A COMPUTERIZED PREDICTIVE MAINTENANCE PROGRAM

ON A

TRUNNION TYPE BASCULE BRIDGE

By:

Robert P. Bloomquist
Turbomachinery Vibration Specialist
BENTLY NEVADA CORPORATION
Houston, Texas

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ABSTRACT

This paper is an expansion of a paper presented at the 1st Movable Bridge Symposium entitled *"The Application of Current Transducer Technology on Bascule Bridges as the Basis of a Computerized Predictive Maintenance Program"*. The initial paper covered the transducers utilized as well as the various measured points and their interaction with the bridge operation. Use of a computer and personnel were introduced.

This paper outlines both the firmware and software aspects of the Predictive Maintenance Program. Discussed are the system operation, frequency of sampling, data formats, printouts, trending, ... The system is installed on a bridge operated by the State of Florida located east of Dania, Florida, over the Intercoastal Waterway. Operation of the system will commence upon finalization of other work associated with the bridge refurbishment.

This Predictive Maintenance Program is to be operational for one year as a prototype system on 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.

INTRODUCTION

Double-leaf bascule bridges are used extensively in the southern part of the United States, particularly for automotive traffic. For the most part, these bridges are in both high roadway and waterway traffic providing key crossing of waterways, such as the Intercoastal Canal. The system application outlined in this paper deals with one side of a double-leaf bascule design.

Reliable operation is the major goal of bridge owners in providing the smooth flow of both roadway and waterway traffic to the general public. In maintaining the safe reliable operation, the mechanical aspects of the lifting and support mechanisms must be properly maintained. This is particularly important since the bridge "tenant" is the only on-site personnel and has the sole responsibility of operating the bridge.

Supporting the mechanical equipment are district maintenance personnel, who provide periodic lubrication and a state wide central group providing periodic balancing work. Work beyond these two aspects generally falls to the broader refurbishment work provided at multi-year intervals.

Modern maintenance methods in other industries use selected transducers to measure key parameters on mechanical equipment to predict machinery degradation. Hence, it was felt by the State of Florida that these techniques could enhance bridge operations. By applying these techniques, it is anticipated that unplanned breakdowns will be minimized and wear of key components will be measurable, enabling more orderly maintenance and bridge reworks.

With any trial or prototype system, flexibility is necessary to allow for changes, revisions and upgrades as more information is acquired. In keeping with this logic, a standard personal computer, along with well known business software, is being utilized in this effort.

For the one year operation of the system, maximum, minimum and average values, where applicable, are stored and trended. The data base for most parameters comes from a single bridge opening/closing daily. Other parameters are monitored continuously and all data is correlated with auto traffic and the number of openings/closings which reflect wear of the mechanical equipment.

MAINTENANCE METHODS

It has been found in other industries that the reliability of mechanical equipment is quite proportional to 1) practices used in installing the equipment and 2) the practices used in maintaining the equipment. Additionally, today's technology allows for sophisticated practices at justifiable costs.

Maintenance costs can be minimized by using the basic program of lubricating equipment, as per generally accepted practices or as recommended by equipment manufacturers. Under this program, when things break, they are fixed. Often, these repairs have to be made under duress at overtime rates and with significant damage. Also, in the case of a bridge, traffic of either the waterway, roadway or both are interrupted. This program is generally called Breakdown Maintenance.

A higher level program is one where equipment is overhauled at some predetermined interval. The logic being that the intervals will be such that the overhaul occurs before major failures. Work, of course, is planned and costs are controlled. Unfortunately, for such a program to work, the intervals have to be conservative, which means overhauls are performed before they're really needed. The result is the expense of throwing away good parts and/or running the risk of damaging good parts during the overhaul. This program is often referred to as Preventative Maintenance.

The successful maintenance programs today certainly require the continuance of a sound lubrication program, but this is augmented with expense up front to continuously or periodically observe certain machinery parameters. By properly selecting transducers, parameters, and data sampling intervals, machinery condition can always be known. Therefore, machinery is repaired only when necessary and in a planned manner. The terminology used today for these programs is Predictive Maintenance.

Other industries have proven the expense of the Predictive Maintenance programs are justifiable, based on the maintenance costs alone. The following outlines the system firmware/software aspects of a Predictive Maintenance Program for a bascule type trunnion bridge.

SYSTEM OVERVIEW

The computerized predictive maintenance system is essentially a two-block system. A data acquisition system automatically controlled by an IBM PC-XT computer is installed in the field, which automatically gathers information and builds a data base. A second IBM PC-XT serves as an office-based data reduction computer used to analyze the field data.

