Paper No. 39

Electrical/Electronic Components

Adjustable Speed Solid State Drives For Heavy Movable Structures

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TENTH BIENNIAL SYMPOSIUM

OCTOBER 25 - 28, 2004
The Omni Orlando Resort at ChampionsGate

ABSTRACT

The requirements for new construction or modernization of present Heavy Moveable Structures is the result of modern traffic growth demands in this growing industry. The use of Adjustable Speed Solid State Drive systems for the Heavy Moveable Structures should be a strong consideration as it provides benefits in bridge operating efficiency as well as speed of operation, and precise control.

This paper will compare three different types of Adjustable Speed Solid State Drives – DC Regenerative, AC drive with Electronic Braking, and the AC drive with line regenerative braking. The basic drive advantages, costs vs. energy usage, Power Factor, system efficiencies & losses, performance characteristics of these three major systems utilized in Heavy Moveable Structure applications will be compared. This comparison will be shown for three different speed points (i.e. full speed, 1/10 positioning speed, and locking mode zero speed) all done under respective load conditions. A brief discussion will also be on drive/motor considerations and system interface logic will be discussed.

TYPES OF CONTROL

D.C. SOLID STATE DRIVE SYSTEM

(Hear after called SCR)

The D.C. SCR system is versatile, economical, and very responsive system for Movable Structures & Bridge applications. SCR Drives offer control information that can be utilized by the bridge control logic to achieve smoother more efficient control of the bridge and lend itself to Multi-motor applications. The following are some typical single line block diagrams and the advantages of each type for Movable Structures & Bridge applications.

A. Single Drive / Multi-motor operation

This configuration utilizes one drive and two motors mechanically connected to a common drive shaft. There are two approaches to this application and they are as follows.

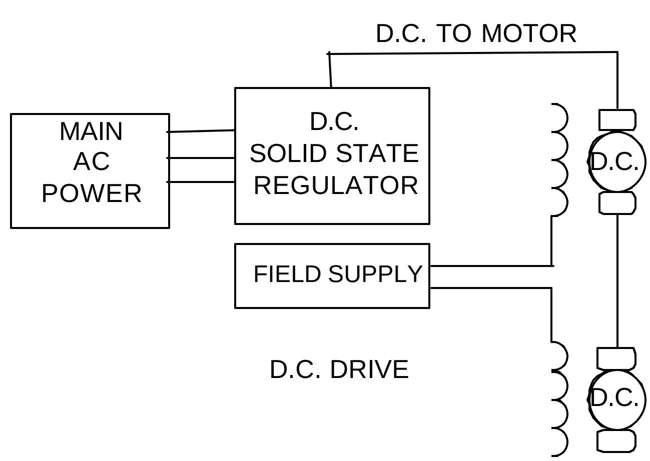
METHOD #1

ADVANTAGE

1) Simple circuitry
2) Since armatures are in series system has Inherent load-sharing.

DISADVANTAGE

1) Since both motors are in series if one motor fails system is down and backup Mode of operation is required.



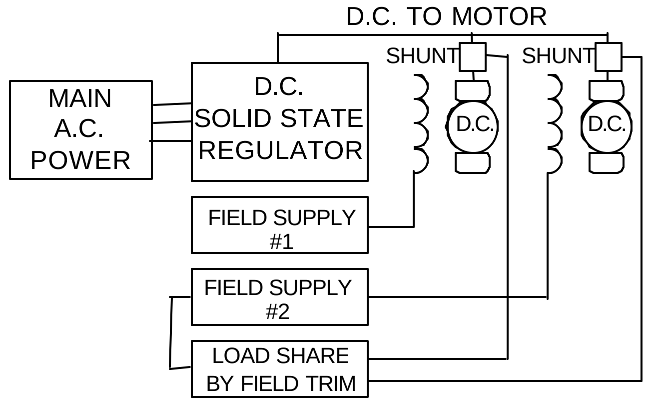
METHOD #2

ADVANTAGE

1) Backup capability. Depending on torque requirements and HP rating, if one motor is inoperative, second motor can still operate system.

