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"AC Motors Replace Hydraulics and DC Motors for Heavy Structures"

by

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AC vs. Hydraulics

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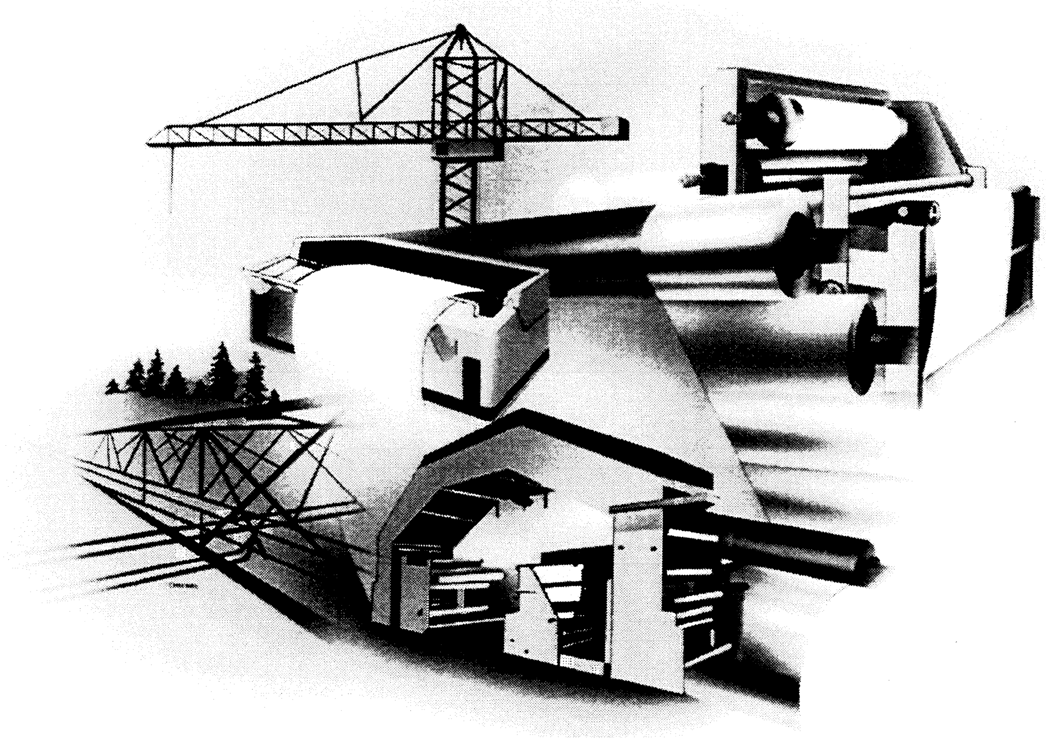


This presentation examines the technological developments that make it feasible to replace hydraulics and DC servo motors with AC motors in heavy movable structure applications. Such retrofitting of old, but mechanically sound equipment with conventional induction motors and/or flux vector servo controls affect safety, production capability and productivity, and environmental issues, and also extends that equipment's useful economic life by bringing performance up to the standards of new machines.

We begin our examination by describing the benefits of AC motor technology over DC or hydraulic motors. The application of AC motors in place of either hydraulics or DC motors affects the reliability, serviceability, and life span of equipment. In addition, deploying AC motors also impacts safety and environmental issues.

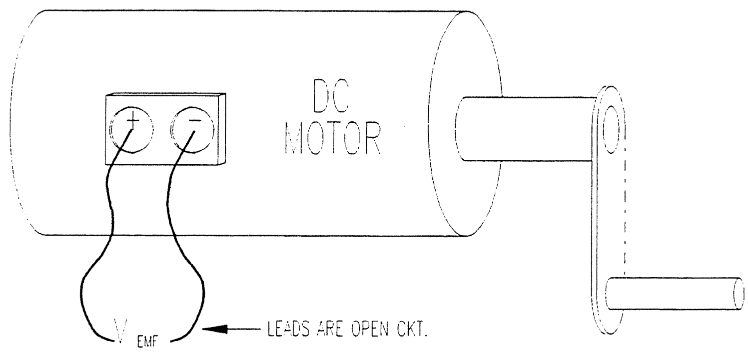
Many heavy structure applications now employing hydraulics, and a preponderance of the situations now using DC motors and controls, will benefit when retrofitted with AC induction motors and/or control systems. AC motors are safer than hydraulics, more dependable, and less expensive to maintain than DC motors AC motors do at least as good a job of positioning and regulating, at a lower initial cost.

