THE APPLICATION OF CURRENT TRANSDUCER TECHNOLOGY

on

BASCULE BRIDGES
as the basis of

A COMPUTERIZED PREDICTIVE MAINTENANCE PROGRAM

by
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Presented at:

THE FIRST BIENNIAL SYMPOSIUM & EXHIBITION
on
MOVABLE BRIDGE DESIGN & TECHNOLOGY

FLORIDA STATE CONFERENCE CENTER
Tallahassee, Florida
4-5 November 1985

ABSTRACT

This paper outlines a prototype predictive maintenance program for a trunnion type bascule movable bridge By applying current transducer technology and computers, there is every reason to believe unplanned traffic interruption and maintenance costs can be reduced.

Current bridge maintenance methodology falls short of systems now being used in other industries. Hardware and basic concepts being applied have been used successfully for years in the oil, petrochemical, pulp and paper, power generation, and other industries.

Discussed are the transducers utilized, as well as the various measured points and their interaction with the bridge operation. Additionally, the use of a computer and personnel are reviewed.

INTRODUCTION

The history of movable bridges dates to the medieval period of castles with moats. Today, movable bridge design encompasses three general groups -- swing span, vertical lift, and bascule. Bascule bridges can be further divided into three basic types -- trunnion, rolling lift (or Scherzer), and heel-trunnion (or Strauss).

This paper deals with instrumenting one side of a double-leaf bascule design (Fig. 1) with emphasis on the mechanical aspects.

Safe, orderly, and reliable bridge operation is very critical to departments and organizations responsible for operating them. In addition to the operational and maintenance considerations, there is the high emotional impact on the community. Interruption of service will adversely impact either water or roadway traffic, and in some cases, both. Hence, bridge operation is not solely one of financial considerations.

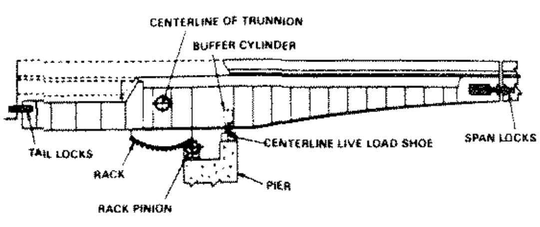


Figure 1. Operating components of a double-leaf bascule bridge.

Maintenance practices in general cover two areas -- lubrication and balancing. Both, for the most part, are handled on a scheduled basis. Periodic bridge inspection results in a maintenance repair list, that is handled separately from the routine lubrication and balancing. Use of predictive maintenance methods can provide daily records of a bridge's mechanical condition, thereby trending changes in its condition. The trend information can be used to enhance all existing programs. Lubrication and inspection schedules can be optimized and balancing need only be performed when required. Mechanical problems requiring special attention, which may adversely impact traffic, can often be determined before reaching a crisis level.

The operating methods used by the individual operators can affect the mechanical condition of the bridge. With most control systems, the operator has significant flexibility in the actual opening/closing process. Powered/non-powered closings, as well as the final closed condition of the braking mechanism, affect mechanical wear points. Information depicting this activity may provide insight into future control system schemes.

Considering the above, a prototype system has been designed to evaluate the feasibility of applying current transducer technology along with predictive maintenance methods on movable bridges. The prototype design incorporates what might be viewed as an excessive number of transducers; however, the data acquired through the prototype system may reduce the quantity needed.

To document the worn condition of a bridge needing refurbishment, data was acquired prior to the commencement of rework. Transducers, which were temporarily mounted to facilitate this data acquisition, provided the basis for the data presented in this paper. It is felt that this data will prove invaluable in comparison to that from reworked machinery.

Finally, a standard personal computer using standard software is being used for data recording and data review. Since the algorithms and parameters needed as a basis for the P.M. system are unknown, this was considered the most prudent approach. The prototype system is being installed in conjunction with refurbishment work. The system will be operational for one year. At the end of the trial period, system concepts along with transducers and hardware will be evaluated. A determination will be made as to the feasibility and justification of an installation.

This design is being installed through a refurbishment project by the State of Florida's Department of Transportation - Bureau of Structures, Preconstruction and Design. The particular bridge is located east of Dania, Florida, over the Intercoastal Waterway.

SYSTEM OVERVIEW

MEASUREMENTS BEING MADE - INPUTS

<u>Motion</u>

- Midspan - 2 Points
- Live Load - 2 Points
- Pillow Blocks - 12 Points
- Gearbox - 1 Point
- Drive Motors - 2 Points
- Trunnion Bearings - 4 Points

<u>Position</u>

- Midspan - 2 Points
- Live Load - 2 Points
- Pillow Blocks - 12 Points
- Trunnion Bearings - 4 Points

<u>Other</u>

- Torque in Drive Shaft - 2 Points
- Current in Drive Motor - 2 Points
- Traffic Count - 2 Directions
- Pressure in Buffer Cylinder (?) (Still being evaluated) - 2 Points

OPERATIONAL CONSIDERATIONS

- Variance in Openings and Closings
- Variances by Operators

DATA COLLECTOR

- High Speed Logger
- Personal Computer for Storage

DATA REDUCER

- Personal Computer with Standard Software
  - Alarm Limit Comparisons
  - Trends
  - Data Correlation

PERSONNEL INTERFACE

DISCUSSION

MID-SPAN MOTION

The parameter most noticeable to the general public is that of the relative leaf-to-leaf motion at the mid-span as vehicle traffic passes over a bridge. In addition to the general annoyance of a severe bump, there is the possibility of a safety hazard should the relative motion become excessive.

Changes in this relative motion can result from wear in the lock bar assembly, changes in the balance state of the bridge, as well as the final loading or wrap-up of the system at the closing. Also, activation of the span lock drive system too early can result in severe damage and/or loss of the socket receptacle. To measure this motion, a noncontact proximity probe will be mounted in the socket of each span lock assembly. (NOTE: Operational theory of the proximity probe is included at the end of this paper along with other transducers referenced in this paper.)

From this transducer, both the relative motion as well as the position of the bar in the socket will be measured. The amplitude of the relative motion between the two leaves will be a problem severity indicator. Position of the bar in the socket will provide some indication of bar and/or bushing wear (Figure 2 depicts a conventional lock bar assembly). The two measurements then will provide a basis for determining when adjustments need to be made on the span lock assemblies.

For data acquisition prior to refurbishment, proximity probes were mounted on top of the bridge to observe the leaf-to-leaf relative motion. Amplitudes were correlated with the size of vehicles ranging from compacts to busses.

