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Flux Vector Drive Application on a Movable Bridge

by

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FLUX VECTOR DRIVE

APPLICATION

ON A

MOVABLE BRIDGE

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INTRODUCTION

Built in 1979 and owned by Palm Beach County, Florida, the double-single leaf bascule bridge with 120 ft. spans over the Intracoastal Waterway is known as the Linton Boulevard Bridge.

The owner of the bridge began experiencing an extremely noisy reducer and excessive trunnion bearings wear. After maintenance remedies were reviewed, the owner elected to replace the drive trains and motors.

The design team was approached to design, among other items, new span drive machinery and prime mover replacement. The existing prime mover consisted of the typical 40 horsepower wound-rotor motors and drum switch controllers with secondary resistor banks.

VARIABLE FREQUENCY DRIVES

As with any movable bridge project, be it new or rehabilitation, after the determination of the power requirements needed to drive the span under all AASHTO conditions are made and the reducer input requirements are defined, the next step for the designer is to select the appropriate motor/drive combination to satisfy these requirements.

MOTOR /DRIVE BASICS

There are three motor drive technologies that should be evaluated for use in moveable bridge drive systems. The three systems vary in levels of performance.

A. Pulse Width Modulated (PWM) AC Flux Vector Motor and Controller

B. DC SCR Regenerative Controller and Motor (DC REGEN Drive, Shunt Wound DC motor)

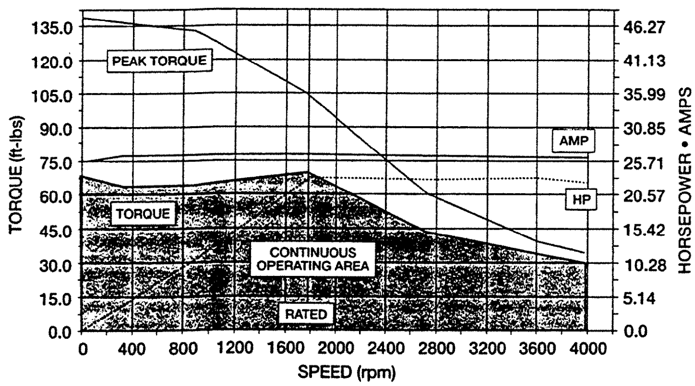
C. SCR Wound Rotor Controller and Wound Rotor Design AC Motor

PWM AC FLUX VECTOR

The basic design of the AC flux vector drive is best described as a closed loop digital motor drive system that controls both torque and speed of AC induction motors. Since the introduction in the late 1970s, flux vector control has been used in more applications that require precise load control. Flux vector control is also sometimes called field-oriented control. The motors used in these systems are standard premium efficiency, cast iron 3-phase induction design, usually built totally enclosed non-ventilated (TENV). Each vector motor has mounted to the opposite drive end, a digital encoder, usually 1024 PPR or a resolver. The encoder or resolver is the feedback device that continually monitors rotor shaft position and speed. Hence the term close loop control. The strategy of vector control is to regulate stator current magnitude and phase to rotor position. The AC currents are decomposed into direct and quadrature axis components. The velocity (rate) controller uses the difference between commanded and actual rotor velocity to calculate required motor torque. There are two independent current loops, the quadrature axis current (motor torque) and the direct-axis current (magnetizing) controller loop.

VECTOR

Motor: ZDM2334T 20Hp
Control: ZD18H420-EO 20Hp



Performance Specifications:

Input Voltage: 415 - 460V AC 50/60 Hz, 3 Phase

Base Speed: 1760 RPM

Operating Speed Range: 0 - 4000 RPM

Constant Torque Speed Range: 0 - 2100 RPM

Constant Horsepower Speed Range: 1300 - 2800 RPM

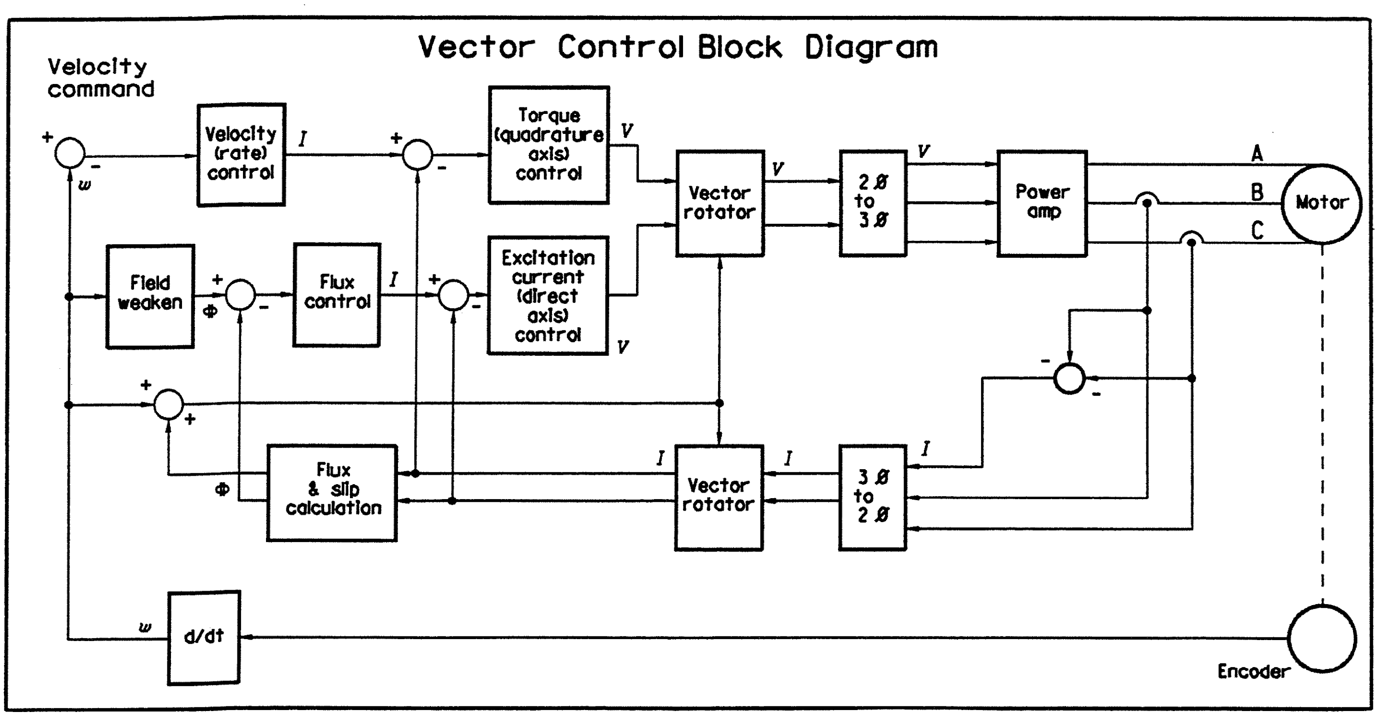
Speed Regulation
 Std. Feedback Type: Encoder, 0.1% of Base Speed