DISADVANTAGE

1) Motor electrical characteristics must be closely matched or additional circuitry may be required (typically 3-5% variance is acceptable).



B. Multi-Drive / Multi-motor operation

One configuration utilizes one drive per motor and the motors are mechanically connected through a common line shaft. The following example is an application of this approach.

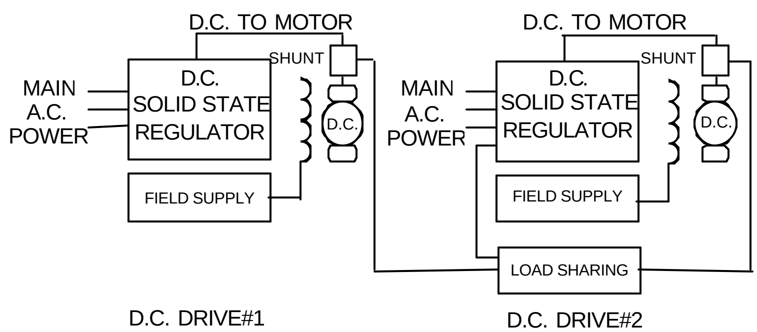
METHOD #3

ADVANTAGES

1) 100% redundancy in electronics.
2) Individual trim capability to insure motor equal load.

DISADVATAGES

1) Requires dual elect. package and motors.



It is important to note that this type control requires a common drive shaft configuration to insure that motor shaft speeds are identical and load sharing is the important key in this approach. Since equal distribution of the motor load (torque) is the main benefit in this approach, Bascule lift bridges with dual motors per leaf typically utilize this method.

The forth configuration utilizing one drive per motor configuration and is utilized in a speed matching scheme. The following is an example of this type control system

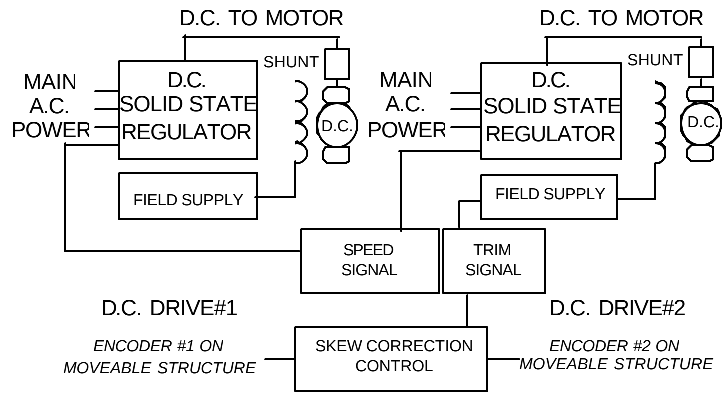
METHOD #4

ADVANTAGES

1) 100% redundancy in electronics.
2) Trim capability to insure motor speed match.

DISADVANTAGES

1) Requires elect. package for each motor.
2) Both drives & motors must be operational *(redundant drives typically utilized)*.



AC ADJUSTABLE SPEED DRIVE SYSTEMS

(Hear after called ASD)

Adjustable Speed AC drives offer some basic advantages in today's applications. It should be noted that the basic operation characteristics of today's ASD's remain much the same as DC systems such as speed range and available low end torque capability of the drives are comparable.

There are three basic technologies available today in ASD design and only two of them are normally utilized in Heavy moveable Structure drive designs.

1. **V/F technology** - A V/F drive today is the basic inverter offering used in today's markets for general applications and single drive / multi-motor applications. It provides a very reliable drive since it offers mature technology. Its speed range is generally limited to between 2:1 to 10:1. The basic V/F drive has the ability to improve motor speed regulation through the drive's software beyond the typical 3-5% slip found in most standard AC motors.