Various parameters reflecting bridge condition are monitored 24 hours/day by the data acquisition computer. Data is temporarily stored on the data acquisition computer's hard disk. On a monthly basis, this data is manually dumped to floppy disks for use with the office-based data reduction computer.

The data reduction computer transfers the data stored on the floppy disks to its own hard disk. The data reduction program allows the user to generate and print graphs displaying the data sampled during that month. Trend analysis can be performed by comparing each month's graphs with previous graphs. Significant trends in the data can be noted and related back to the bridge condition as a basis for predictive maintenance.

PC-CONTROLLED AUTOMATED DATA ACQUISITION

An IBM PC-XT is being used to control data acquisition. The data acquisition software routine runs automatically, continuously, and requires personnel interface only once-per-month during the transfer of data. A battery back-up supplies power to the computer in the event of a power outage so that no data will be lost.

Each day, the computer opens several data storage files in which are kept running records of the various parameters being monitored. An internal clock is used to prompt the computer to end a day's sampling. Data files for that day are stored on the computer's hard disk and new files are opened for the following day.

Two types of data are sampled. With the bridge in the closed position, "Static" data is sampled continuously from various transducers. Sampling of "Static" data is temporarily interrupted when the bridge opens and "Dynamic" data sampling from additional transducers is initiated. To enable the computer to differentiate between "Static" and "Dynamic" data acquisition, signals indicating bridge status (i.e. closed, opening, open, closing) are relayed directly from the bridge's control console to the data acquisition system. The computer monitors these status signals and samples "Static" or "Dynamic" data accordingly. The bridge's current status and the task currently being performed by the data acquisition software are displayed on the CRT so that an observer can check operation without interrupting the program.

During "Static" data acquisition, raw data taken directly from all the appropriate transducers is temporarily stored electronically in signal conditioners. At 15-minute intervals (field adjustable) the computer reads information from the signal conditioners and updates the "Static" data file being built for that day. This scheme enables uninterrupted acquisition of "Static" data while the bridge remains in the closed position.

"Dynamic" data is sampled during one bridge opening/closing per day. The computer receives a "bridge opening" status signal upon a bridge opening and temporarily interrupts "Static" data acquisition. If the bridge opening is the first to occur after 12:00 noon (also field adjustable), "Dynamic" data is gathered from all the appropriate transducers at approximately one (1) second intervals. Sampling is momentarily paused while the bridge is held open for boat traffic but continues during the closing. Normal acquisition of "Static" data is resumed once the bridge is fully closed.

On a once-per-month basis, data is manually dumped from the data acquisition computer's hard disk to "floppy" disks for transfer to a remotely located data reduction computer. The data dump procedure is quite simple and is the only function which requires personnel interface. As this is a prototype system designed for one (1) year of operation, the manual method of data transfer was selected over a remotely controlled method via a communications modem.

OFFICE-BASED DATA REDUCTION SYSTEM

An office-based IBM PC-XT and peripheral printer is used for data reduction. The data reduction computer is configured with customized Lotus Symphony spreadsheet programming to allow both flexibility and efficiency for processing bridge data and generating graphs for trending and analysis. Each month's data is transferred from the "floppy" disks to the data reduction computer's hard disk, where it can be readily accessed by the data reduction software. The used "floppy" disks can then serve as back-up disks and storage for archival purposes.

The data reduction software consists of a spreadsheet (similar to Lotus 1-2-3), which is automatically loaded at the start of each data reduction session. The user controls use of the spreadsheet by selection of customized menu-driven commands structured with Symphony's Macro Command Language (Fig.1). The menu selections help the user load, scale, and format data, and allow the user to preview and print graphs for analysis and trending purposes. The user need not be familiar with spreadsheets to run the data reduction software. Menu-driven commands standard to Symphony are also available to the user for normal spreadsheet tasks.

Spreadsheet-style data reduction was chosen for this prototype system over formally written software for several reasons. Spreadsheets offer good visibility of data being processed and are excellent for handling large amounts of data. For example, a typical month's worth of bridge data will take up approximately 400 K-bytes worth of computer memory. Spreadsheets also offer flexibility in the event of additions or modifications. The graphics and macro-