 Opt. Feedback Type: None

Motor Cooling: TEBA

Relative Cost: $$$

Benefits: Full Torque at 0 Speed
Torque Control
Speed Control
Programmable
Orientation
No Brushes



Because the controller is a closed loop current regulating design, it is capable of continuous operation at full motor torque, from true zero speed to twice base speed, of the induction motor. The output torque from the flux vector drive system is 4 quadrant with AC line regeneration as an option. The motor will provide up to 350% braking torque when the heavy structure is overhauling the prime mover. The flux vector control provides line regeneration that meets standards established by the IEEE Standard 519-1992 "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems".

Because it is possible to command the drive/motor to run at zero speed and produce full torque, the prime mover can hold the load at any position or angle without the machine brakes being set. This functionally adds redundancy to the control system, thereby giving the operator greater safety and control during bridge operation. Vector drive control systems exhibit very low maintenance service, since the vector drive motor uses induction design, regular lubrication is the only necessary maintenance. MTBF should exceed 50,000 hrs. of continuous duty.

DC SCR REGEN DRIVE

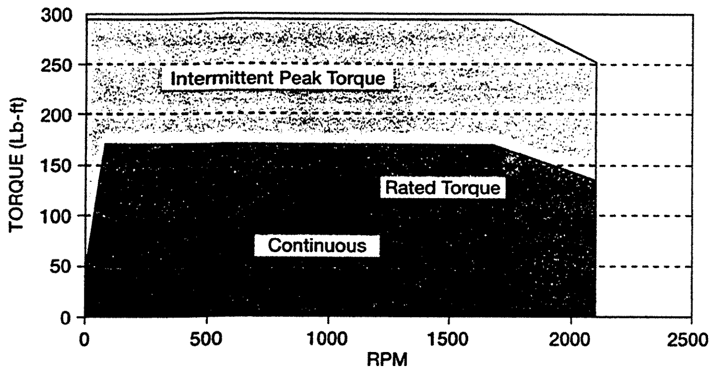
The Direct Current Drive and Shunt Wound motor drive system will provide good performance in movable bridges. This technology has been utilized for many years where constant torque load requirements exist.
Four quadrant DC drives are usually 12 step SCR digital controllers that rectify 3-phase AC voltage into DC voltage to vary the speed and torque of DC drive motors. The DC motor is designed around a wound armature and a wound field in the motor housing. Voltage and current are electro-mechanically transferred to the armature through carbon brushes onto the commutator bars mounted at the end of the armature shaft. Most DC machines use tachometer or encoder feedback to close the loop for speed regulation. Typical speed range for most DC machines are 50:1 from base speed. Regen DC drives can function as speed or torque controls. Like the flux vector, they have active control algorithms. Their response band width is limited to 70Hz where as a flux vector system has 400Hz current band width. Response bandwidth allows for the motor and drive to react quickly to changes in the driven load, while keeping tight speed and torque control of the movable bridge.

Enclosure design of the DC motor typically is totally-guarded, blower-ventilated (TGBV). Ambient air is circulated within the motor housing to cool the motor and increase rated output torque. Smaller motors can be designed totally enclosed non-ventilated (TENV). Consideration should be given to maintenance of the brushes and the commutator assembly. It's important that the DC machine not be subjected to high levels of moisture or contaminants such as salt air, road dirt, etc. System designers can reduce the effects of the hostile environments by designing DC motors with proper filters or heat exchangers. Another option is to house the prime mover to reduce exposure of the DC machine to such environments.

All SCR designed drive systems should have included as part of the drive package, a properly sized drive isolation transformer. Silicon controlled rectifiers, by the nature of their design, increase total harmonic distortion in the users AC feeder mains. Isolation drive transformers add impedance and reduce harmonic distortion. They also provide additional short-circuit protection for the drive and motor.