2. **Sensor-less Flux Vector *(torque)* technology** - This approach to drive technology is an improved version of the basic V/F drive technology and offers the distinct advantage of improved torque control especially at low speed. As a result of this feature, a wider speed range of typically 50:1 is achievable. Basic applications include machines requiring high breakaway torque conditions. Typically single drive / multi-motor applications do not utilize this technology since the drive is tuned for an individual motor. It should be noted that the motor design plays an important part in utilizing the wide speed range achievable by this drive technology.

3. **Flux Vector control** - The top-level drive is referred to as closed loop Flux Vector *(torque)* Control. With the advancements made in today's digital drive technology this approach is becoming very affordable while offering a distinct advantage in performance at zero or near zero speed. The speed range of this control is typically 1000:1 but depending on motor ability may be as much as 2000:1. By fine tuning the drive on the actual application, operation down to true zero speed is possible. Basic applications include Bridge & Crane systems and precision machines requiring very fine control. It should be noted that the motor design and a separate feedback device (i.e. encoder) play an important part in utilizing the wide speed range achievable by this drive technology.

The Sensor-less Vector and Flux vector both lend themselves to Heavy Moveable Structure applications as they offer the ability to control both speed and torque. In single motor bridge systems (i.e. Swing bridges) the open loop Sensor-less Drives performs very satisfactorily. The Flux Vector control offers the highest degree of control and it requires a independent device providing actual shaft speed. This element along with the ASD's ability to accurately control true torque provides equal performance to the DC drive approach with encoder feedback.
The following is a basic single line diagram of a Flux Vector ASD utilized in bridge operations.

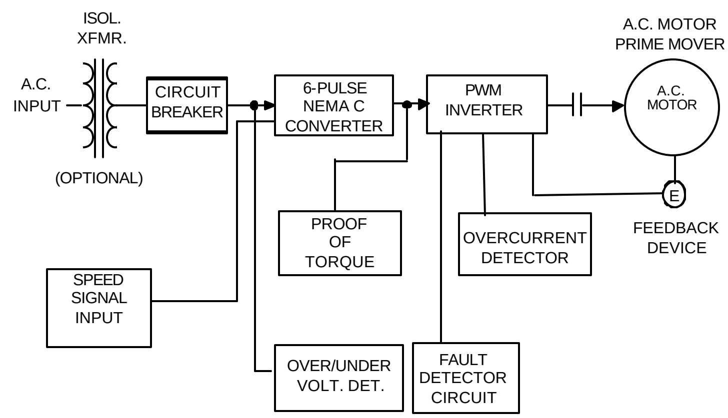
ADVANTAGE

1) Advanced circuit designs.
2) Cost advantage (typically 125HP and below).
3) No brushes. minimal motor maintenance.

(May or may not be an issue in applications)

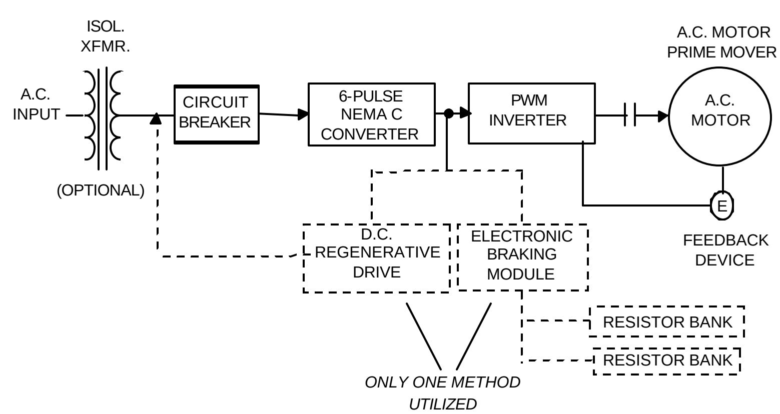
DISADVANTAGE

1) Troubleshooting is usually done with computer software.
2) One drive required per motor (flux vector mode).
3) Can not provide single drive / multiple motor with individual motor speed trim.