DANIA BRIDGE
DATA REDUCTION PROGRAM

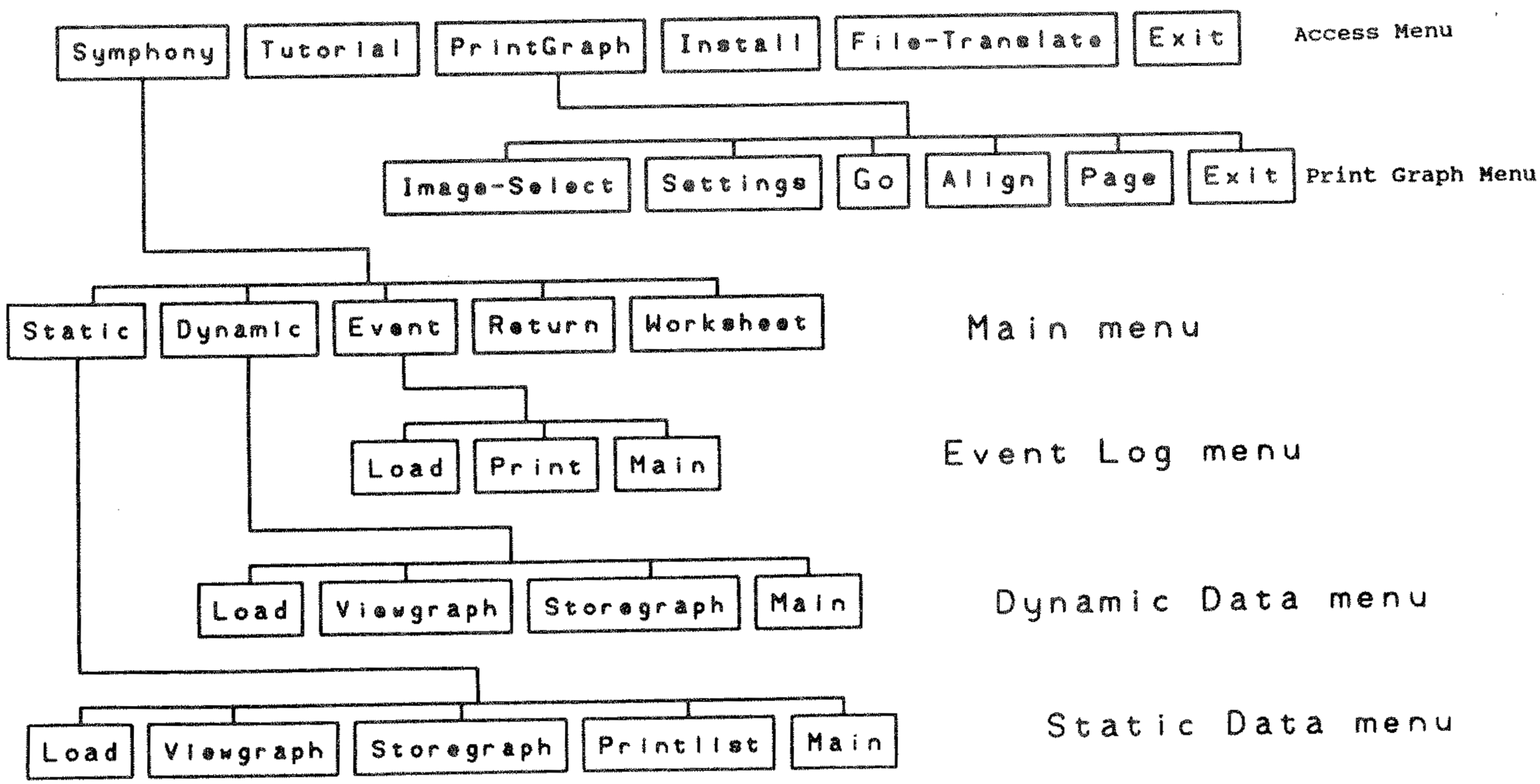

Fig. 1 Menu Structure

programming capabilities included with the Symphony software are also well suited for this application.

DATA PRESENTATION FORMATS

Each graph presents approximately 30 day's worth of data so that trend analysis can be performed while maintaining good resolution of individual data points. Mechanical failures due to daily wear and tear should exhibit visible trends in the graph data early enough for corrective measures to be taken. To perform trend analysis on a larger data base, graphs are compared from month to month.

All graphs use a similar format, plotting various measurements for each day over the 30-day data base. Daily absolute maximums and minimums for some parameters are presented while daily absolute maximums and averages are presented for other parameters where appropriate.

"STATIC" DATA ANALYSIS AND INTERPRETATION

When the bridge is closed and automobile traffic permitted, various parameters comprising "Static" data are sampled continuously. Deflections at the midspan locks and live load pad areas are monitored, as well as eastbound and westbound traffic counts.

MID-SPAN MOTION

Data from non-contacting proximity probes observing motion of the midspan lockbars within their guides is presented in the daily maximum/minimum format. The difference between the absolute maximum and minimum values for a given day is indicative of the amount of relative motion of the lock bar within the guides. This can be better interpreted as the maximum relative leaf-to-leaf motion to occur at the midspan during automobile use (Fig. 2).