DC SCR

Motor: D5050P* 50 HP
Control: BC20H450-CL



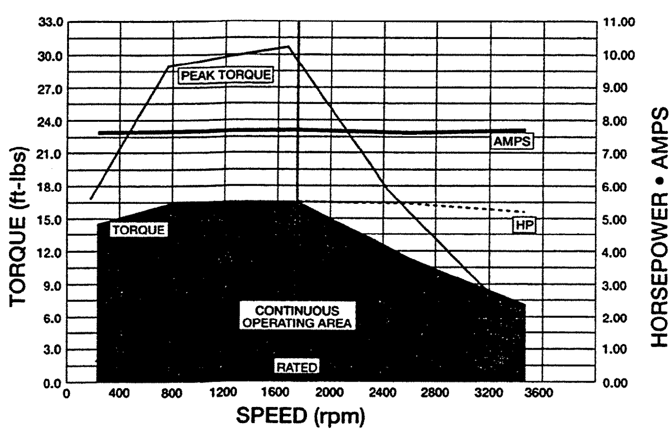
* Blower & filer added - Enclosure is Drip-Proof Blower Cooled

Performance Specifications:

Input Voltage:	415 - 460V AC 50/60 Hz 3 Phase
Base Speed:	1750/2300 RPM
Operating Speed Range:	0 - 2300 RPM
Constant Torque Speed Range:	0 - 2100 RPM
Constant Horsepower Speed Range:	1750 - 2300 RPM
Speed Regulation Std. Feedback Type:	Armature 1% of Base Speed
Opt. Feedback Type:	Tachometer 1% of Base Speed
Motor Cooling:	DPBV
Relative Cost:	$
Benefits:	Low Cost Constant Torque

INVERTER

Motor: IDM3665T 5 HP
Control: ID15H405-E



Performance Specifications:

Input Voltage:	415 - 460V AC 50/60 Hz 3 Phase
Base Speed:	1780 RPM
Operating Speed Range:	225 - 3320 RPM
Constant Torque Speed Range:	900 - 2100 RPM
Constant Horsepower Speed Range:	1500 - 2800 RPM
Speed Regulation Std. Feedback Type:	3% of Base Speed
Opt. Feedback Type:	None
Motor Cooling:	ODP
Relative Cost:	$
Benefits:	High Efficiency High Speed Programmable No Brushes

When establishing a base line torque requirement for the prime mover, the designer should take into account that DC machines should run at least 80% fully loaded for best operation and life span. Due to intermittent duty associated with movable bridges, it is good practice to include space heaters for the DC motor to reduce internal moisture and maximize motor performance.

Therefore, DC machines are logical choices for the prime movers in movable bridge systems. Some of the advantages are extended horsepower range, robust design and standard product availability.

WOUND ROTOR MOTOR AND CONTROLLER

Wound rotor motor controls have long been the motor control of choice for handling loads that required high starting torque and some control over the motor speed. Wound rotor design motors where one of the few choices system designers could utilize prior to the invention of solid state power components, where standard AC machines were not acceptable designs for variable speed or torque control. Stepping resistors were wired to the rotor winding for speed control. These resistors were added or removed by electromechanical contactors, actuated by the bridge operator's drum switch. These methods at one time were state of the art, but by today's standards have all but been abandoned. By adding the slip ring assembly and a wound rotor instead of a laminated rotor , motor designers were able to achieve stepped speed changes. The equipment required to put such a system into service takes considerable floor and wall space. Maintenance of wound rotor design motors can be higher than an AC induction design. These motor controls were provided usually as engineered systems, made to order. Replacement motors and spares are usually associated with long manufacturing lead times.

Wound rotor SCR controllers are being utilized by industry to provide an updated approach to the standard wound rotor motor control. The SCR controller operates similar to standard AC variable speed controls. The control uses tachometer and current feedback typically to an analog drive control circuit that regulates speed and the amount of current required by the load. Operational speed range of this type of control is typically 10:1 of motor base speed. The principle of design employed to control the wound rotor motor is a combination of electromechanical devices and solid state power components that establish motor velocity and manage torque required for the load.

Motor current and back EMF (electro-motive force) from the wound rotor motor are monitored by the current transformer. A proper amount of torque (current) is applied through power components to the motor to move the load. As back EMF increases, during times when the load is overhauling the motor, counter torque is applied through a secondary set of power components. This is typically referred to as Dynamic Braking.

As with DC SCR Control, it will be necessary to evaluate the effects the SCR based controller has on the AC line in terms of harmonic content (THD, total harmonic distortion) reflected onto the utility mains. Isolation transformers and or filters may be required by the local utility to abate this condition.

The would rotor motor control is a solid choice for movable bridges that have existing serviceable wound rotor motors, or if the movable bridge is not in a high service environment. Limitation of this mature technology in terms of efficiency and product availability should raise questions as to the future use of wound rotor designed motor drive systems in heavy structures.

DESIGN PARAMETERS

The existing spans were each driven by a single 40 HP wound-rotor motor and controlled by drum switches and associated secondary resistor bank. Studies determined that the existing reducers needed to be replaced and the remaining drive train assembly reworked. In addition, the movable span decking was scheduled to be replaced. All of these factors led to determination of new torque requirements to meet the AASHTO conditions and owner's criteria.

Once these parameters were determined, available drive technologies were investigated. Typically, span drive system selection weighs the aspects of drive/motor performance, application, feasibility, and configuration with respect to installation cost and maintenance issues such as training, availability of parts and service, and ruggedness of construction.