Both the mid-span and live load shoe motion data are presented on Plot 1. Two operational modes are included. One reflects a response with gearing wrap-up and the other with no wrap-up. Wrap-up refers to a condition that occurs when the bridge is lowered to contact the live load shoe with motor torque maintained before applying the brake. A closed bridge with wrap-up is generally preferred, as it tends to assure a more positive contact at the live load shoe area.

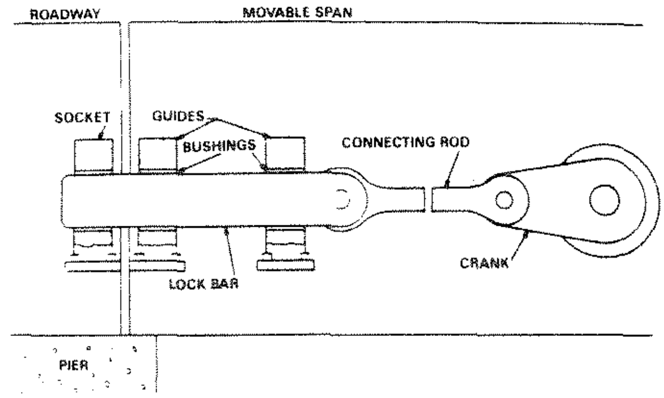


Figure 2. A conventional lock bar assembly.

Interestingly, there was generally more motion at the mid-span in the wrap-up condition. Values ranged from 30-460 mils (1 mil = 0.001 inch) with wrap-up to 115-220 mils without wrap-up. The response was significantly different in pattern with the larger vehicles as well as with the two modes. The non wrap-up mode response was typical of

resonant elements with the characteristically log-decrement decay pattern. The wrap-up mode tended to reflect a dampened response.

The limited test data confirms the responsiveness of the proximity probe to the mid-span motion. Due to the probe mounting, the dc component had no real significance in relation to prototype system. Hence, dc information is not provided.

LIVE-LOAD SHOE

In a normal "bridge closed" mode, there should be continuous contact of the live-load shoe with the strike plate (Fig. 3). Lack of continuous contact may result from changes in the bridge's balance condition, lock-bar problems, the final loading or wrap-up of the system at closing, ... These problems are very similar to those noted in the mid-span motion discussion above. A noncontact proximity probe will be mounted at each live-load position to measure any motion occurring or to detect any wear between the shoe and plate. With many bridges operating in salt water environments, corrosion/erosion is also a problem at the contact points.

Test data was acquired from transducers at both load points and under different closing conditions.

On this particular bridge, there is always motion at the live-load shoe with traffic crossing. Little variance in the amplitudes between the two modes was detected. The amplitudes ranged from 1.5-12 mils. As with the mid-span data, the response patterns differed between the two modes. However, the resonant/dampened characteristics were opposite that of the mid-span response. Note the resonant characteristic of the data in the wrap-up condition.

Good data was obtained from the probes at the live-load shoe. Both the dc and ac component should prove meaningful.

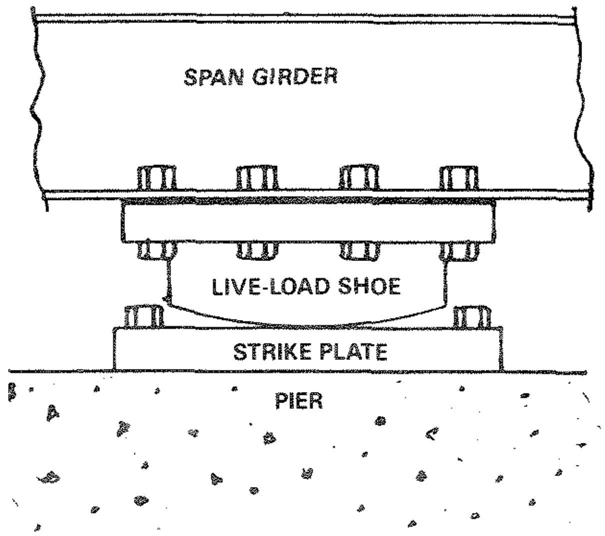


Figure 3. Strike plate and load shoe.

PILLOW BLOCK BEARINGS

The drive mechanism on the Dania, Florida, bridge is of the Hopkins Drive design (Fig. 4). Components consist of dual drive motors inputting to a double reduction gearbox with two additional external reduction stages. The external reduction gearing is supported by six (6) pillow block bearings -- three (3) on each side of the gearbox. Cylindrical sleeve inserts with spiral lubrication grooves provide the journal supports. As the journals rotate within the constraints of the bearings, they are free to move or vibrate, as well as exhibit changes in their relative position within the bearing clearances (Fig. 5). Both the forces transmitted through the gearing, as well as the bearing clearances, will affect these two parameters. To document both the motion and position changes, two noncontact proximity probes will be mounted in the top half of each pillow block bearing at a 90° orientation to one another.

Plot 2 depicts data from normal opening/closing cycles. To evaluate data consistency, three runs (openings/closings) were made. Each data run starts and ends with the bridge in a closed position -- See the bottom trace for the bridge opening angle. Transducer data for each run consists of the dc offset and ac motion with the ac motion amplified on the far right. All three parameters are plotted against time.

All runs, particularly the dc offset data, reflect the same pattern indicating shaft to bearing motion is repeatable. Note particularly, the beginning and end points of each run, frequency pattern of the opening and closing cycles and a couple of unique responses near the full opening and near the closing. The ac motion indicates a lot of high frequency activity requiring further investigation. Various gear mesh frequencies are likely causes of the high frequency activity.

The predominant frequency in the dc offset signals is 15.64 cpm, which is the running speed of the shaft. Some or all of this motion may represent runout, which could be something like an egg-shaped target area.

On Plot 3, the opening and closing dc offset data varies greatly. This is quite different from the data on Plot 2. Both plots

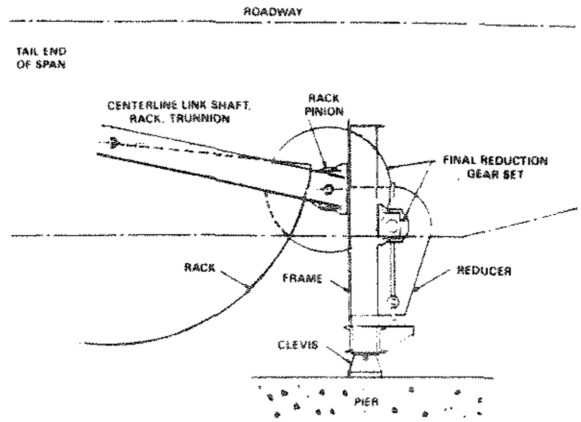


Figure 4. Elevation of Hopkins Drive.