One big restricting factor in the application of ASD's in Moveable structures is the requirement and ability to handle continuous regenerative energy in an overhauling load condition. This usually occurs in the down (closing mode) of operation. DC regenerative drives offer this ability inherently in its design. In ASD technology, all drives offer the regenerative ability back to the internal DC bus circuit. From this point the ASD must be configured with an optional Electronic Braking circuit or a line regeneration circuit. The Electronic Dynamic Braking (known as Electronic DB for short) monitors the internal DC bus voltage and at a predetermined level "electronically" connects load resistors to absorb the energy being fed back from the prime mover (main AC motor). The line regenerative form of braking is basically DC regenerative drive elements which utilize the excess voltage and regenerates it back to the line much like a DC regenerative drive operates. The Electronic DB is the most cost effective approach for this application. The drawings to the right is a basic single line of a Electronic DB and line regenerative approach for Heavy Moveable Structure applications.

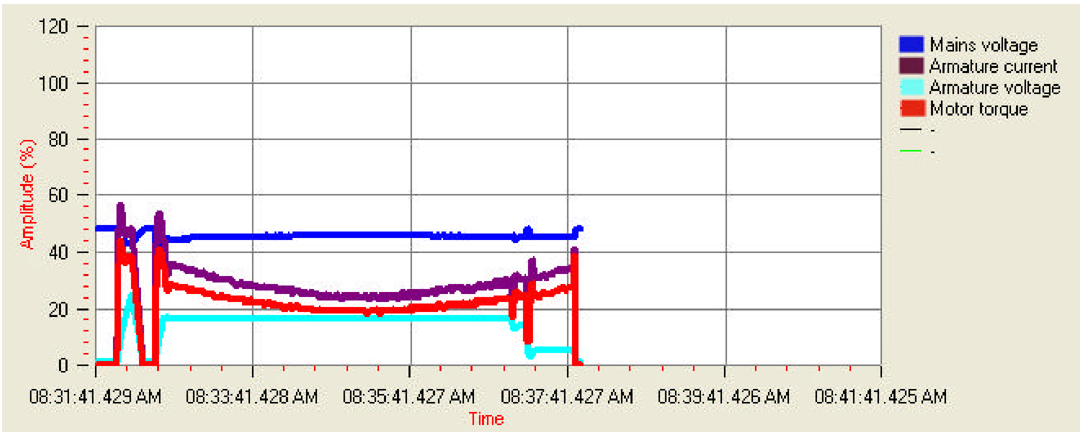
ONLY POWER SECTION SHOWN FOR SIMPLICITY



SYSTEM ENHANCEMENTS & CONSIDERATIONS

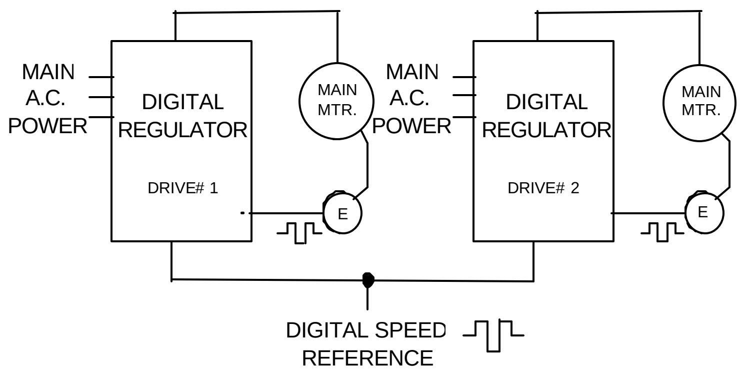
DIGITAL DRIVE CAPABILITIES

With the inception of the digital drive regulator, the drive can now offer valuable data about the operation of the Moveable bridge operation on a continuous basis about the structure mechanical integrity. The following is such a representative load monitoring capability offered in today's technology.



The digital drive today also offers the ability to maintain peak performance by non-technical personnel. Precise speed matching can be achieved by the use of encoders mounted on the motors. During speed changes (i.e. reducing speed to allow locking mode positioning) the individual motors shafts actual position could lag each other up to a max of 90^{O} which is very acceptable in today's applications.