From the initial onset of the design, it was critical that the new drive system provide smooth movement of the span(s) with controlled acceleration and deceleration speed transition and ramping. The motor/drive technologies which satisfy these torque requirements and other parameters included:

A. SCR controlled, wound-rotor motor/drive
B. Inverter controlled, DC motor/drive
C. PWM controlled, AC motor/drive

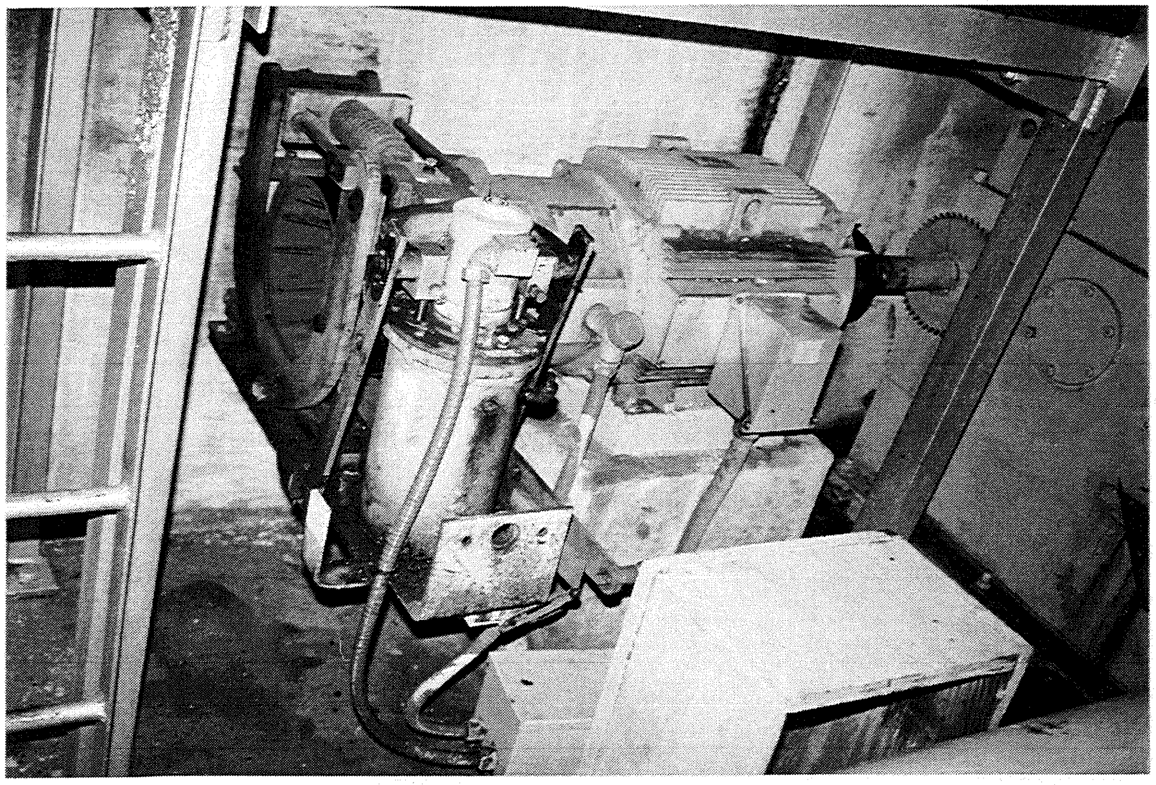
These motor/drive systems were studied and evaluated with the recommendation that PWM controlled, AC motor/drive system be employed, specifically, the flux-vector technology providing the optimal solution.

The SCR controlled, wound-rotor motor/drive solution was not recommended, mainly because of the owner's preference for a non-wound-rotor motor solution. The inverter controlled DC motor/drive was not highly favored due to the close proximity of the motor to the marine environment and open pier construction. It was felt this condition would increase the maintenance effort and (as with the wound-rotor motor) that a replacement motor would not be an off-the-shelf item.

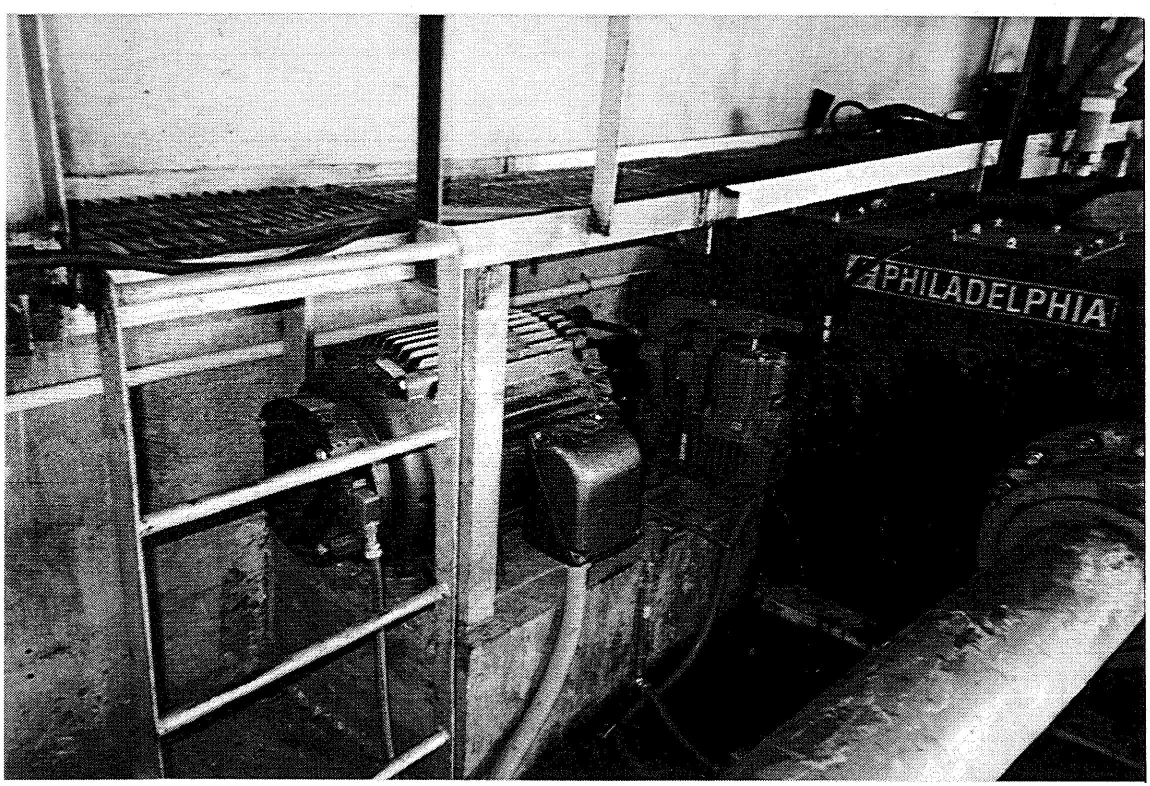
PWM controlled, AC motor/drive systems were looked at next. Experience with earlier variable frequency drives were met with limited success, with most of these motor/drives being significantly oversized in order to provide the low speed, low end torque necessary. As innovative new technologies become available and their track record becomes stable, the designer is obligated to explore all practical solutions. Recent industry publications and manufacturer's literature relating to the features of the flux-vector controlled AC motor/drive technology led to a more in-depth investigation of the design. The key feature being the ability to produce and maintain full load (100%) torque at zero speed with the use of an AC induction motor utilizing position feedback.