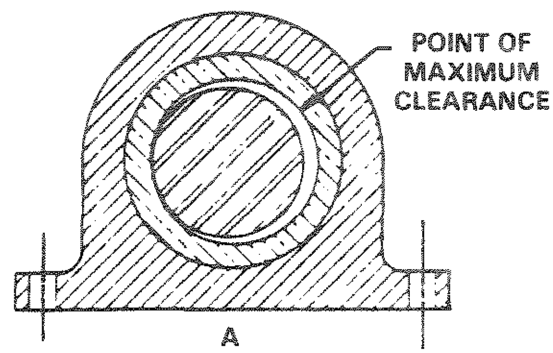
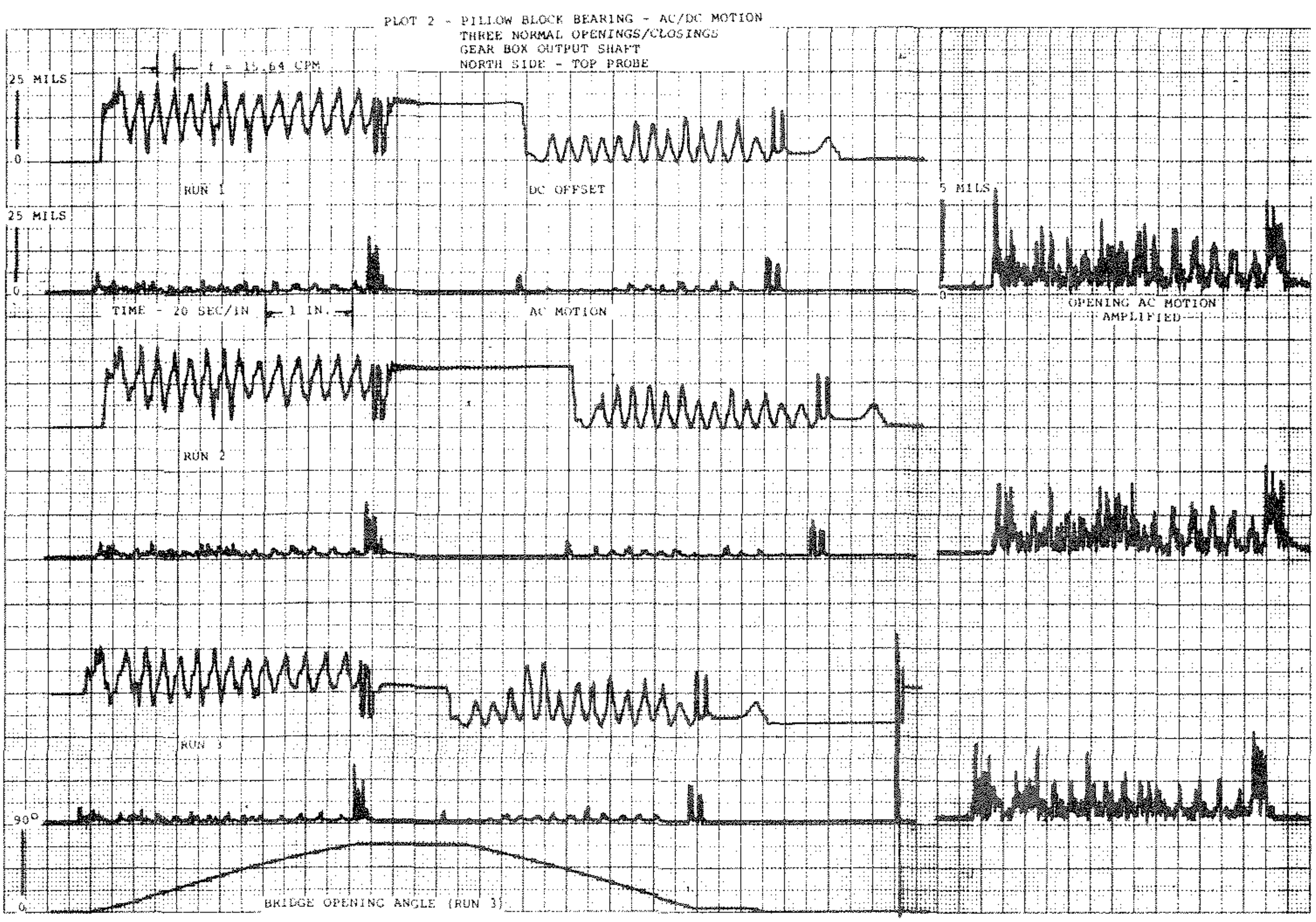
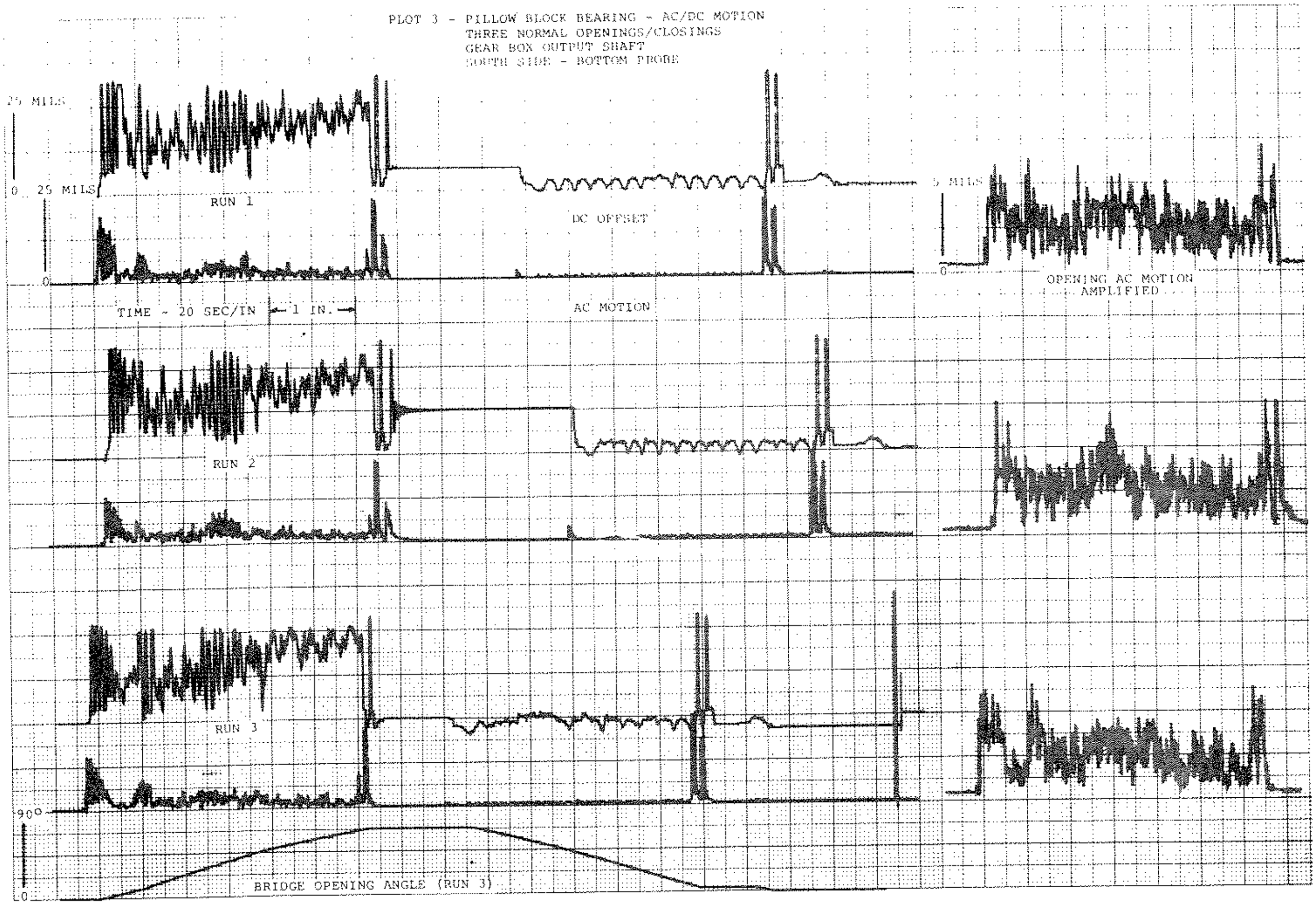


