components, which increases their lifetime and reliability. (See figure 13.)

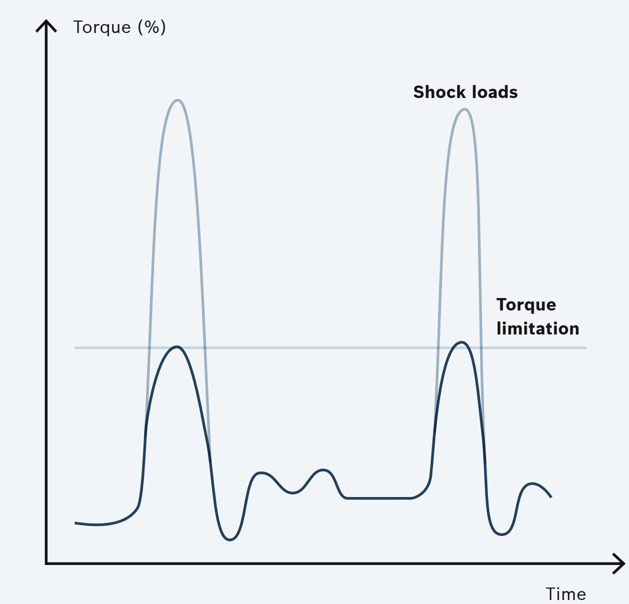
Four-quadrant operation

In certain applications, where energy needs to be absorbed by the machine, it is necessary for the drive to operate not only in forward and reverse, but also in both driving and braking mode. This is known as four-quadrant operation and it places unusual demands on a drive system. (See figure 14.)

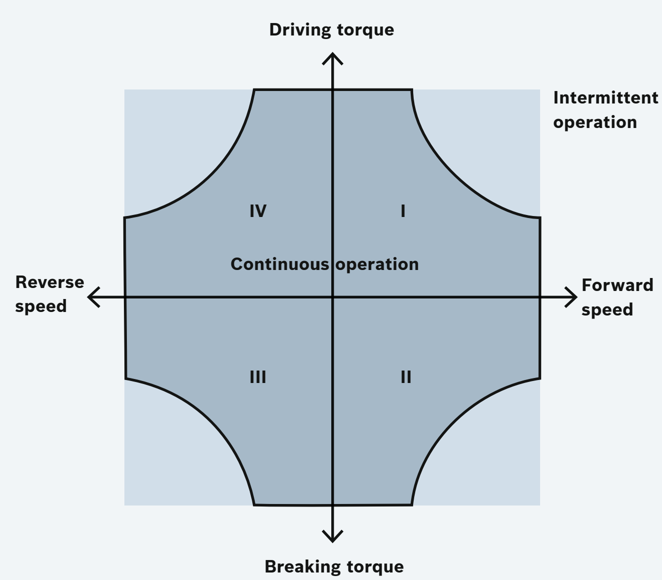
For an ACD or DCD to meet these demands, special equipment is required at an additional cost. Even with this equipment installed, it takes a long time to change the direction of rotation, because the mass in the drive transmission has to be stopped and re-accelerated.

When an HDD or HMD is chosen, four-quadrant operation is possible without any additional equipment. Hydraulic systems are able to switch automatically from driving to braking mode, and the direction of rotation can be changed quickly by changing the direction of the oil flow. An HDD reacts especially quickly, due to its very low moment of inertia.

Likewise, an HDD or HMD can be used in a regenerative drive system without any additional components.



▲ **Figure 13: Torque limitation in a Hydraulic Direct Drive.**



▲ **Figure 14: Four-quadrant operation.**

Efficiency

Determining the efficiency of an installation is one of the aspects of selecting a drive system. But efficiency depends on the interaction of complex variables, many of which tend to be miscalculated or overlooked altogether. To compare different drive systems fairly, all variables within a specific application must be considered. Also worth considering is the improvement in overall efficiency and productivity that might be made by the drive system's versatility and reliability.

Calculating efficiency

Put simply, a drive's efficiency is the relationship between the power it provides to the driven machine and the power it consumes. The relationship, however, is not a simple one to establish. It is difficult to determine the nature and extent of the losses, especially when the drive system itself is complicated.

When calculating power consumption, the only way to achieve an accurate value is to include all of the power-consuming components. These comprise not only the components in the drive transmission, but also the equipment for cooling, lubrication and electrical filtering. Any power consumer that is not directly included in the drive chain must be evaluated and factored in separately.

In addition, calculations of efficiency should be made using actual operating data, rather than the rated data for individual components. Operating efficiency is inevitably lower than rated efficiency, which means calculations based on rated data yield estimates built on faulty assumptions.