Trending this relative motion over time can reflect changes in the bridge balance condition as well as wear or damage to the lock bar assembly. Though this can be considered a relative measurement, the direction of wear propagation can be determined by absolute changes over time in either the absolute maximum or minimum measurement.

LIVE-LOAD AREA MOTION

Similarly, absolute maximum and minimum measurements are obtained from proximity probes observing relative motion of the live-load shoes relative to the pads. Bridge balance condition, wear and positioning of the live-load contact areas, as well as lock-bar problems are several factors which contribute to this relative motion. Measurements here are also indicative of how well gearing wrap-up is assuring positive contact on the live load pad area after bridge closures. Again, changes in absolute measurement values are indicative of the direction of propagation and may be helpful to determine the source of the problem (Fig. 3).

TRAFFIC COUNTS

Daily car counts of eastbound and westbound automobile traffic are also tallied for further correlation between bridge component wear and traffic use. This type of information can also be used when scheduling routine maintenance requiring temporary closure of the bridge.

"DYNAMIC" DATA ANALYSIS AND INTERPRETATION

PILLOW-BLOCK AND TRUNNION BEARINGS

Proximity probes observing shaft surfaces within the pillow block bearings of the Hopkins Drive unit will provide two types of measurements during bridge opening/closing data acquisition: 1) shaft centerline position within the bearing, and 2) peak-to-peak motion of the shaft relative to the bearing. Daily maximums and averages of these measurements are presented graphically. Measurements here will be