For large horsepower motor, positioning applications, you can successfully apply induction servo solutions to motors up to 1200 HP. In addition, they may have overload capacities exceeding 64,000 lb-in at 1800 rpm. This positioning or regulating market is unserved today by standard AC control solutions.

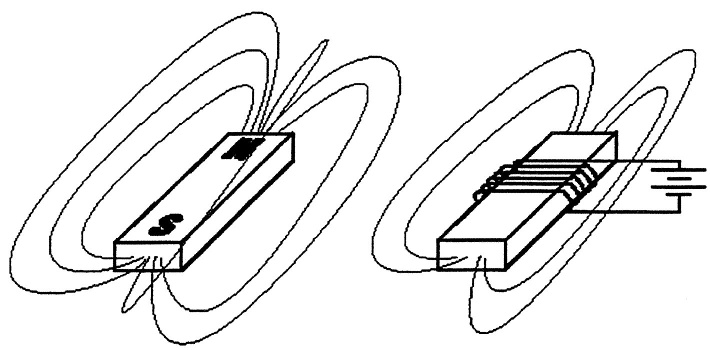
Motor technology review

Magnets and Motors

A hydraulic motor develops torque by directing the flow of hydraulic fluid at the rotor vanes, making most effective use of the fluid forces. Similarly, electric motors develop torque by directing the magnetic forces created by the electrical currents in the machine. In fact, the Latin word 'flux,' which is used to describe the lines of magnetic force, means 'flow.'



All electric motors -- AC, DC, permanent magnet, switch reluctance, or others -- work by manipulating magnetic forces. Both permanent magnets and electromagnets create magnetic force. 'Refrigerator magnets' are permanent magnets. Wrapping a coil of wire around a piece of iron forms an electromagnet.



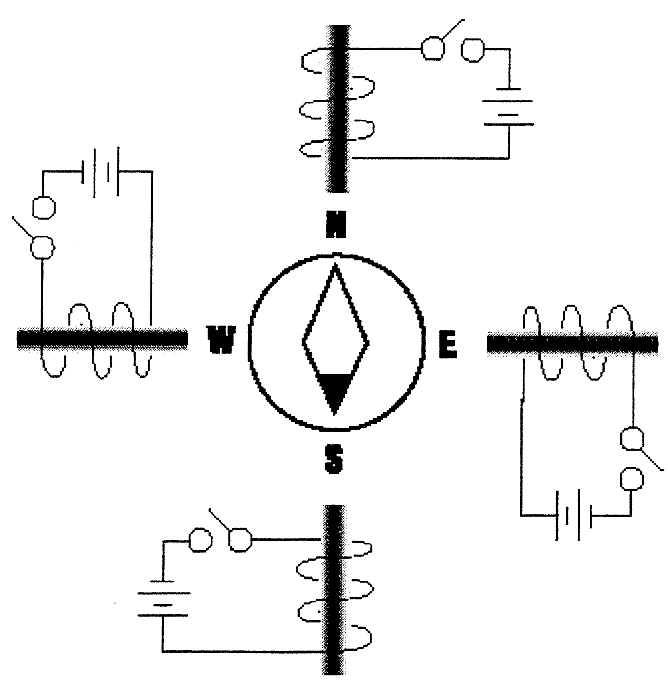
Permanent Magnet **Electro Magnet**

The magnetic fields produced by a permanent magnet and an electromagnet are indistinguishable except for one thing. The electromagnet can be controlled – turned on and off, increased or decreased, even reversed, whereas the permanent magnet is permanent.