Figure 5. Typical sleeve bearing.




PLOT 3 - PILLOW BLOCK BEARING - AC/DC MOTION
THREE NORMAL OPENINGS/CLOSINGS
GEAR BOX OUTPUT SHAFT
SOUTH SIDE - BOTTOM PROBE
25 MILS
0
25 MILS
0
RUN 1
DC OFFSET
AC MOTION
TIME - 20 SEC/IN
1 IN.
5 MILS
0
OPENING AC MOTION AMPLIFIED
RUN 2
RUN 3
90°
0
BRIDGE OPENING ANGLE (RUN 3)


PLOT 4 - PILLOW BLOCK BEARING - AC/DC MOTION
THREE NORMAL OPENINGS/CLOSINGS
SOUTH DRIVE SHAFT-SOUTH BEARING-BOTTOM PROBE
25 MILS
f ≈ 2.8 CPM
0
25 MILS
RUN 1
DC OFFSET
0
TIME - 20 SEC/IN
1 IN.
AC MOTION
5 MILS
0
OPENING AC MOTION AMPLIFIED
RUN 2
RUN 3
90°
0
BRIDGE OPENING ANGLE (RUN 3)

are from probes observing the gearbox output shaft bearing; however, one is from a "top" probe and one is from a "bottom" probe.

Plot 4 is of data from a bearing on the final drive shaft. Note the substantially lower dc offset frequency response and the varied opening/closing pattern.

These three plots, along with data from the other nine probes, indicate useful information will be obtainable from a set of probes at each of the Pillow Block Bearings. The meaning of the ac/dc patterns, frequency content, ... are still to be resolved.

GEARBOX VIBRATION

With gearboxes, the two primary areas of concern mechanically are the bearings and gear teeth condition (Fig. 6). A history of minimal bearing problems and financial considerations dictated the elimination of bearing measurements on this project. However, a velocity transducer will be incorporated to measure the casing motion, which is expected to reflect to some degree the gearboxes' general condition. Gear mesh frequencies at the maximum drive motor speeds of 860 rpm are 12,900 cpm and 1,408 cpm. Both frequencies fall within the frequency response of the velocity transducer.

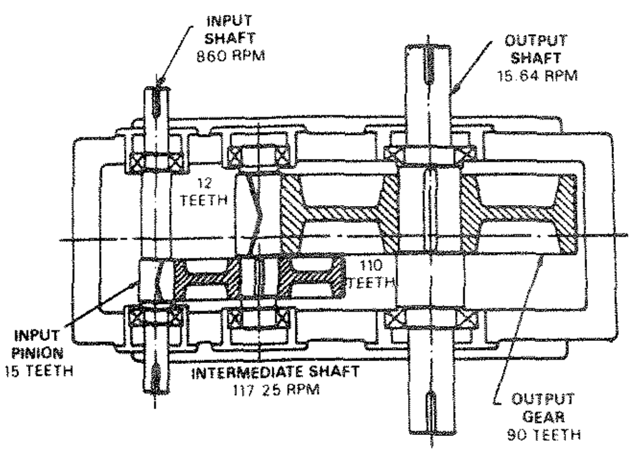


Figure 6. Plan view of the offset herringbone reducer.

For most of the opening/closing cycle, the gearbox vibration amplitude was just below 0.1 inches/second (ips). At the start of the opening/closing cycle, amplitudes spiked to 0.6-0.8 ips. Near the end of the closing cycle, one spike reached 2.2 ips.

Amplitudes of 0.1 are quite typical of those found on industrial gearboxes. The spike amplitudes are to the high side, particularly the 2.2 ips figure. Gearbox vibration monitoring appears beneficial based on the data acquired.

MOTOR VIBRATION

As with the gearbox, a velocity transducer will be used on each motor to measure their vibration characteristics. Motor bearings are of the rolling element type, providing good energy transfer from the rotating element to the casing. Velocity coils have been used successfully in similar applications for years.

Test data amplitudes varied from a nominal 0.1-0.2 ips level with spikes to 1.3 ips. Amplitude levels and general patterns are typical of those found on similar motors. See Plot 5 for test results.

TRUNNION BEARINGS

The two (2) trunnion bearings support the weight of the entire leaf (Fig. 7). Shaft misalignment is of concern, since it greatly affects the loads on the bearings and supports. Additionally, lubrication condition will also affect bearing wear and perhaps journal motion in the bearing. As with the pillow block bearings, two (2) proximity probes will be mounted on each bearing.

Test data, as shown on Plot 6, proved quite interesting. Two presentation formats are presented. One is identical to that of the pillow block bearings with the ac/dc components plotted against time. The second is a polar presentation of the dc information representing a shaft centerline position change. Data indicates the north shaft moved up and to the east, while data from the south bearing indicates motion almost straight down. An explanation of this action cannot be given. Little ac motion was detected.