The drawing to the right is a basic block diagram of such a system utilizing digital regulators. Please notice that the system could be either DC or AC with no advantage in drive performance for either choice.



A.C. MOTOR CONSIDERATIONS

A.C. Motor manufacturers today offer two basic types of motors – Inverter rated and Inverter duty. The motor/drive compatibility must also be considered.

Inverter Rated

These motors are a class of motors that are capable of operation from ASD's. They are general purpose, NEMA Design B motors generally utilized on variable-torque applications such as fans, blowers and pumps. While the motor design accommodates a variable speed application, the typical design limits are normally no more than a 10:1 speed range. These motors typically do not have provisions for mounting encoders, but are suitable for use with open loop vector drive applications (i.e. Swing bridges, Traveler Drives).

Inverter Duty

These motors are class of motors that are specifically designed for operation from an ASD Flux Vector controls, with or without feedback devices. This motor design features a wider constant torque (up to 2000:1) and are performance-matched to current technology IGBT drives. Each is equipped with provisions to accept several standard encoders. These motors are specifically designed for operation through an inverter to provide long trouble-free service.

Performance matched Motor/drive compatibility

Inverter Rated and Inverter Duty motors offered today may directly handle the wave shape output of the ASD drives offered with no optional output motor filters required. Some manufactures even have gone to the extent of completely redesigning and redoing their performance heat runs and offer no degradation in insulation life regardless of motor lead length between the drive output and motor location. This motor enhancement is becoming the norm these days in the high tech world of ASD applications and is offering a very cost effective system.

SYSTEM APPLICATION PERFORMANCE CHARACTERISTICS

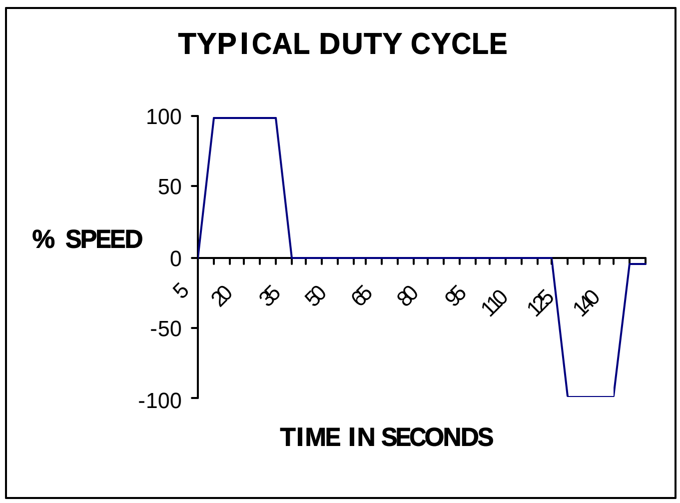
Today's drive applications demand accurate performance and excellent control but also must provide the most economical energy usage for the end customer on a day to day operating cost. All the following comparisons are with reference to a 100HP system with an operating duty cycle of 20 open/close operations per day, seven days a week. The typical demand cycle and system efficiencies for each open and close operation the drive system operation would be:

OPEN MODE OPERATION CYCLE:

OPEN ACCEL TO TOP SPEED – 5 SEC.
TOP SPEED RUN OPERATION – 20 SEC.
DECEL TO STOP – 5 SECONDS

CLOSE MODE OPERATING CYCLE:

CLOSE ACCEL TO TOP SPEED – 5 SEC.
TOP SPEED RUN OPERATION – 15 SEC.
SLOW MODE DECEL - 5 SECONDS
LOCKING MODE - 5 SECONDS



SYSTEM EFFICIENCIES & LOSSES

Controller Type	***Controller Efficiency***	***Power Conversion Efficiency***	***AC Line Input Power Factor***	***Typical Motor Efficiency***	***Total System Efficiency***
REGENERATIVE SCR DC Regulator & DC Motor	99%	94%	80%	92%	86%
AC Adjustable Speed Drive with Electronic Braking & AC Motor	97%	100%	88%	95%	92%
AC Adjustable Speed Drive with Line Regeneration & AC Motor	96%	100%	88%	95%	91%