Why it Spins

Imagine a compass mounted on a table, with each of four electromagnets around its periphery pointed at a different one of the compass' cardinal points (N, S, E, and W). Each electromagnet coil is attached to a battery through a switch. Each time a switch is closed the compass needle jumps to that position. Close the north switch and the needle points to 'N'. Close the east switch (while opening the north) and the needle points to 'E,' and the same with south and west. Closing the switches in this circular pattern in rapid succession will rotate the needle.

Now arrange the switches so that when the needle points north, it turns on the east switch; when the needle points east, it turns on the south switch; south, the west; and west the north switch.



Now clearly the needle will spin. Each time it reaches a target destination there is a new target, and the needle keeps spinning.

Like the mechanical rabbit at the dog track, the magnetic field of the switched electromagnets stays just one jump ahead of the pursuing needle.

Fundamentally all electric motors work like that compass needle. In the conventional DC motor, the permanent magnet is in the case and the switched electromagnet in on the rotor. The switched part of a motor is called the armature. The commutator-and-brushes-assembly switches the current to the coils in the DC motor armature slots. Then, like the compass switch example, the magnetic field of the armature is always chasing the field, but is never allowed to catch it.

Generator = Motor

Turn the shaft of a hydraulic motor and the motor pumps fluid. Turn the shaft on an electric motor and it generates electricity. Just as some hydraulic motors make better pumps than others do, some electric motors make better generators of electricity. Permanent magnet DC motors make excellent generators: the voltage out is directly proportional to the speed.

II. AC Flux Vector Technology

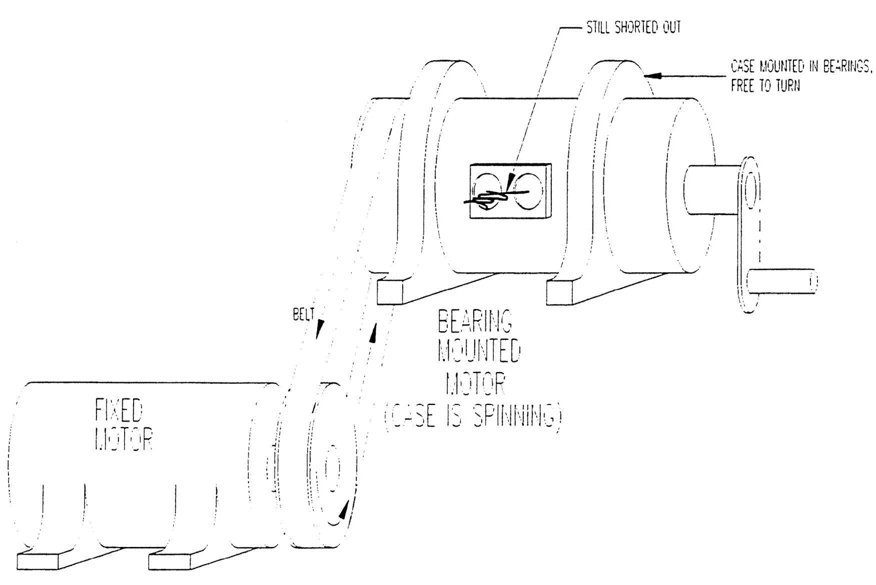
How Vector Control Works

Imagine a permanent magnet DC motor with a crank handle on the shaft. Turn the crank and the motor generates a voltage (V_{emf}) at its terminals proportional to the speed. The terminal leads are unconnected, so no current flows. No current means no torque and the crank is easy to turn.