Trending the trunnion bearing data *over the duration of* this project should prove quite interesting. The proximity probes may provide unique insights into the operation of this critical bearing.

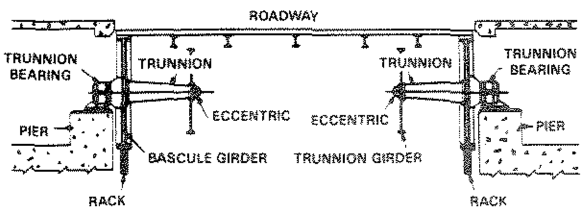
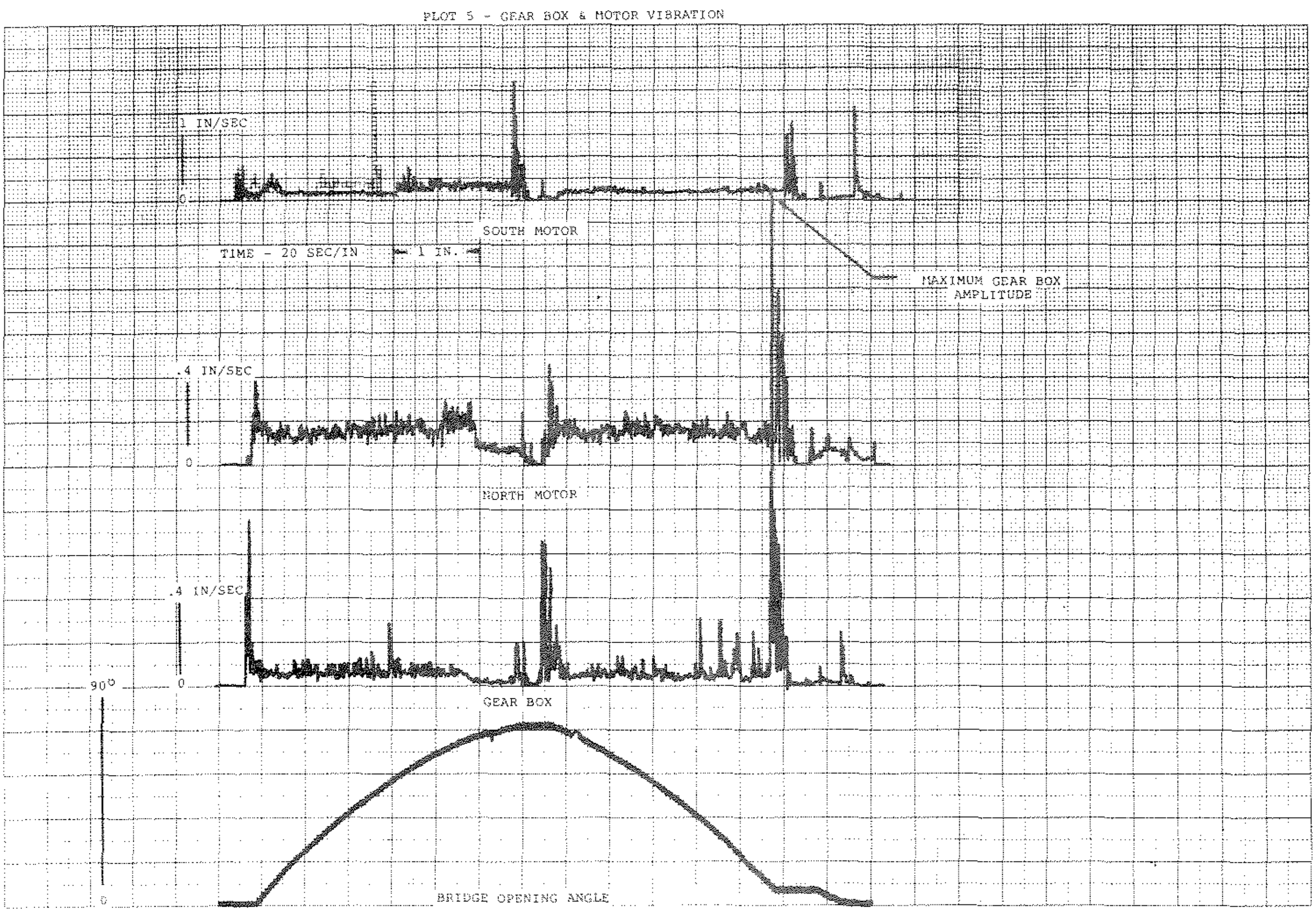


Figure 7. Trunnion assemblies.

TORQUE/BALANCE

A standard maintenance program is periodically checking the balance condition of the bridge. Many things can cause the balance condition to change. Point wear, trash collecting on the bridge, items falling off the bridge, ... are but a few examples. Ideally, the balance places the bridge in a somewhat leaf heavy mode; however, there seems to be no real standards. Many balance jobs are handled on a trial and error basis. *The Florida* Department of Transportation in conjunction with the University of Florida, have developed a computerized balance system utilizing strain gages on the drive shafts. Figure 8 depicts three curves of torque versus opening angle. Curve #1 is considered unacceptable because of the high torque requirement, and because of the negative value in the closed position indicating the possi bility of automatic span opening if *left unlocked. Curve #2 is* generally considered ideal with maximum torque at one-half the opening angle or approximately 35-40°.

Two (2) strain gages will be installed on each final drive shaft to monitor the torque and, consequently, balance condition of the bridge.



During the opening cycle, the torque remained positive (torque required to open) with an average value of 75 klb-ft. Amplitudes during the closing cycle were very close to zero, going slightly negative near the closing. Averaging these two signals would result in a fairly flat curve with an amplitude of 30-40 klb-ft, which is close to an ideal balance.

Monitoring of this parameter should enhance the existing balance program. As noted previously, the experience for interpreting this data exists within the Florida Department of Transportation.