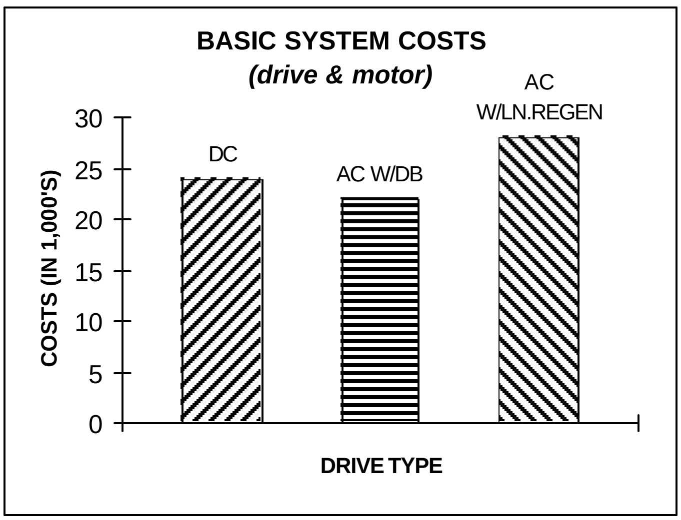
Note: All Percentages shown above are applicable at Motor Full Speed and Full Load only.

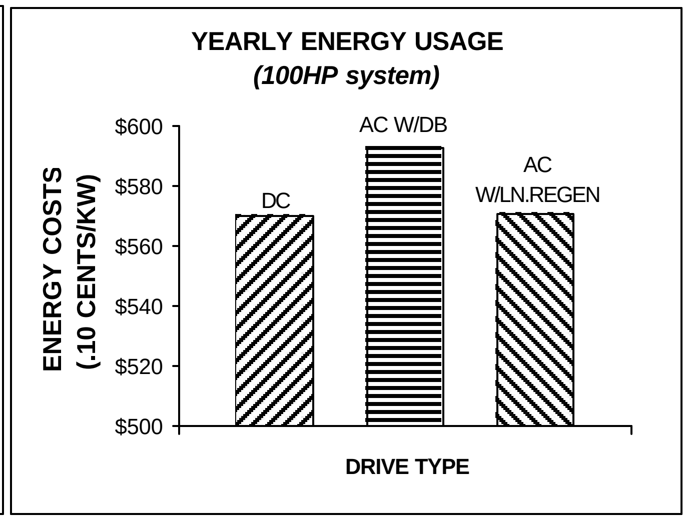
The drive efficiency performance is a very important owner concern from the resulting energy usage. Since the owner is the actual beneficiary of selecting the highest efficiency rated system this is an "up front" decision that requires consideration in determining the control method approach. The best control method approach may not necessarily be the best choice for the customer from a day to day energy operating cost. The following chart shows typical control power usage/year for the different types of controls.

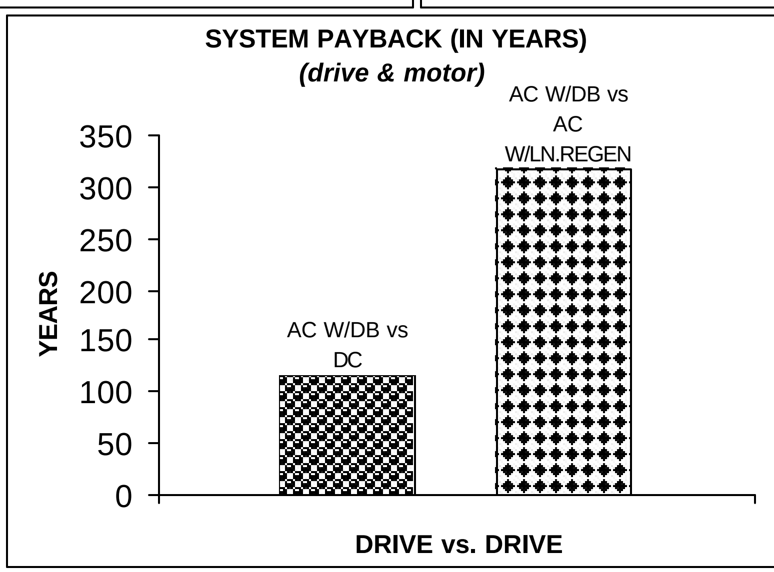
Energy usage in Killowatt-hours						$0.10 per KW-Hour	
Category	Open	Close	Tl.	Daily Tl.	Weekly Tl.	Wk. Cost	Yr. Cost
DC SCR Drive	0.44	0.34	0.78	15.62	109.31	$10.93	$570.07
AC Adjustable Speed Drive	0.45	0.36	0.81	16.23	113.63	$11.36	$592.56
Line Regenerative AC ASD	0.44	0.34	0.78	15.63	109.40	$10.94	$570.50