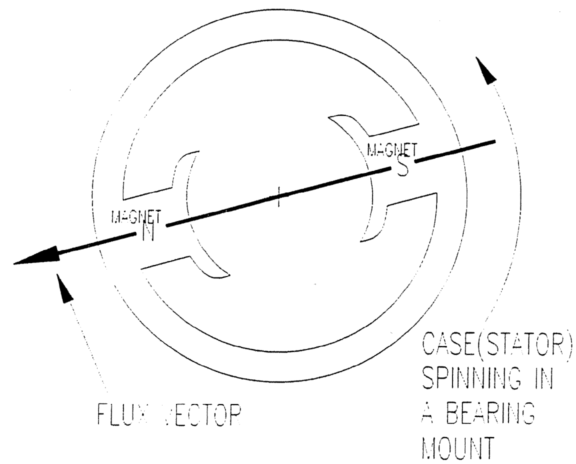
Now, short out the motor leads. Current (I_a) flows in the armature circuit when the crank is turned. The motor produces torque proportional to armature current. The crank now becomes harder to turn. The faster it turns, the harder it resists. That is because:

- Torque is proportional to current.
- Current is proportional to voltage.
- Voltage is proportional to speed.

THEREFORE, torque is proportional to Speed for a shorted DC motor. Presented graphically this is a straight line.



Imagine that this DC motor with the shorted terminals is mounted in bearings. The motor case is now free to rotate. Imagine that a second fixed motor is mechanically connected so it can spin our shorted DC motor's case. As the case spins, so spins the field (flux vector) of the permanent magnet. Note that the unloaded shaft of the shorted DC motor is spinning along with the case.



HOWEVER, the spinning motor knows only the relative speed between the case and the rotor. Loading the shaft of the shorted DC motor will slow the shaft. In order to develop torque, there must be armature current. To get current, there must be voltage. To get voltage, there must be speed difference between the rotating motor case and the shaft. The amount of the speed difference (slip) is proportional to the load torque. (Remember that the motor's terminals remain shorted!)

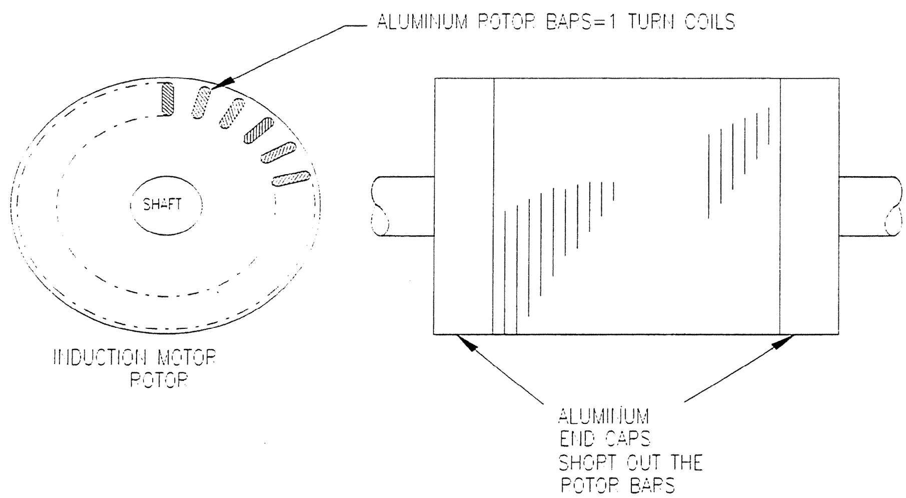
To maintain the shaft speed as the load increases, it is necessary to similarly increase the speed of the case by the amount of slip needed to balance the load torque.

Even though under load the mechanical rotor is spinning slower than the case, the commutator assembly maintains the 90° angle between the stator (case) field and the rotor (armature) field.

WHY 90°? The angle that gives the most torque per amp of current is 90°.

Induction Motor

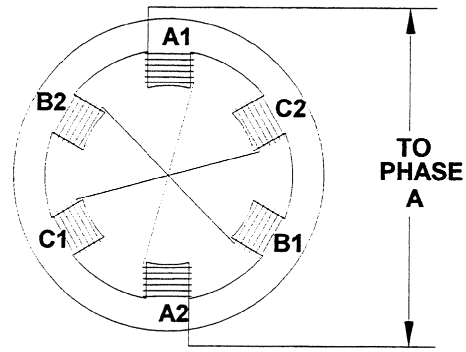
Induction motors have a "Squirrel Cage" rotor that is like the shorted out DC motor armature. However, there is no commutator assembly to maintain the field 90° relationship.