DRIVE MOTOR CURRENT

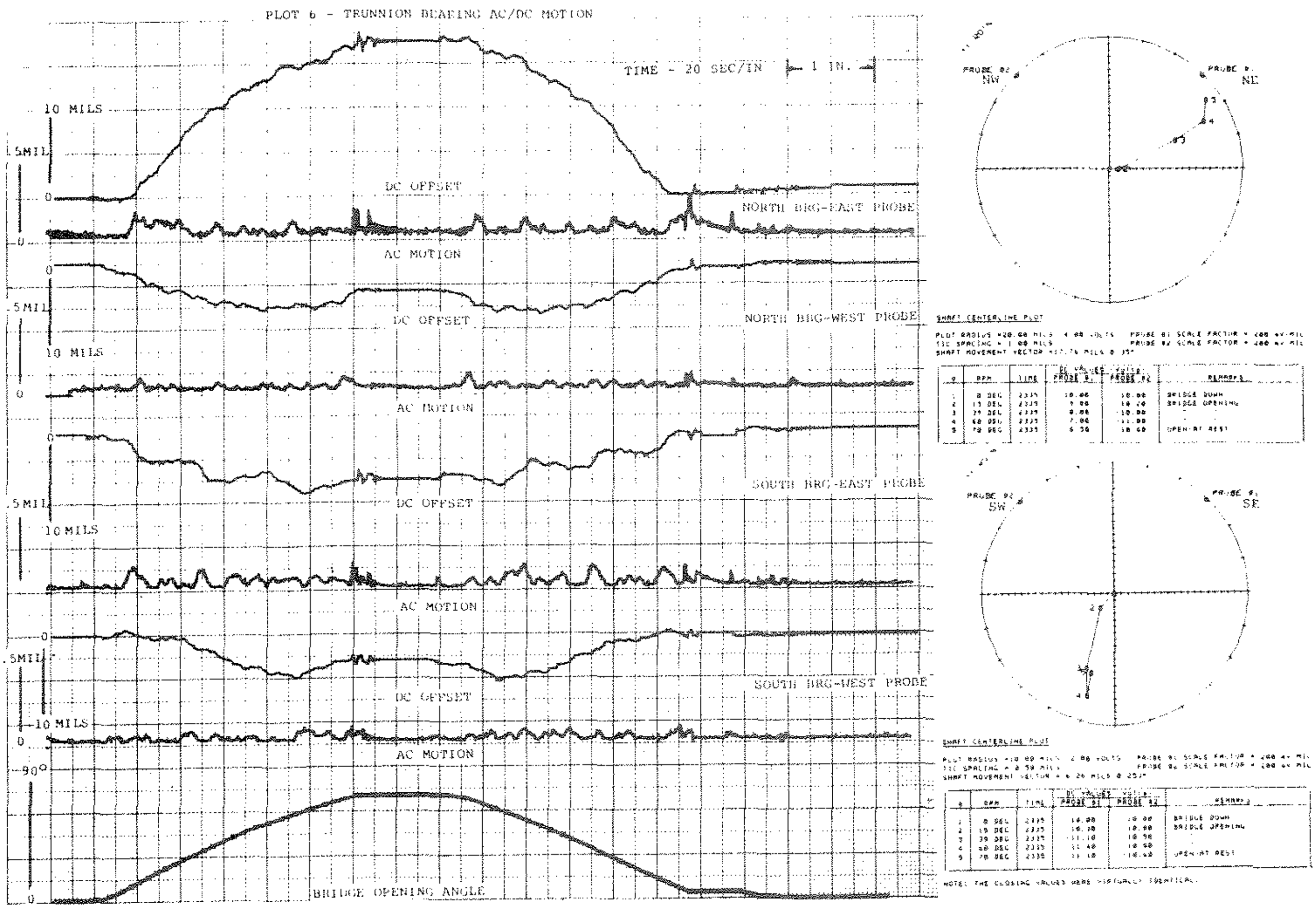
Less than optimum conditions in the trunnion bearing, caused by such things as insufficient lubrication and misalignment, may not be reflected in the trunnion bearing transducers. The torque and drive motor currents will be measured. They may be a better indicator of the bearing condition.

Drive motor currents from the north and south motors are indicated by the second and third data lines on Plot 7. The response curves are as one would expect with opening/closing cycle values of 140 amps. Spikes up to 400 amps occurred during start cycles.

Variance in the response pattern may vary from one bridge tender to the next. Data of this nature was not acquired during the test.

BUFFER CYLINDER PRESSURE

Not all bascule bridges are equipped with buffer cylinders, which perhaps reflects the belief by some that their need is questionable. In concept, the piston rod drops, pulling air into the cylinder through a check valve as the span opens. Upon closing, the end of the piston rod contacts a strike plate, forcing the piston into the cylinder, compressing the air. Air exiting the cylinder is controlled by a simple globe valve. The buffer



cylinder system, through air pressure, then absorbs shock during the final stages of the closing cycle (Fig. 9). Since the operator can control the rate of span descent, some variance in the pressure pulsation is expected. A determination to include this parameter in the prototype system has not been made.

A matching problem between the sensor and power supply resulted in an unidentifiable scale for the cylinder pressure amplitude. The response of the signals, however, is presented on Plot 7. As expected, the only activity is near the end of the closing cycle. Additional data is needed for thorough evaluation of this parameter's usefulness.

TRAFFIC COUNT

Since the roadway traffic is expected to have some effect on bridge wear, the number of vehicles crossing in both directions will be recorded. Although the number of bridge openings/closings will also

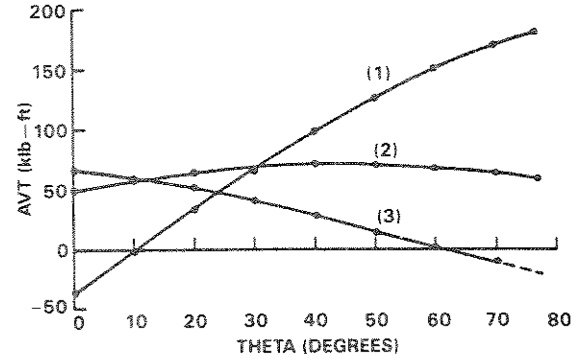


Figure 8. Examples of AVT versus THETA.
(1) Unacceptable because of negative torque at theta = 0.
(2) Near optimal (3) Acceptable