BEFORE: Existing Control Desk Layout (Drum Switches)

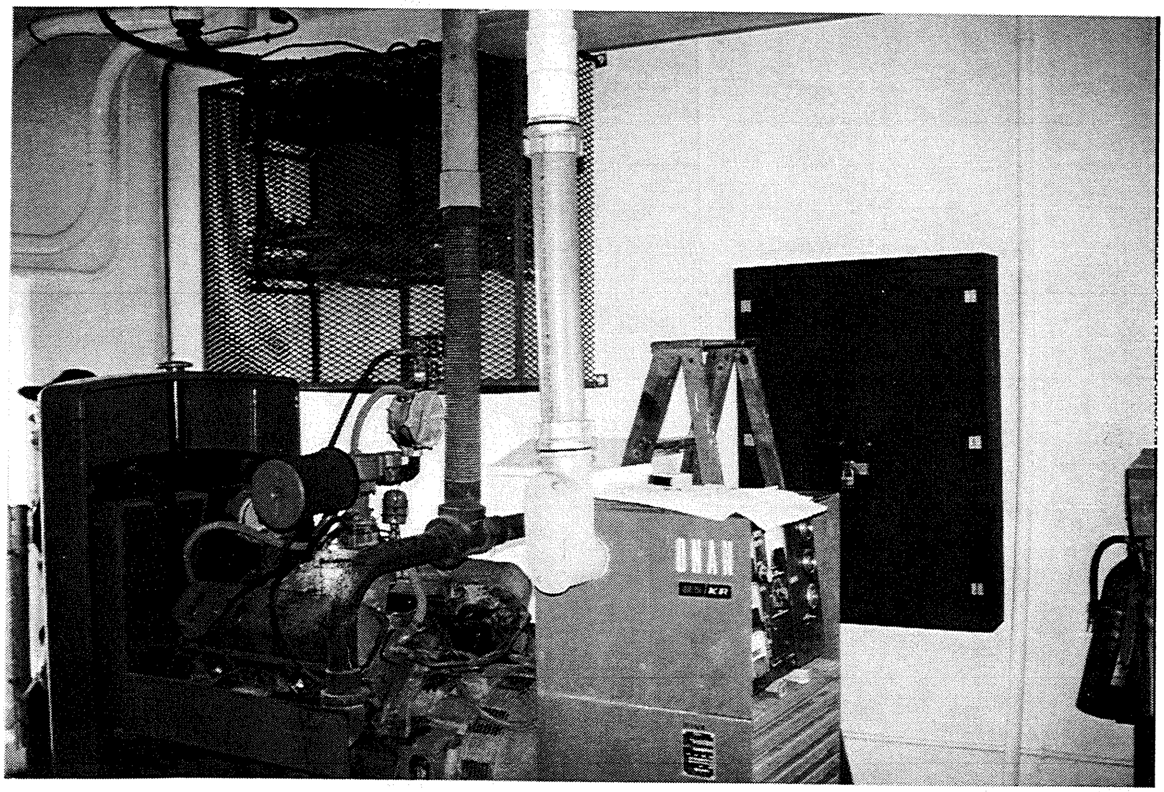
AFTER: New Control Desk Layout (Joysticks)



BEFORE: Existing Wound-Rotor Motor



AFTER: Flux-Vector Motor



BEFORE: Existing Motor Resistors and Existing Generator

Control of the movement of the spans was to be operator controlled by joystick(s) with spring-return to center as OFF position, forward (push) to RAISE the span and backward (pull) to LOWER. Speed control was to be communicated to the drive by use of bidirectional potentiometers, integral to the joystick(s), providing an analog signal for magnitude. Operator controlled speed signal was overridden by limit switches and relay logic for the typical creep speed zones of nearly-open to full-open during span raising and nearly-close to full-close during span lowering. Also, time delays were incorporated to prevent any instantaneous direction change.

SPECIFICATIONS

As important to the design as the construction plan drawings are the specifications, particularly in this case with the lack of previous guidelines. It was specified that the motor and drive be obtained from a single supplier, in order to provide single source responsibility and to allow the manufacturer to coordinate the motor and drive performance.