The stator windings of the induction motor can be energized to make a rotating magnetic field that is exactly like the rotating case of the shorted DC motor.

The three motor phases are connected to a three phase current source that produces a rotating magnetic field.

3-PHASE MOTOR WINDINGS



Induction Motor Stator

To the rotor placed within it, this rotating magnetic field is indistinguishable from the field produced by the spinning DC motor case.

Therefore, to produce torque at the shaft, rotate the stator magnetic field faster (or slower) than the rotor is spinning. The varying speed generates rotor voltage, which generates the torque producing rotor currents. Note that it makes no difference how fast or slow the rotor is spinning. In fact, the rotor need not be spinning at all. Only the Relative Speed (slip) between the stator's rotating magnetic field and the rotor is important.

Torque is proportional to Slip Frequency, and current is proportional to Torque,

- REGARDLESS OF SPEED OR DIRECTION!
- This includes ZERO SPEED.

It's like algebra -- Zero (0) is just another number like +1 or -1 or +1800 or -1800.

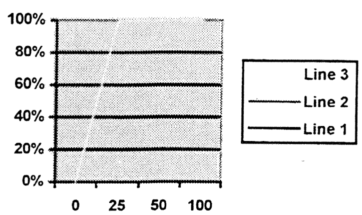
The Thor Vector Drive will produce full torque.

An induction motor only needs SLIP and CURRENT to produce TORQUE. Read the nameplate. The NAMEPLATE specifies the amount of slip and current needed to produce full load.

Benefits of Vector Control	
Full torque at zero speed	Ensures load positioning capacity
Full torque at rated speed	Precludes need for special motors
Full range torque control	Adjustable: available from 150% motoring to zero to 150% braking With no deadband
Instantaneous torque transient response	No zero-lag in torque control loop

Advantages of AC vs. DC Technology

Advances in motor modeling, power electronics, and software algorithms make it possible to have an AC drive system, motor and control, that provides many of the benefits of DC technology, while eliminating its encumbering disadvantages. Following is a comparison of these points. The basis for comparison for DC is a wound-field, four-pole motor; for AC, it is a squirrel-cage, three-phase, four-pole induction motor.



Advantages of AC

- Lower installation costs
- Lower maintenance costs
- Smaller motor size
- Better suited to hostile environments
- Better power factor and line harmonics
- Better motor thermals
- Provide over-speed capabilities
- Standard motor solutions

Torque/HP Comparison

Figures 1 & 2 show speed vs. torque curves for both DC and AC vector drives. As long as the motor cooling is dependent on motor speed, the low speed limit of the constant torque speed range is a thermal limit. By providing separate cooling, that is independent of the rotational speed of the motor, extended low speed operation can be obtained.

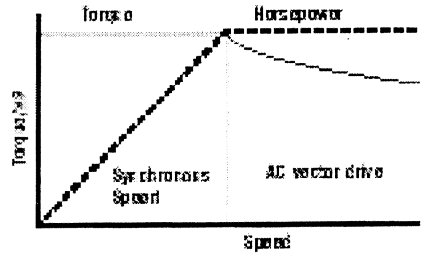


Figure 1

In the DC machine with speed independent cooling, the constant torque region can be extended from base speed down to near zero. Although the DC machine can produce full torque at zero speed, doing so will produce localized heating of the commutator.