ACD and DCD efficiency

Due to its complexity, the efficiency of an ACD or DCD is especially hard to determine. The output power on the gear reducer shaft can only be measured with sophisticated equipment, and the losses in the system are difficult to assess.

Generally speaking, ACD or DCD efficiency is calculated using rated data instead of operating data. Exactly how much the efficiency is reduced in actual operation depends on how over-dimensioned the drive is, as well as on the type of gear reducer and the number of gear stages it has. The efficiency of a converter, electric motor and three-stage gear reducer drops considerably when calculated at 50% of rated data, for example, rather than at 100%. (For more on over-dimensioning, see pages 14-15.)

It is important to note that only the converter, motor and gear reducer are considered in most ACD and DCD calculations. Overlooked power consumers include components for lubricating and cooling the gear reducer, components for forced cooling of the motor, and components for cooling the converter. With many larger drives, the converter is also installed in a climate-controlled room, where a power-consuming fan is used for cooling and air filtration. (For more on these components, see page 12.)

In addition, an ACD or DCD generates harmonic distortion. The distortion itself causes losses in the motor, cables and transformer, and additional losses are caused by the electrical filters protecting the mains. These losses are difficult to pinpoint, but a drain of a few percent can be expected. (For more on harmonic distortion, see page 13.)

HDD and HMD efficiency

Compared to that of an ACD or DCD, the efficiency of a hydraulic drive is easy to establish. No special equipment is needed to measure the output power, and the components are simpler and fewer in number.

To determine the output power on the driven shaft, a simple mathematical formula can be used. The differential pressure at the hydraulic motor is multiplied by the shaft's speed, and this figure is divided by a constant.

As for losses, the power consumers are easily identified. If no gear reducer is used, the main consumers in a hydraulic drive are the AC induction motor, the pump and the hydraulic motor, with some further losses in the pipes due to pressure drops. Rather than consuming additional power, as in an ACD or DCD, cooling and filtration is part of the closed-loop hydraulic system, unless an extra air/oil cooler is used.

Applying the above to a continuous application with a normal operating pressure of 150-225 bars, the overall efficiency of an HDD falls in the same range as that of an ACD or DCD. And at higher levels of pressure, the efficiency of the system increases.

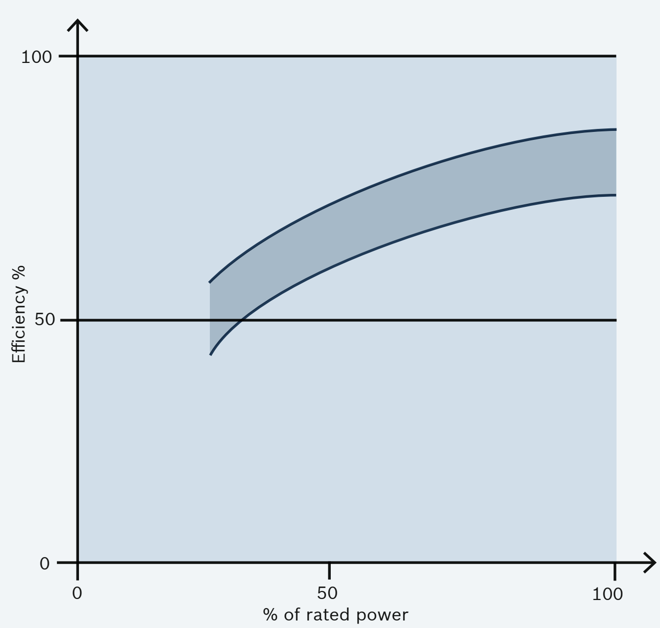
If a gear reducer is added, as in an HMD, the efficiency of the system is reduced. A high-speed hydraulic motor with a three-stage planetary gear reducer operating at 50% of its rated data has 8-10% less output power than a HDD motor of equivalent size. So to achieve the same output power as an HDD, an HMD's operating pressure or motor displacement must be increased by this percentage – a choice affecting either service life or cost.

Summary

It is impossible to say which drive consumes the most power in relation to its output. In low-power applications involving light to medium duties, an ACD or DCD with minimal over-dimensioning is probably most efficient. But in applications involving higher power and heavier duties, an HDD offers equal or perhaps even better efficiency, and certainly better versatility.

What is clear is that for a fair comparison of drive efficiency, all variables must be included. The total consumption of power must be measured or calculated, and attention must be paid to the application in focus and productivity as a whole.

In making a choice, the most important variables are the amount of over-dimensioning and the type of gear reducer needed to deal with application requirements.