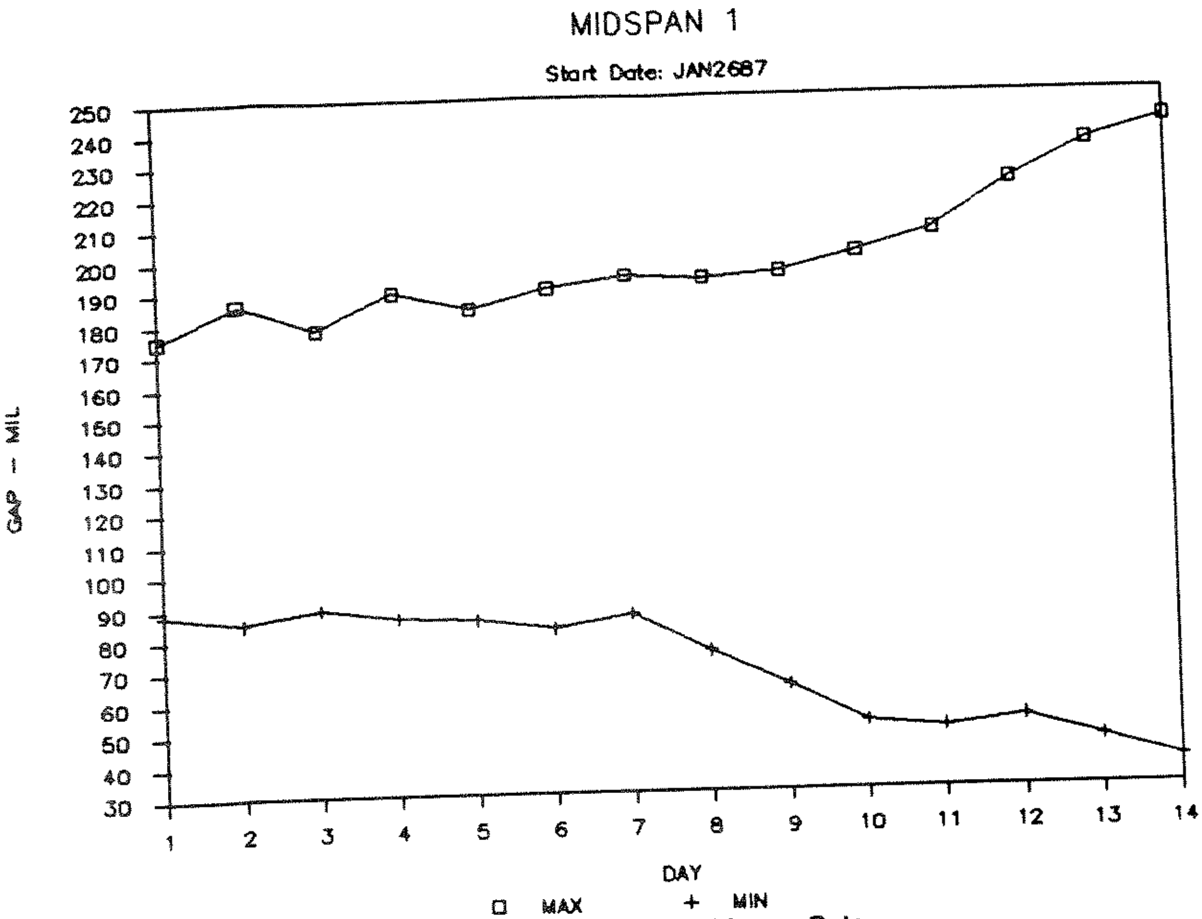

Fig. 2 Simulated Midspan Data

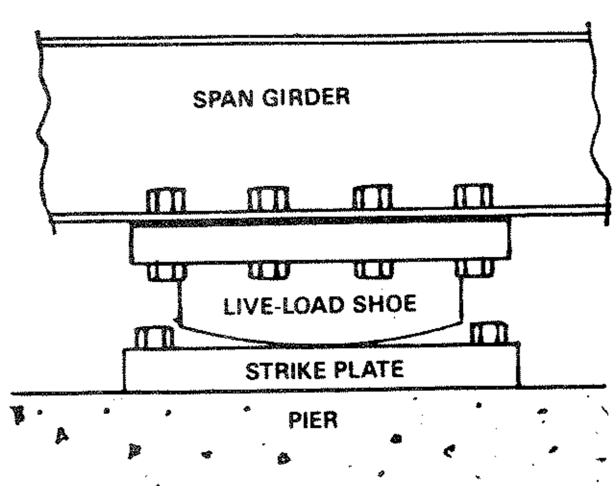

Fig. 3 Strike Plate and Load Shoe

indicative of gear alignment, gear forces (bridge balance state), bearing lubrication, and bearing clearances. Due to the high sensitivity of the eddy-current proximity probes being used, however, shaft surface irregularities are likely to contribute "false" readings as the probes observe the rotating shaft surfaces. Because these "false measurements can easily be confused with real dynamic measurements, trending is especially important since any changes reflected in the data are considered real (Fig. 4 and Fig. 5).

Shaft measurements are also made with proximity probes mounted in the trunnion bearings. Daily maximum and average measurements of shaft position and peak-to-peak motion are presented in the same format as the pillow block bearing data.

GEAR BOX AND MOTOR VIBRATION

Daily maximum and average vibration readings on the gear box casing and drive motor housings are presented graphically as well. Changes in average values may be indicative of deteriorating rotating elements such as gear teeth and shaft journals, or of bearing deterioration. The maximum values are likely to correspond to the step-increases in torque normally experienced during motor starts. Changes here over time could be indicative of a torque-transfer problem.

DRIVE MOTOR CURRENT

To cover one important electrical aspect of bridge operation, daily maximum and average measurements of drive motor current are also presented graphically. Changes over time which could be noted here may be indicative of mechanical restraints to bridge opening such as bridge imbalance or friction due to poor lubrication. Trend analysis may also pinpoint electrical problems should they occur.

TORQUE/BRIDGE BALANCE

Maximum and minimum drive shaft torque measurements provide information directly related to the bridge balance condition. This information is provided in the form of torsional strain measured with strain gages mounted on the geared shafts which drive the racks to open and close the bridge (Fig. 6). A simple conversion factor can be calculated to convert strain values directly to torque (ft-lbs). The maximum and minimum values basically represent the end points of the balance curves currently used by the Florida Department of Transportation to perform bridge balance analysis (Fig. 7). Different torques, either positive (leaf heavy) or negative (tail heavy) are transmitted through the drive shafts as a function of bridge opening angle. Optimum balance is achieved when a slightly leaf heavy bridge requires a small amount of positive torque to open. This will prohibit accidental opening of the bridge should span locks not be driven.

Bridge balance can change over time due to dirt and debris deposits, and point wear among other things. Trending of this parameter can be used as a basis for future re-balancing. The bridge torque measurements can also shed light on other problems associated with torque-transmission such as friction caused by poor lubrication, and electrical and mechanical aspects of drive motor operation.

FUTURE HARDWARE AND SOFTWARE POSSIBILITIES

Refinements and modifications standard to any prototype system should result from this project as well. It is expected that some parameters will provide more useful information than others; some may even be eliminated from a future system. Also, looking at data on a 30-day basis for trending may be sufficient to anticipate some mechanical failures while mechanical failures of other types may occur over a much shorter period of time. For example, degradation of the bridge balance may take many months to propagate to a condition of concern whereas a damaged lock-bar assembly may fail from only a minimum number of bridge opening/closing cycles.