TORQUE/HP COMPARISON

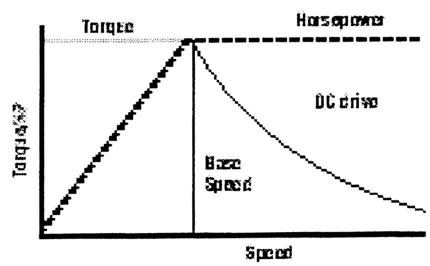


Figure 2

This will cause premature motor failure. For this reason, DC motors are not rated for 100% torque at zero speed. Conversely the limitations on the upper speed, constant horsepower range are determined by the ability of the motor to commutate the current without destroying the brushes or result in a dielectric breakdown between the commutator bars of the motor.

Advantages of DC			
	AC	DC	Thor S7000
Positioning capability	Poor	Good	Good
Handling of high starting torque loads	Poor	Excellent	Excellent
Handling of shock loads	Poor	Excellent	Excellent
Speed regulation	Not Precise	Precise	Precise
Constant torque applications	Good	Excellent	Excellent
Dynamic braking	Poor	Excellent	Excellent

The development of the field-oriented AC flux vector controls around 1969 made it possible to control both the flux and torque-producing currents within an induction machine. The result was the ability to provide 100% constant torque from base speed down to zero speed. The thermal limitation of the motor is the limiting factor for a drive system to reliably achieve 100% torque at zero speed. As a result of recent advances in vector duty motors, commercially available motors can produce 100% torque at zero speed constantly without damaging the motor. In the constant horsepower range, the limitations on the upper speed range is the flux level within the motor, which becomes effectively inversely proportional to percent motor speed.

Costs of AC vs. DC Systems

DC motors require a higher initial capital expenditure, because of the added complexity of the armature. Also the construction of the DC machine is such that all of the power is dissipated in the rotor, which has the windings and is in the middle of the machine. Because the stator is mounted around the rotor, heat must go through the stator to dissipate on the skin of the motor. To cool the motor, large blowers are required to move air through the machine to dissipate the heat. Because of this, producing totally enclosed motors above 5 HP becomes impractical, and in some cases, physically impossible. This makes them a poor choice in explosion proof, wash down, or marine applications.

The AC machine has the power carrying component -- the windings -- located on the stator. This is mounted directly on the skin of the motor, and allows for good thermal transfer. It also permits motor manufacturers to produce higher-horsepower, totally enclosed motors cheaper than their DC counterparts. Because of this, AC machines are more cost effective than DC in explosion proof, wash down, or marine, applications where environmental sealing requirements are high.

V. AC versus Hydraulics

Advantages of AC vs. Hydraulics Technology

As with the DC solution, advances in AC control technology have allowed it to provide many benefits, while eliminating several deficiencies of the hydraulic solution.

AC vs. Hydraulics		
	AC	Hydraulics
Environmental impact	None	Potential Hazard
Installation	Easier, low cost	More complex
Maintenance	Low	Continuous
Accuracy & repeatability	High	Based on fluid conditions
Energy Efficiency	High	Low

Environmental Impact

Because of concerns regarding pollution to ground water supplies, the Environmental Protection Agency (EPA) tightened regulations surrounding the use of hydraulic fluids. By converting installations to solid state controls, users can not only reduce the risk of damage to the environment and the accompanying fines, but also can greatly reduce or eliminate governmental paper work, such as Material Safety Datasheets that are required when using hydraulics.

Energy Efficient

The efficiency of the AC flux vector controller is between 96% and 98% compared to pump efficiencies in the 70% to 90% range. However, ultimately either system must match the speed and torque requirements of the load. counterpart.

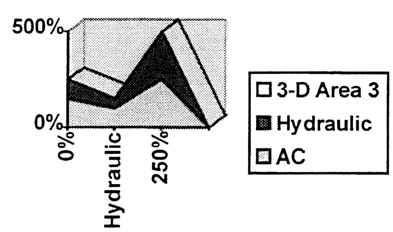
This results in lower energy usage and shorter payback periods on capital investments.