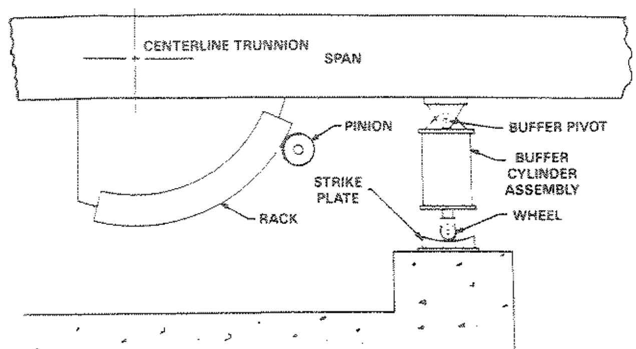
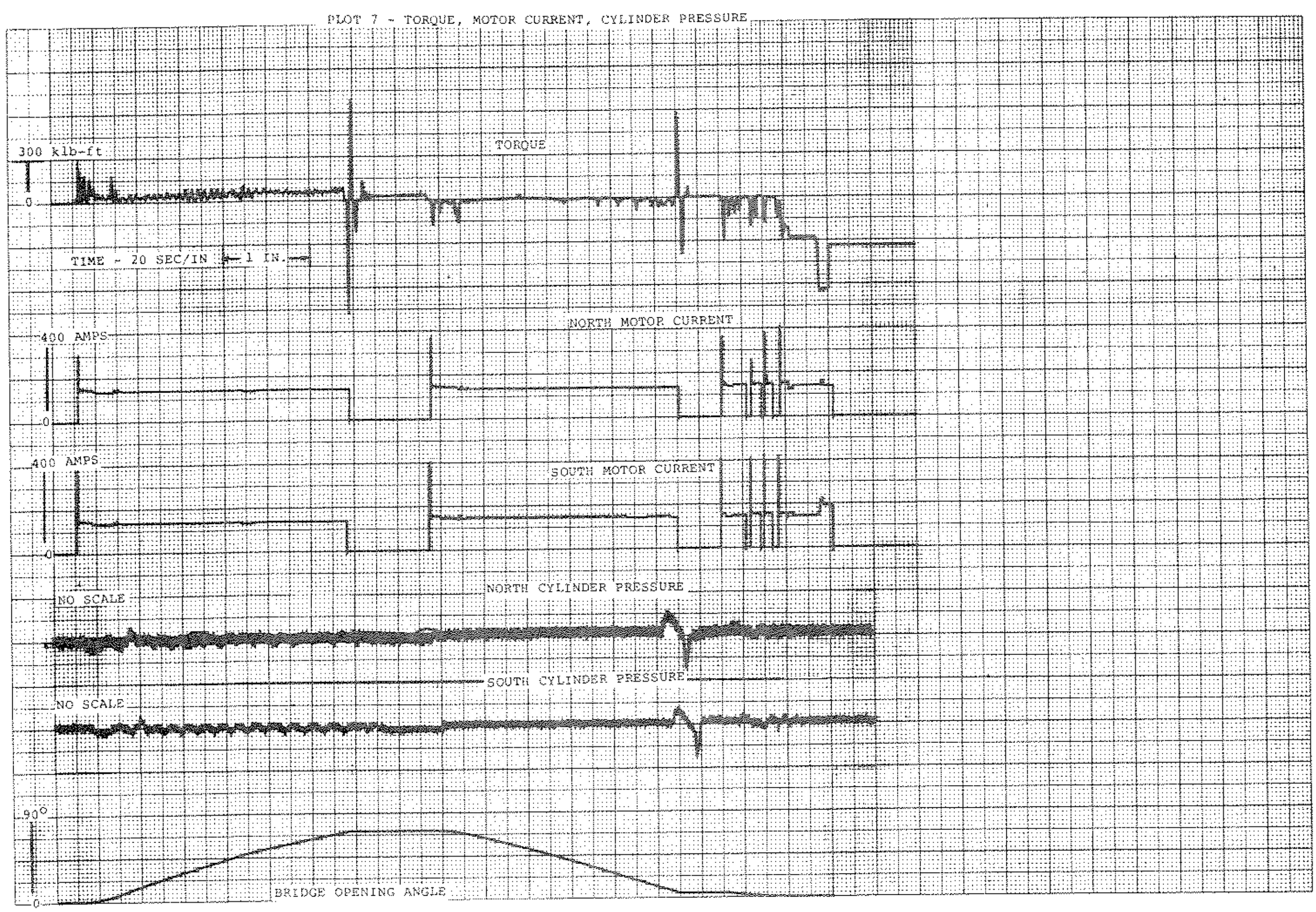


Figure 9. Buffer arrangement of double-leaf bascule.



impact wear, automatic recording is not planned. Water traffic is relatively light, requiring few openings and the entry can be made manually with little effort.

DATA COLLECTOR

This component of the system consists of two (2) major items. The first is a multiplexer/voltmeter that is computer controllable. It will be located under the bridge in an appropriate lockable, weatherproof enclosure. All transducer outputs will be connected to this unit in appropriate fashion. This unit will be connected to the controlling computer (the second item) via an RS-232 communications link. The controlling computer will consist of an IBM PC-XT mainframe, CRT and keyboard; which will be located in the control house with an uninterruptable power supply. Special software is being developed to interface the data acquisition unit and the controlling computer.

A system alarm will "awake and initialize" the data acquiring routine. This will occur once a day at a defined time. At the next bridge operation, data will be gathered from all the appropriate transducers at one (1) second intervals by the data acquisition unit. The time interval is field changeable, should the sample rate need to be changed. The information will then be transferred to the computer for storage. This acquisition will be linked to the bridge controller for timing purposes.

The traffic counts, peak span lock-bar motion and peak live load shoe movement will be a header for the daily information file. Each of these files will be structured and stored to match the Lotus Symphony™ data structure. At least once a month, the daily data files will be retrieved from the controlling computer. This will be accomplished by transferring the data from hard disk to floppy disk.

The data reducer consists of a second remotely located IBM PC-XT personal computer mainframe, along with appropriate peripherals such as printers, extra storage,... Operating with Symphony software, the P.M. system will have all of the capabilities of a state-of-the-art spread sheet. The information can be manipulated in various ways for presentation purposes, allowing interpretation for further system definition. Trends and alarm levels will all be handled through the data reducer system.

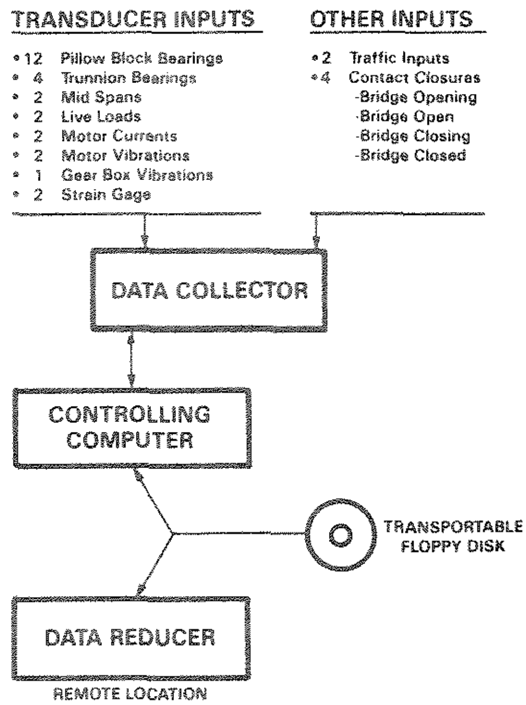


Figure 10. System block diagram.