Torque requirements were listed and specific parameters relating to motor/drive performance and construction were detailed. Among these were provisions for dynamic braking resistors, current fall back for overhauling loads and the need for impedance matching equipment. Additionally, to verify motor/drive performance, extensive shop testing was specified.

It should be noted that once preliminary design and specifications were drafted, manufacturer's representatives were contacted as to the capability of their respective product lines to meet the projects criteria. Their feedback confirmed the design of a 75 HP AC induction motor and respective drive assembly. Since more than one manufacturer could provide the equipment, a particular manufacturer was selected by the designer to serve as a design basis for equipment sizing and control interface requirements. The close dialog established between the designer and the manufacturer's representative through the remainder of the design process, during construction and start-up proved invaluable to the success of the project.

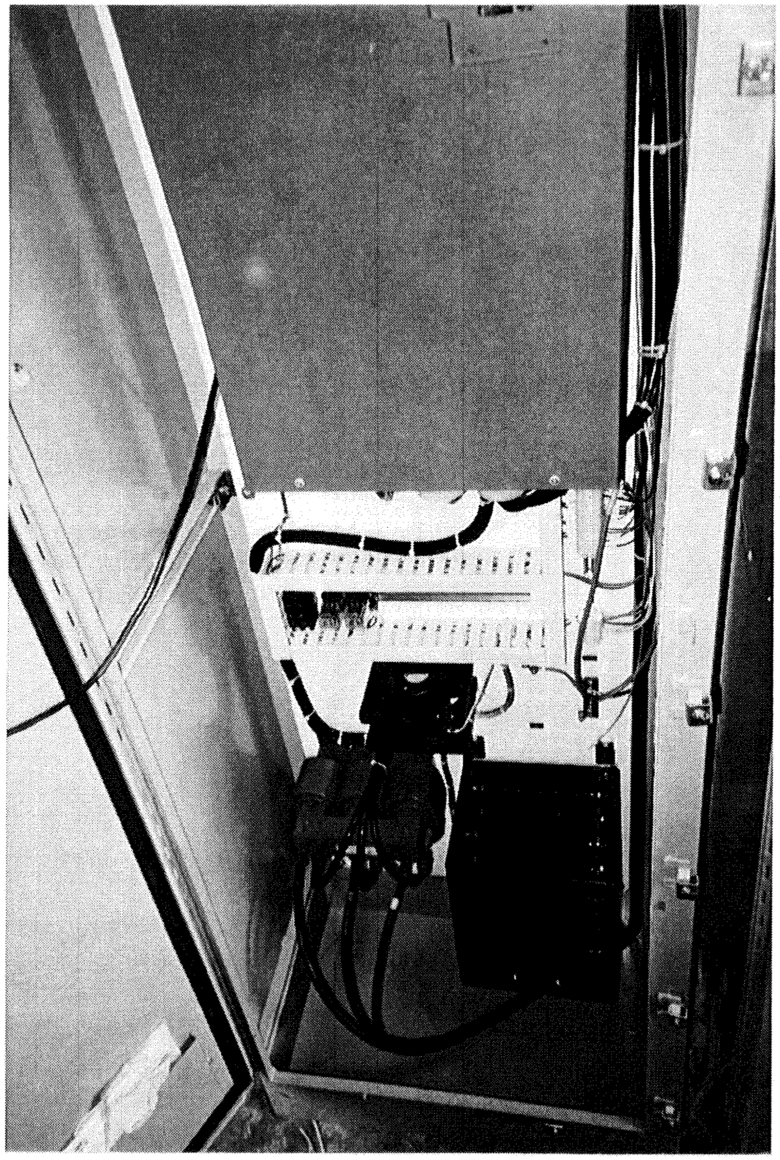
The specifications were written for performance and function of the motor/drive and when specific manufacturer's equipment was identified to establish quality and construction interface, "or approved equal" clauses were incorporated. Once the contract was awarded the successful contractor elected to supply the particular manufacturer's equipment.

SHOP TEST

Motor/drive shop drawing submittals were approved and coordinated with changes relating to the reducer manufacturer. The equipment was assembled and shop test procedures were approved. The shop test was conducted at the manufacturer's facility and witnessed by the designer as the designated owner's representative.