▲ **Figure 15: Efficiency range Variable Speed Drives.**

Summary

Abbreviations
ACD: AC Drive
DCD: DC Drive
HDD: Hydraulic Direct Drive
HMD: Hydro-Mechanical Drive

Comparing drives with variable low speed and high torque

- Modern production demands put increasing pressure on drives.
- Variable-speed ACD are still the most common.
- Variable-speed HDD are gaining in popularity.
- HDD offer some unique advantages and are valued by heavy/process industries.

The Hägglunds solution

- The HDD is particularly effective in demanding applications.
- An HDD can sustain high torque even at minimum speed.
- Pump oil flow determines the speed and direction of the drive. Due to the hydraulic motor's low moment of inertia, response is almost instantaneous.
- A pre-set pressure-limiting function prevents maximum torque from being exceeded.
- The drive can operate in all four quadrants (driving, braking, forward and reverse) without the need for special accessories.

Geared solutions

- Geared drive solutions often require considerable space; a direct drive is much more compact.
- High additional torque from heavy shock loads can cause breakdowns. With a direct drive the additional load is negligible.
- With ACD and DCD, cooling capacity is reduced at lower speeds, which also reduces permitted continuous torque. There are no such limitations with HDD and HMD.

Installation

- HMD, ACD and DCD all require considerable space for the drive transmission, and installation work can be difficult and costly.
- In a harsh environment or a high-power application, the converter may require an isolated, air-conditioned enclosure. High-power applications require external cooling and lubrication for the gear reducer.
- These complications are avoided with an HDD. The hydraulic motor mounts directly onto the driven shaft, requiring no foundation or alignment. There is no gear reducer or fluid coupling, and the drive unit can be installed anywhere.
- Hydraulic drives produce no harmful harmonics; they use only standard AC motors that operate continuously at the rated speed.

Over-dimensioning

- Geared drive solutions need to be over-dimensioned in order to cope with shock loads and to be able to reach the required service life. This reduces efficiency during normal operation.
- Additional over-dimensioning is needed when an ACD or DCD is chosen for an application with frequent starts and stops, creating further performance losses.
- Over-dimensioning is also required if an ACD or DCD has to operate at a constant torque over a wide speed range. Such over-dimensioning is not necessary with an HDD or HMD; the electric motor always runs at the synchronised speed and is never stopped during operation.

Operation

- If a sudden stop occurs, the drive's moment of inertia can place extreme additional torque, and great stress, on the driven machine.
- Both HMD and HDD systems have a far lower moment of inertia than ACD or DCD systems. An HDD has no gear reducer, giving the greatest protection against shock loads.

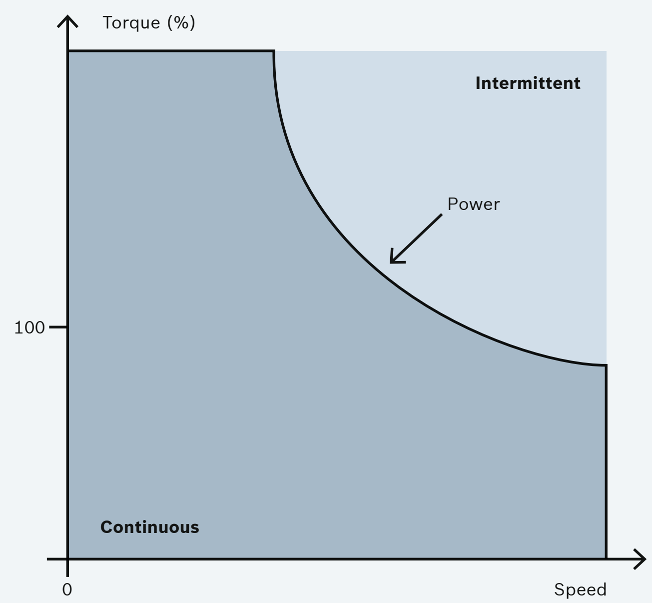
- An HDD’s maximum torque can be set at any desired level, protecting the drive and the driven machine from shock loads and limiting stress on components.
- Four-quadrant operation places unusual demands on a drive system, for which ACDs and DCDs require special equipment.
- With an HMD, the gear reducer must be selected and dimensioned for a four-quadrant operation.
- With an HDD, four-quadrant operation is possible without any additional or special equipment.