The prototype system will provide the information necessary to determine optimum

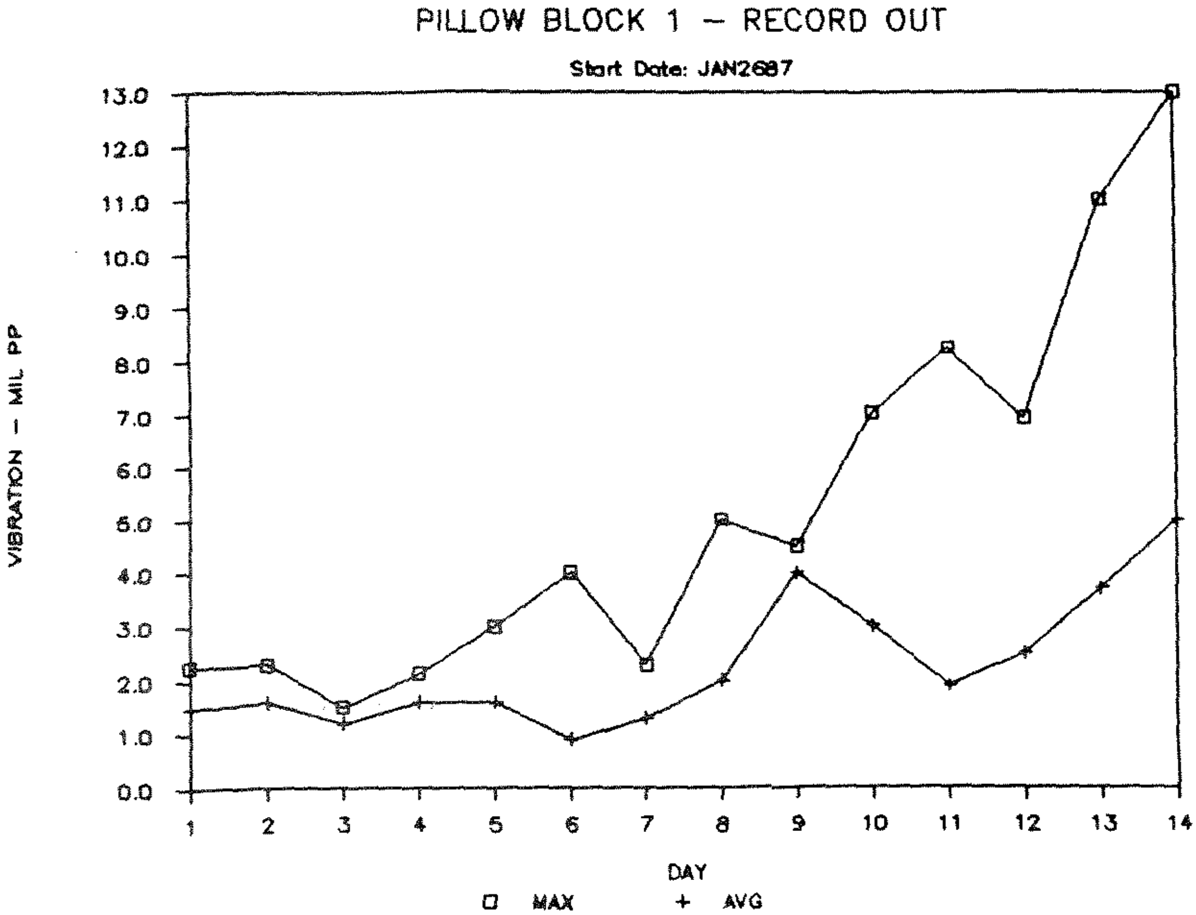

Fig. 4 Simulated Pillow Block Bearing Data

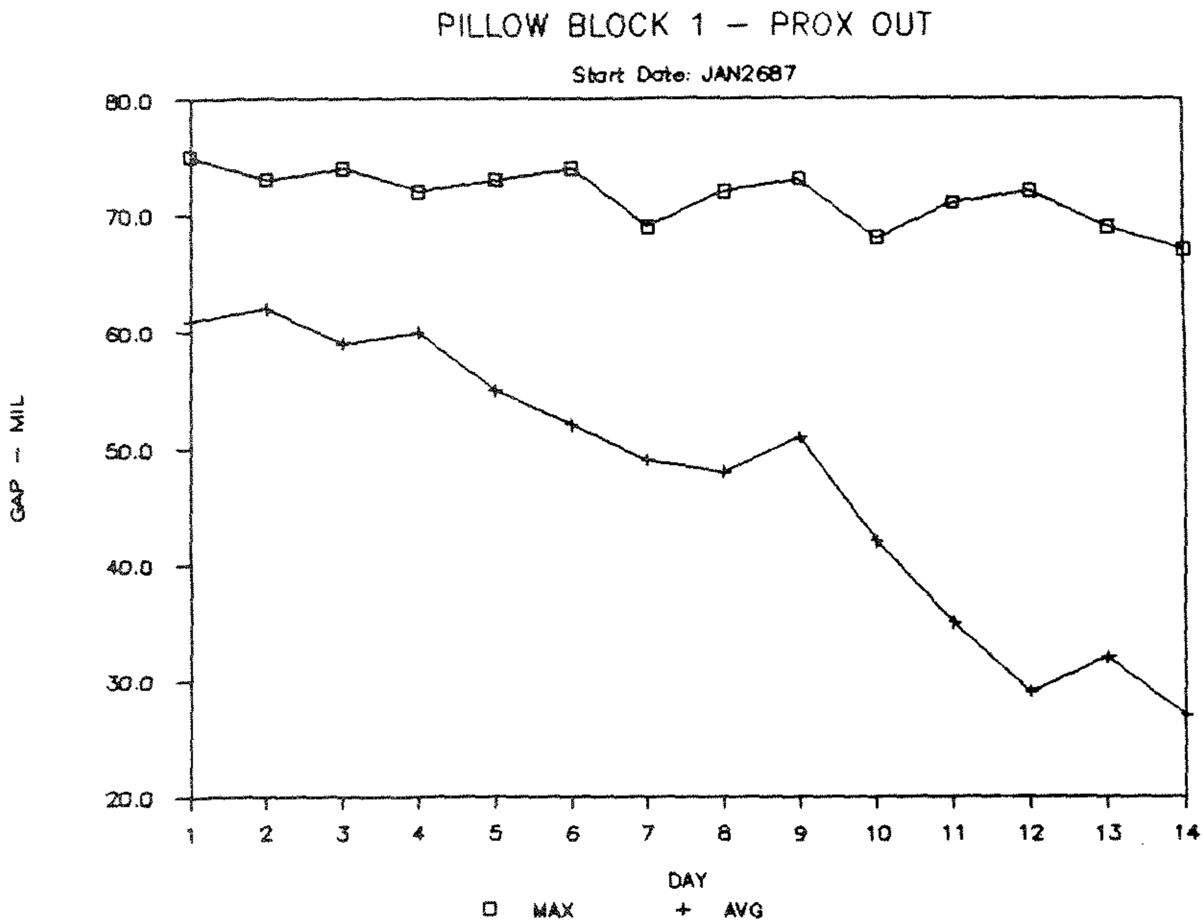

Fig. 5 Simulated Pillow Block Bearing Data

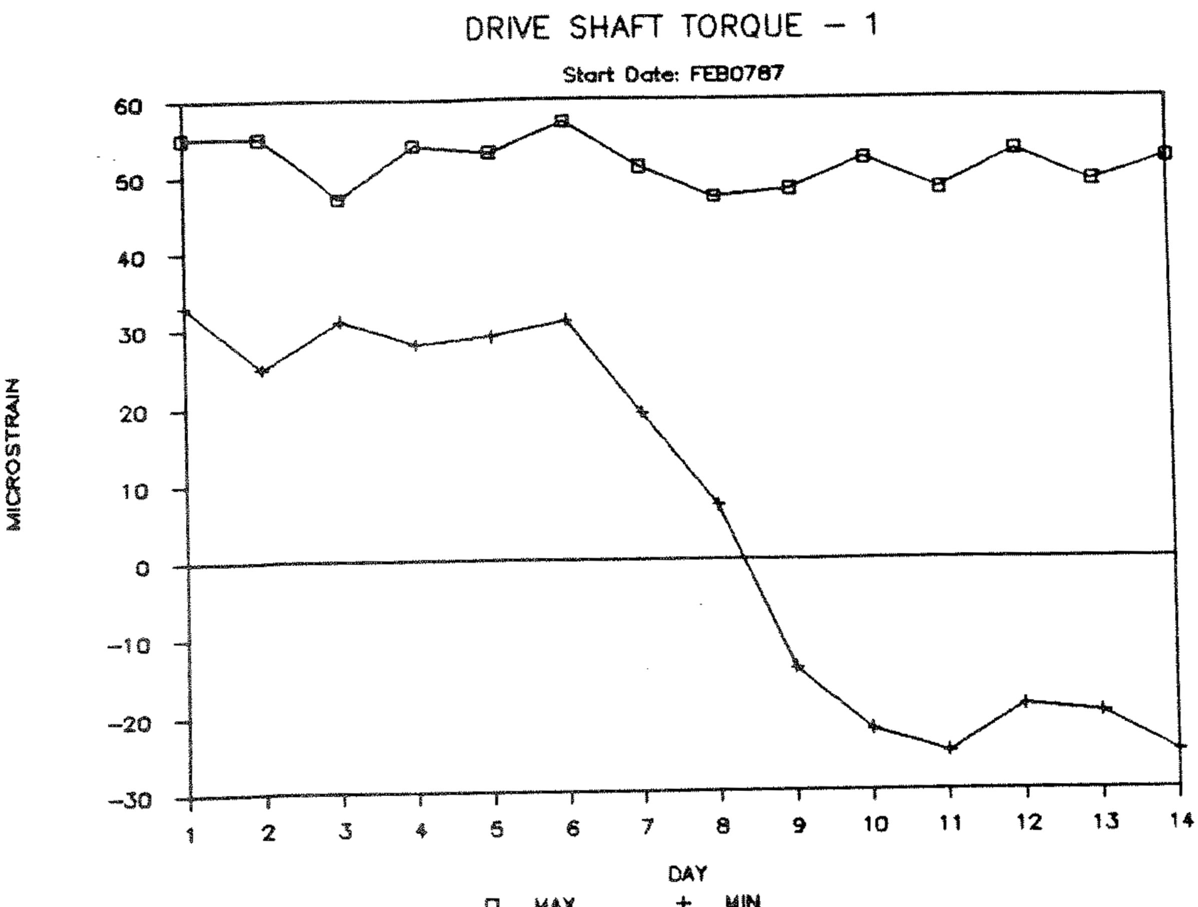

Fig. 6 Simulated Drive Shaft Torsional Strain Data

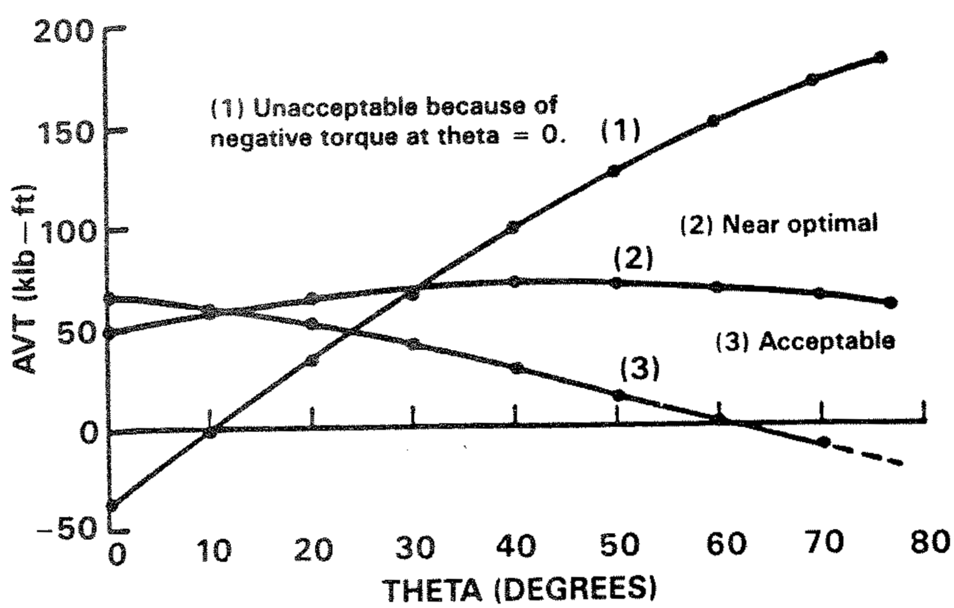

Fig. 7 Examples of Torque Versus Opening Angle

data acquisition sampling rates and optimum trend analysis periods for various parameters. Data sampled during the one (1) year trial operation can be used to establish the appropriate boundaries between data values reflecting mechanical conditions satisfactory for operation and those requiring immediate attention.

One way to accommodate these requirements is to employ direct communication between the data reduction/analysis system and the data acquisition system. Once transducer and signal conditioning system refinements are known, automated data acquisition can be accomplished through minimal instrumentation. A microprocessor-controlled data recorder, basically a computer and data acquisition device rolled into one, can be used to handle data acquisition. Communication between the data acquisition system and the office-based PC used for data reduction can be established at daily intervals or even less through a telephone communications modem. The data reduction system can immediately process the data and can provide "alarms" if any of the parameters have reached critical condition.

One office-based PC can continuously monitor, through communications modems, data gathered from a network of bridge data acquisition systems, providing up-to date information from a number of bridges and indicating which parameters require the most immediate attention. Maintenance measures can be scheduled on a more timely basis, and maintenance costs reduced.

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