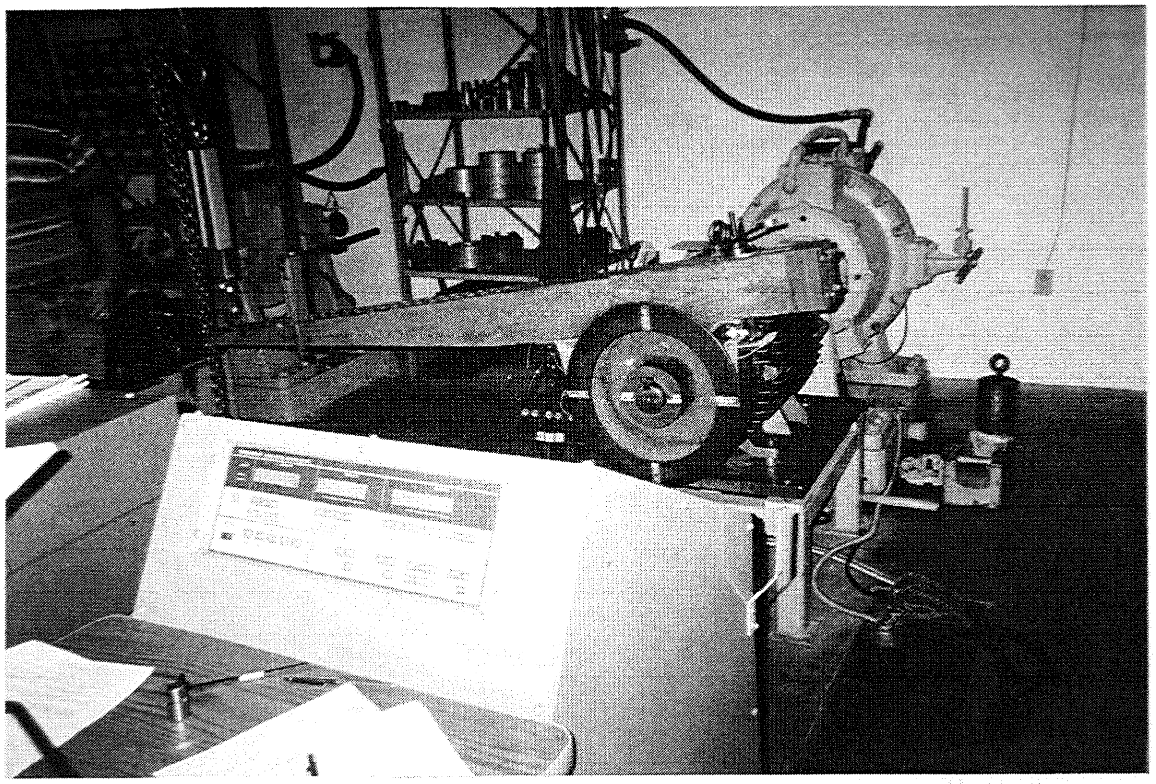
Shop testing included dynamometer testing for each motor/drive combination with actual performance curves generated by the test equipment. In addition, the drive output power was monitored to document the evidence of any harmonics.

The shop tests demonstrated the required performance prior to shipment.