Efficiency

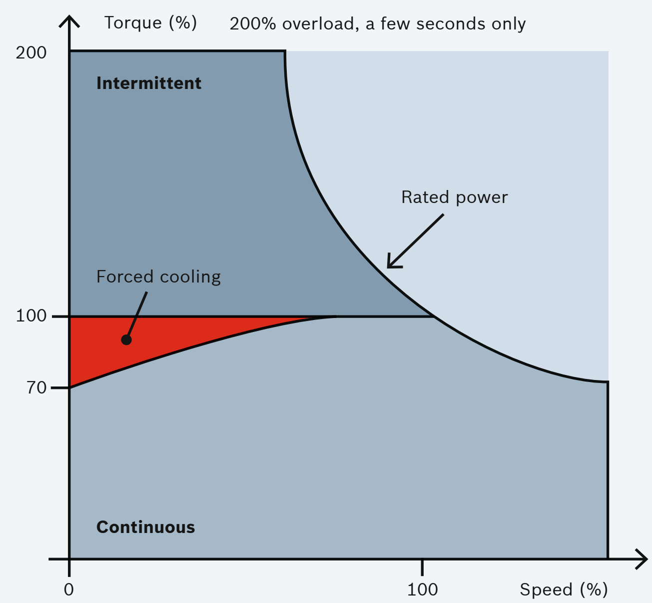
- Due to its complexity, the efficiency of an ACD or DCD is hard to determine. Sophisticated equipment is needed, and losses in the system are difficult to assess.
- The efficiency of a hydraulic drive is easy to establish, with no special equipment needed.
- It is impossible to say which drive consumes the most power in relation to its output.
- In making a choice, the most important variables are the amount of over-dimensioning and the type of gear reducer needed to deal with application requirements.

Comparative overview

Characteristic	Hydraulic Direct Drive (HDD)	Hydro-Mechanical Drive (HMD)
Starting torque	200-300%	200-300%
Standstill time at load	Unlimited	Unlimited
Torque capacity throughout speed range	Full torque	Full torque
Sensitivity to shock loads	Not sensitive	Sensitive
Safety coupling due to shock loads	Not required	Not required
Variable speed	Yes	Yes
Bi-directional drive	Yes	Yes (maybe special gear reducer)
Four-quadrant drive	Yes	Yes (maybe special gear reducer)
Gear reducer required	No	Yes
Foundation required	No	No
Moment of inertia	1	30-100
Weight of units connected to driven shaft	Low	Higher (dependent on gear reducer size)
Size at driven shaft	Very compact	Longer axis than direct drive
Sensitivity to harsh environment	Not sensitive	Not sensitive
Harmonic distortion	No	No



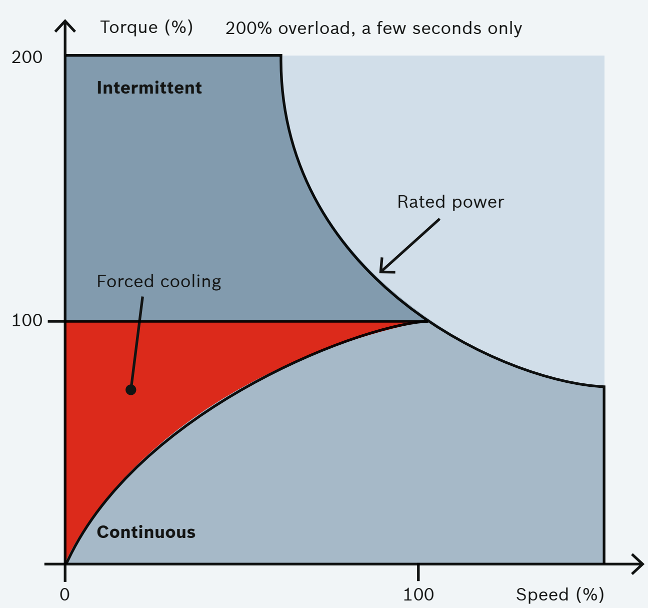
▲ **HDD and HMD**



▲ **ACD**

The table presented here is a quick reference covering the characteristics of low-speed, high-torque drives. It allows an at-a-glance comparison of the different drive types, both in terms of their construction and their operational advantages.

	Variable-speed AC Drive (ACD)	Variable-speed DC Drive (DCD)
	200% for a limited time	200% for a limited time
	Limited (due to motor overheating)	Limited (due to motor overheating)
	Reduced torque at lower speed	Reduced torque at lower speed
	Very sensitive	Very sensitive
	Required (unless drive is over-dimensioned)	Required (unless drive is over-dimensioned)
	Yes	Yes
	Yes (maybe special gear reducer)	Yes (maybe special gear reducer)
	Special equipment required	Special equipment required
	Yes	Yes
	Yes (unless a torque-arm-mounted gear reducer is used)	Yes (unless a torque-arm-mounted gear reducer is used)
	100-1000	100-1000
	Higher (dependent on drive size, foundation, etc.)	Higher (dependent on drive size, foundation, etc.)
	Bulky (especially at higher power)	Bulky (especially at higher power)
	Converter must be insulated or installed in an air-conditioned room	Very sensitive
	Yes (low-harmonic converter or filter required)	Yes (low-harmonic converter or filter required)



▲ **DCD**

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R999000409A (2014-04)

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