All values shown based on 20 open and close cycles per day, 7 days a week

Since the major energy user of the Moveable Structure is the prime mover machinery, this is the cost basis when considering the operating costs. With energy at an ever increasing cost this factor can no longer be ignored. The following is a comparison of equipment cost, operating cost, and payback based on energy usage for the prime mover only. Consideration of the control logic being relatively equal regardless of the main drive type reflects a constant and therefore not considered in the energy usage.







APPLICATION CONTROL CIRCUITS

The D.C. and ASD's drives available today should have some basic features to adapt them to applications for Heavy Movable Structure requirements. The following are some key advantages and features that a Heavy Moveable Structure "drive system" should provide in addition to the basic drive as related to the structure operation.

1. Proof of torque for mechanical brake release:

A circuit is utilized in the drive to insure that motor current (torque) is applied to the motor before the mechanical brakes are released. This function insures by positive feedback (torque) that the mechanical brake will not release without adequate motor torque being supplied to hold the load. Consequently, it provides a smooth transition between the mechanical brake release and the commencing of movement of the structure or bridge. This approach is a definite plus over previous time delay methods as it provides a positive feedback logic approach to insure machine integrity.

2. Locking Mode Operation:

After the vessel has passed and the moveable structure has returned to its normal position the drive system insures that the motor(s) torque is limited to a safe level in the locking mode (load float) while the bridge locking system is set. This provides proper motor protection at zero speed during this mode of operation while the bridge mechanical locking system is set.

3. Resetting of the mechanical holding brake:

When the stop command is initiated for the drive, a circuit monitors the motor current (torque) and when it reaches a preset low level the brake is initiated to set. This is an adjustable level and should be a separate adjustment from the starting proof of torque setting. With this sequence this allows the benefit of a Drive system to provide "hold back" torque or Regenerative Braking with the mechanical brakes utilized only as a holding brake. The advantage of this is that it extends the life of the brakes mechanically while providing trouble free service.

TRAVELER DRIVES

Fixed bridges also have an application for both ASD and D.C. Drives that being the Traveler Drives. The inspection capability and/or repair of fixed bridges is greatly enhanced with the introduction of the Traveler Drive for this application. A very desirable feature is the "S" curve accel/decel profile curve enhancement. This feature provides a smooth initial start when a speed change is initiated and a soft final approach to minimize quick speed changes and minimize overshoot. The Acceleration profile approximates that of an "S" curve. The ability to run at an infinitely adjustable speed either preset or operator control adjust is another advantage of both ASD & D.C. drives. The drive features are similar to the Movable Bridge application with multiple motors and/or drives in a speed matching mode to minimize traveler alignment and skew.

SUMMARY

ASD's and DC control systems are becoming the most widely used systems for operating Movable Structures & Bridges. Adjustable Speed drives in general provide more reliable and efficient control of either single or double leaf bascule, swing, or lift bridges. Digital ASD and DC drives provide a more refined control over other methods and these drives should be seriously considered where the ultimate in refined control is desired, for bridges where operation is frequent and the fastest possible operating time is required, and for bridges where maintenance is a problem and the repair cost is at unacceptable levels.