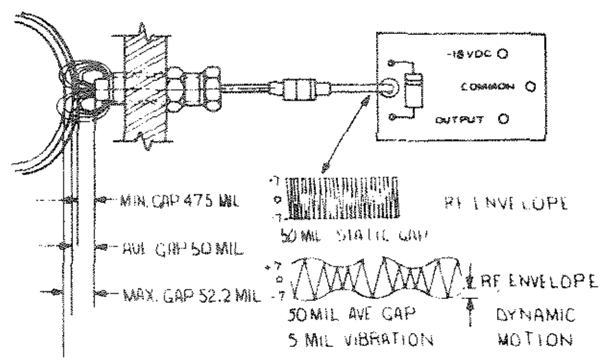


Figure 11. Output of the proximitor is a d.c. voltage which varies as the gap distance varies, thus providing the average gap distance from the probe tip to target surface, plus the vibration excursion level in both frequency and amplitude of the observed motion.

PERSONNEL INTERFACE

At the bridge, no system interaction with the bridge operators will be needed. The system will run automatically, including auto restarts on loss of power. Monthly data will have to be manually retrieved and transported to the data reducer. Virtually all personnel involvement is then limited to the individuals associated with the data reduction/correlation system.

The bridge operator's idiosyncrasies via his/her interface with the control system may have an effect on the data and transducer response patterns. Therefore, trend data will have to be given due consideration for this aspect of the operation. Test data was not acquired in an attempt to depict this.

TRANSDUCERS

The noncontacting proximity probe uses the eddy current principle to measure the gap between the probe tip and the target (Fig. 10). Output from the transducer system is a voltage proportional to the gap change, which is linear over a fixed range (Fig. 11). The probe tip diameter primarily governs the extent of the transducer range. Typical gaps are 50-60 mils (1 mil = 0.001 inches) (Fig. 12).

Two (2) output values are available from the system. One is an ac component which represents the motion of the target relative to the probe. The second is a dc component, representing the average distance between the target and the probe. This allows use of the transducer to measure both vibration (ac component) and position (dc component). The frequency response of the system is from dc to 600,000 cpm, providing a practical range for most applications of dc to 120,000 cpm. Hardware used in this project incorporates additional electronics along with the transducer to provide two (2) conditioned 0 to 10 Vdc output signals proportional to a predetermined ac and dc range.

The velocity transducer is used for measuring casing motion. Output from the device is a voltage proportional to the relative motion between a magnetic field and a coil of wire. Depending on the particular design, either the coil of wire or the magnet is rigidly mounted to the base and the other is suspended as an inertial element. General preference is to rigidly mount the coil.

Frequency response limitation for the velocity transducer is 300 cpm (5 Hz) to 120,000 cpm (2 kHz) with the response curve having a roll off characteristic on both the low and high side. At maximum motor speed, the velocity coil will detect the input speed to the gearbox, both gear mesh frequencies and the motor/rolling element bearing frequencies.

A third vibration transducer is that of the piezoelectric accelerometer. Since it is primarily used for obtaining high frequency information, it is not being used on this project. Mention of the unit is made only for the sake of completion.

Strain gages used are standard two-element Chevron® units with appropriate amplification. Torsional shear strain is measured by mounting gages on the final drive shaft. The motor current transducers are of the transformer type, which are mounted around the input power lines to the motor. Quartz element pressure transducers with an internal IC amplifier were utilized. The units have a maximum range of 1,000 psi with a sensitivity of 5 mV/psi.

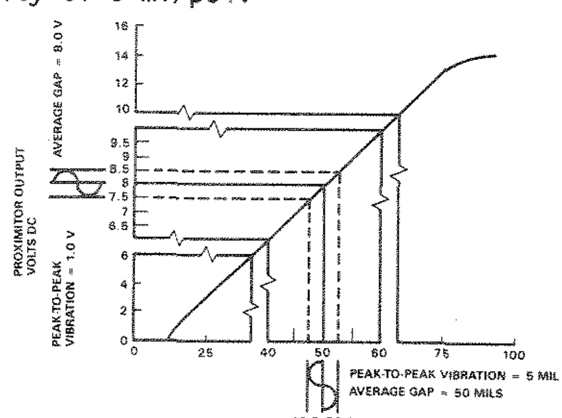


Figure 12. Proximity measurement system for vibration monitoring and machinery malfunction diagnosis, has linear output generated by Proximitor as a function of gap size; and this is key to system performance capabilities.

SUMMARY

From data acquired prior to the refurbishment work, the transducer selection and application seem reasonable. The data is considered useful for several reasons:

- Provide the basis for establishing alarms in the Data Reducer System.
- Enhance the software development work.
- Provide a basis for comparison to reworked machinery.
- Indicates data sampling rates of approximately once/second will provide the resolution initially needed.

Evaluation of the data is beyond the scope of this paper. However, when accomplished and compared to that of reworked machinery, a better understanding of the mechanical aspects of a trunnion bascule bridge is expected.

After running the system for one year, all data will be correlated and used to evaluate all aspects of the design. A determination will be made as to the usefulness of the design, weighing the results obtained against costs of an industrial system.

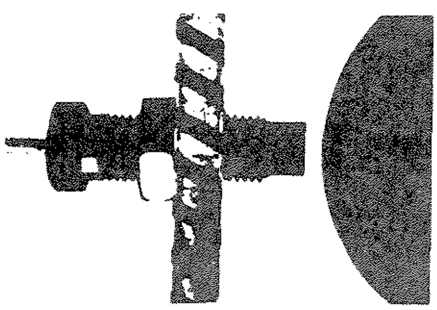


Figure 13. *Typical probe to target* gaps are 50-60 mils.

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BIOGRAPHY

Glenn Poché is the Regional Manager of Mechanical Engineering Services (MES) for Bently Nevada Corporation. He oversees the MES engineers and gives support to the sales representatives within his region.

Poché joined Bently Nevada Corporation in 1972 as a sales representative. In 1983 he was promoted to Regional Manager. In 1984 he was promoted to his present position. He worked for Union Carbide prior to joining Bently Nevada.

Poché graduated from La Mar University in Beaumont, Texas, in 1966 with a Bachelor of Science Degree in Mechanical Engineering.

Bently Nevada Corporation manufactures electronic systems that monitor rotating machinery. Bently Nevada's products and services are sold worldwide.