Component Comparison	
Hydraulic system	Flux Vector system
Hoses	Control
Tubes	Motor
Filters	Gearbox
Cylinders	
Heat exchangers	
Tanks	
valves	

Installation

The hydraulic system employs a series of complex hose networks, tubes, filters, cylinders, heat exchangers, tanks, and valves. These are necessary to enable one or more pumps to drive all of the machine's movement. By contrast, the flux vector solution consists of a motor, control, and possibly a gear box. (SCHEMATIC OF SCHEME) Because of the high starting torque and wide speed-range of the flux vector control, it may be economically feasible to eliminate the gearbox altogether, thus eliminating both additional cost and a potential source of mechanical wear-and-tear.

Maintenance



An extensive preventative maintenance system must be in place with the hydraulic system to insure continued safe operation. The AC flux vector solution can provide years of maintenance-free operation

Accuracy & Repeatability

The accuracy and repeatability of the hydraulic system over time is a function of the viscosity, compressibility, degradation, and thermal properties of the fluid. Changing ambient conditions can also adversely affect the performance of the hydraulic system. AC flux vector technology can provide superior positioning and repeatability over a wide range of environmental conditions that will not be effected by time of use factors.

V. Specifying Flux Vector Solutions

Bridge applications

Specifying AC flux vector controls in bridge applications requires answers to some relatively simple questions.

1. What torque is required to move the bridge?
2. How fast must the bridge move up and down?
3. What power distribution is available: AC, DC, voltage ratings, and current capability.
4. What are the environmental considerations?
   - Ambient temperature
   - Humidity
5. What is the duty cycle of the bridge?
6. Is there any space limitation for the motor or control?
7. Are there regulatory issues for installation:
   - UL, CSA, NEMA, NEC, others?
8. Are there bypass requirements, in the event of a control failure?
9. Are there interlock or safety considerations that need to be considered, such as fail safe mechanisms for power loss?

Torque and Gearing

The force needed to lift a bridge is the same whether it is provided by a hydraulic, DC, or AC electric motor. The speed at which the bridge can be lifted also does not depend upon the motor type. The mechanical design process of determining what it takes to lift the bridge (counter-weighted or not) is the same. The difference is in the gearing. Hydraulic systems, to be efficient, operate at high pressure and low flow rate. For this reason, hydraulic motors tend to be low speed, high torque devices. Typical hydraulic motor rated speeds range from 30rpm to 800rpm. Although electric induction motors can be designed for almost any rated speed, the motors commercially available have rated speeds of 900rpm, 1200rpm, or 1800rpm.

Remember: the rated speed of an induction motor determines the constant torque range of the vector drive.

Consequently, an electric drive generally requires a higher gear reduction.

Holding Brake

Safety requires a holding brake that can support the bridge when electric power fails. These are usually disk or drum brakes with a 'spring-set power-release' mechanism, either air or electrically operated. A spring holds the pads against the disk (or the shoes against the drum), which sets the brake. Applying current to a solenoid releases the brake by compressing the spring and releasing the brake. Therefore, if electrical power is lost, the brake will set. Such a brake can be interlocked with fault detection circuitry to provide safe operation.

An AC flux vector electric drive can hold a bridge in position with the force of the motor alone, this is never used as the primary means of supporting a bridge. Nevertheless, the ability to support the weight of the bridge with the drive torque alone affords a means of greatly reducing brake wear and increasing safety. Brake wear is reduced by allowing the flux vector drive to bring the bridge to position before setting the brake. Energizing the drive before releasing the brake eliminates the 'droop.'

Site Planning

Consideration of the electrical power distribution system, the temperature and humidity, space requirements, atmospheric conditions, etc. all fall under 'site planning'.

The bridge is outdoors. The motor operating the bridge and its associated gearing will be outdoors, generally exposed to the elements. If these 'elements' include salt water, ice and snow, or sand, the motor must be appropriately selected.

Flux vector drive controllers need to be in a clean, dry, and temperate location. Avoid dust (particularly conductive dust like iron or graphite), corrosive vapors, moisture, oil mist, salt spray, and condensation. Outdoor use requires enclosing the drive controller in a protective cabinet rated for outdoor use (such as NEMA 4, 4x or IP66).