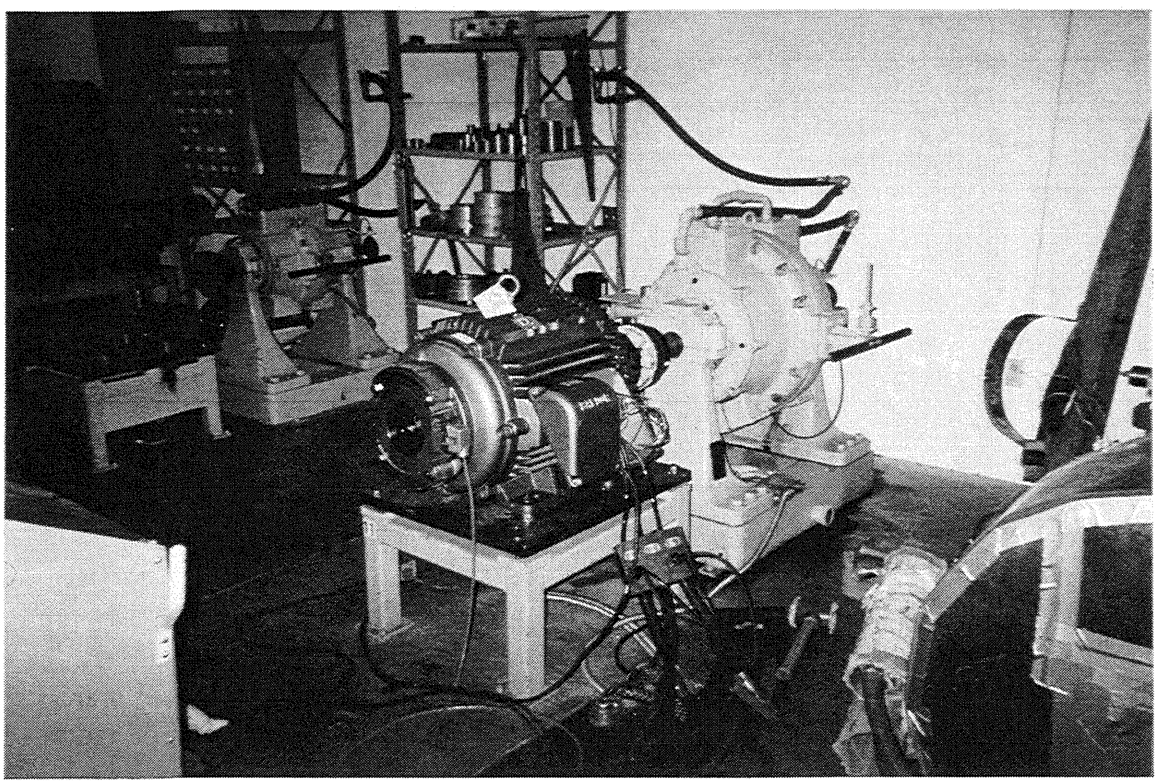


DRIVE ENCLOSURE: Drive, Resistors, & Linear Reactor

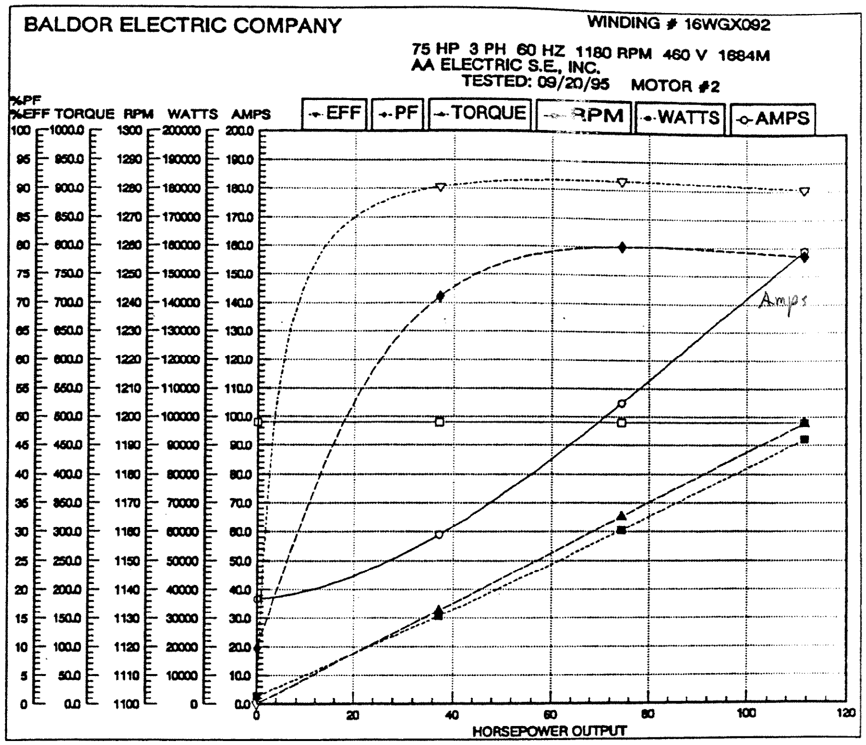
DRIVE ENCLOSURE: Location of Generator



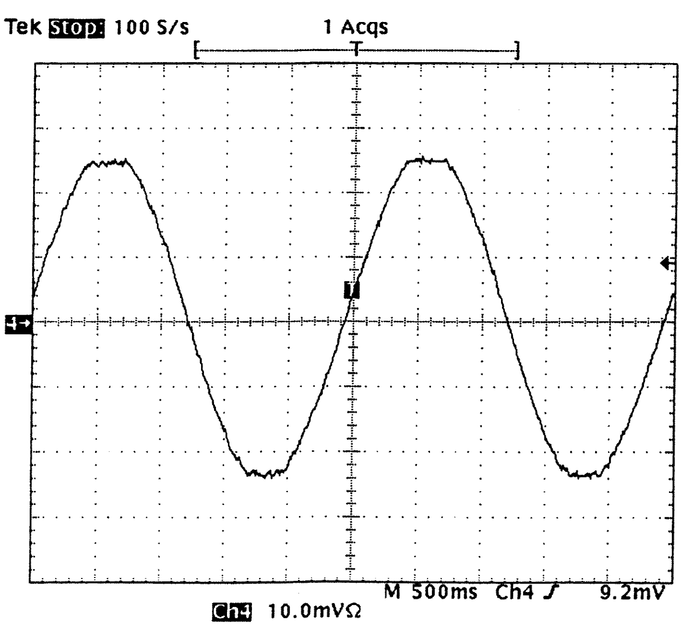
SHOP TEST: Prony Brake (Full Load at Zero Speed)



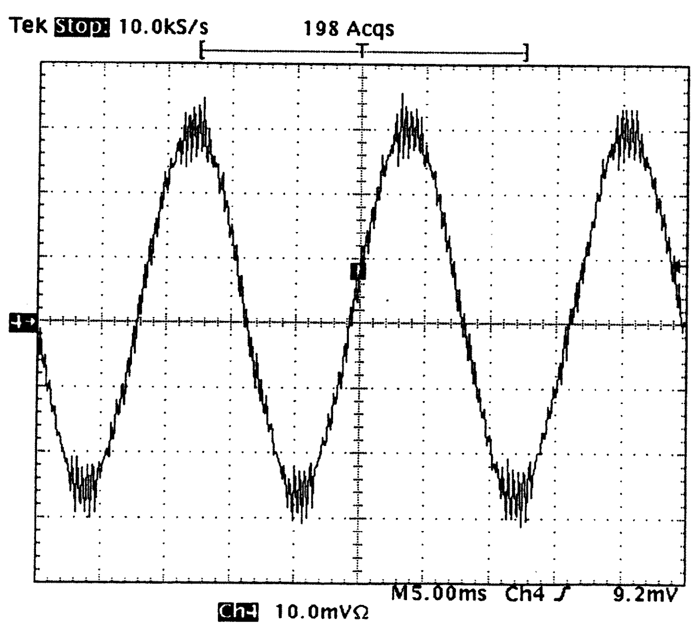
SHOP TEST: Dynamometer



MOTOR/DRIVE: Performance Curve



DRIVE OUTPUT: Full Load at Zero RPM



DRIVE OUTPUT: No Load at 1200 RPM

INSTALLATION

The motor/drives were delivered to the site as scheduled and the drive was installed in a NEMA 4 enclosure which also housed the linear reactor, dynamic braking resistor and ancillary equipment. The common enclosure was employed to mitigate any adverse effects from the close proximity to the diesel generator and to provide protection from the marine environment.

STARTUP

Full functional testing of one span was conducted by the contractor and manufacturer's representative and witnessed by the owner and designer. The motor/drive and control interface performed as anticipated and speed control was smooth in all positions. The remaining span was tested 5 months later and identical performance was demonstrated. Training of the owners personnel was conducted as both spans were completed. The owner is pleased with the motor/drive performance.

CONCLUSION

Recommendations to ensure successful application of the flux-vector technology include:

- Motor and drive be a product of one manufacturer
- Specific motor/drive performance parameters be specified
- Full load testing of motor/drive system be performed in the shop
- The designer should be involved in all phases of the project including post-design activities

It has been demonstrated that flux-vector controlled, AC motor/drive technology can be successfully installed on a movable bridge application. To the authors knowledge, this is the first application of this technology on a bascule bridge in the state of Florida, if not the first in the USA.

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