Shield enclosures from direct sunlight and other radiant heat sources. Paint the enclosure a reflective white so it does not absorb solar heat.

The drive controllers produce some heat when running the motor. The drive ratings state the amount of heat produced by the drive controller at full-load, including heat created by fans, contactors, and transformers, as well as the power components. The drive controller units can withstand an operating temperature range of 0°C (32°F) to 50°C (122°F). When mounting the drive controller in a sealed cabinet (NEMA 4, 4x, IP66, etc.), either make the cabinet large enough to dissipate the heat through its surface area, or equip it with an air-to-air powered heat exchanger or an air-conditioning unit.

Consider locating the control units in a building near the bridge. If the building atmosphere contains no corrosive vapors, excessive moisture, oil mist, or other atmospheric contaminants, then a ventilated enclosure with air filters may be acceptable. Plan for enough air flow to remove the heat, even with a dirty air filter. An 'indoor' location has the added advantage of being a relatively comfortable location to do service or setup. Put a preventative maintenance program in place to clean or replace the air filters on a schedule.

Some installations will require cabinet heaters to keep the operating temperature and humidity within range.

Installation and Setup

A lot of excellent electronic equipment is ruined at the job site awaiting installation. This is particularly true of outdoor applications.

VI. Retrofitting Hydraulic systems with Flux Vector Controls

In general the power rating of an electrical flux vector drive system to move a given load will be the same or less than the equivalent hydraulic system. The reason is clear. The hydraulic system has an electric motor driving a pump. This drives the hydraulic motor, which drives the load. The electric drive system has a flux vector control driving the motor, which drives the load.

The efficiency of the flux vector controller is between 96% and 98% compared to pump efficiencies in the 70% to 90% range. However, ultimately either system must match the speed and torque requirements of the load.

VII. Maintaining Flux Vector Systems

Maintenance-free service

When proper steps are taken during system design and installation, the AC flux vector system can provide years of maintenance-free service.

Only two parts of the system require a maintenance schedule: the filter medium on any air conditioning system used for cooling the control enclosure; and gear boxes, if they are part of the design.

VIII. Summary

AC Flux Vector Servo Control

Vector control using flux vector drives is not generally understood.

We can quickly summarize the benefits of vector control by listing four features:

Full Torque at zero speed.

- This ensures load positioning capacity

Full torque at rated speed.

- This precludes the need for special voltage motors.

Full-range torque control.

- Adjustable torque control is available from 150% motoring to zero to 150% braking with no deadband.

Instantaneous torque transient response.

- There is zero lag in the torque control loop.

Features built-in to this unique, high-performance control include positioning-indexing, load sharing, 100% torque at 0-RPM with a 1000:1 Constant Torque Speed Range, 150% torque for "one minute at zero speed," and brake interface allowing precise positioning and unique torque control capabilities for many applications. All of this can be achieved using a standard, inexpensive induction motor with an encoder.

AC Flux Vector controls are efficient and cost-effective replacements for applications demanding high starting torque, wide speed range and fast dynamic response. In addition to hydraulic drives, these include closed loop DC, eddy current, mechanical, and most servo drives.

Among the many advantages and benefits:

- lower operating costs
- use of economical, low maintenance AC induction motors
- use in environments requiring totally enclosed and/or explosion-proof motors (important for equipment washdown).
- easier and quicker set-up and start-up than alternative drive systems
- speed and torque control and response performance that exceeds the capabilities of other drives
- speed range up to 100 times greater than DC, eddy current, inverter or brushless drives
- precision servo position control
- significant reduction in harmonic line disturbances
- better protection against short-circuit type faults than other systems

In both commercial and industrial applications, this flux vector solution:

- prolongs useful life of aging equipment
- improves coordination between various pieces of equipment
- eliminates environmental hazard of spilled hydraulic fluid
- lowers maintenance costs
- is energy efficient