F R A
TASK ORDER #30A
WORK EFFORT 2
SHORT TERM TEST

FINAL REPORT

Acquisition and Analysis

of

Wayside Acoustical Noise & Infrared Heat Signatures

associated with

Roller Bearing Defect Progression

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111 New South Road
Hicksville, New York 11802

June 1989

INTRODUCTION & SUMMARY

Under FRA Task Order #30A, Work Effort 2, Short Term Test, twenty-four (24) Class F (6½ x 12) 100-ton roller bearings with a range of cone bore/axle interference fit tolerances and end clamp loads were operated until failure, or for a maximum of 5,000 miles under loaded cars on the RTT at TTC, Pueblo.

In an extension of the program, bearing acoustical noise signatures and infrared heat signatures were acquired wayside by Servo's Advanced Development System.

Analysis of the data was expected to uncover acoustical noise and infrared heat patterns indicative of the rate and degree of bearing failure progression.

However, except for two (2) bearings that did not survive the 5,000 mile test and a third that did, all of the others operated normally under load for 5,000 miles without emitting significant heat or acoustical noise, or exhibiting any other indication of distress.

The two (2) exceptions that did not survive have severe cup and cone raceway defects in addition to radial and lateral retention anomalies. They were removed in the first few days of the 5,000 mile test after generating excessive heat. Only one (1) emitted some acoustical noise. However in a following supplemental 800 mile test, the other severely defective bearing emitted discernible acoustical noise and generated excessive heat.

The third exception occasionally generated excessive heat during the 5,000 mile test, but otherwise operated normally. During the 800 mile test, no excessive heat was generated and operation was normal.

ROLLER BEARING FAILURE MECHANISMS

Evaluate Twenty-four Roller Bearings

Interference Fit Range: $0 \leq IF \leq 0.0045''$

End Clamp Load Range: $0 \leq ECL \leq 20{,}500$ lb.

Grooved Axle Condition

5000-mile Test on RTT

Test Variables

- Cone/Journal Interference Fit
- End Clamp Load
- Cone Slippage Rate
- Bearing Operating Temperature
- Lubricant Leakage
- Bearing Component Wear
- Train Speed

WAYSIDE ACOUSTICAL & INFRARED DETECTOR

In Servo's Advanced Development System, acoustical detector functions consisting of two (2) Trackside Acoustical Sensors (TAS), an Acoustical Signal Processor (ASP), associated software and a DATAGRAPH chart recorder/printer are added to, and integrated with, the SYSTEM 9000 microprocessor-based HBD. A detailed description of the system configuration and basic principles of operation is presented in a paper published in the proceedings of the 9th International Wheelset Congress, and in Servo brochures, included in the Appendix.

Initially, Servo had proposed to convert the SYSTEM 9000 HBD at the AAR Committee F site on the RTT into an Advanced Development System configuration by adding and integrating acoustical detector functions.

However, since that SYSTEM 9000 HBD has been calibrated and used by Committee F in characterization tests of new trucks, to avoid any possibility of disturbing the calibration, or of interfering with its use, Servo voluntarily installed a new and independent Advanced Development System at the site for this program.

Data processed by the system in real time was displayed and recorded on DATAGRAPH charts, one for acoustical signatures and another for infrared signatures. Ancillary instrumentation recorded raw acoustical and infrared sensor signals on multi-track magnetic tape.

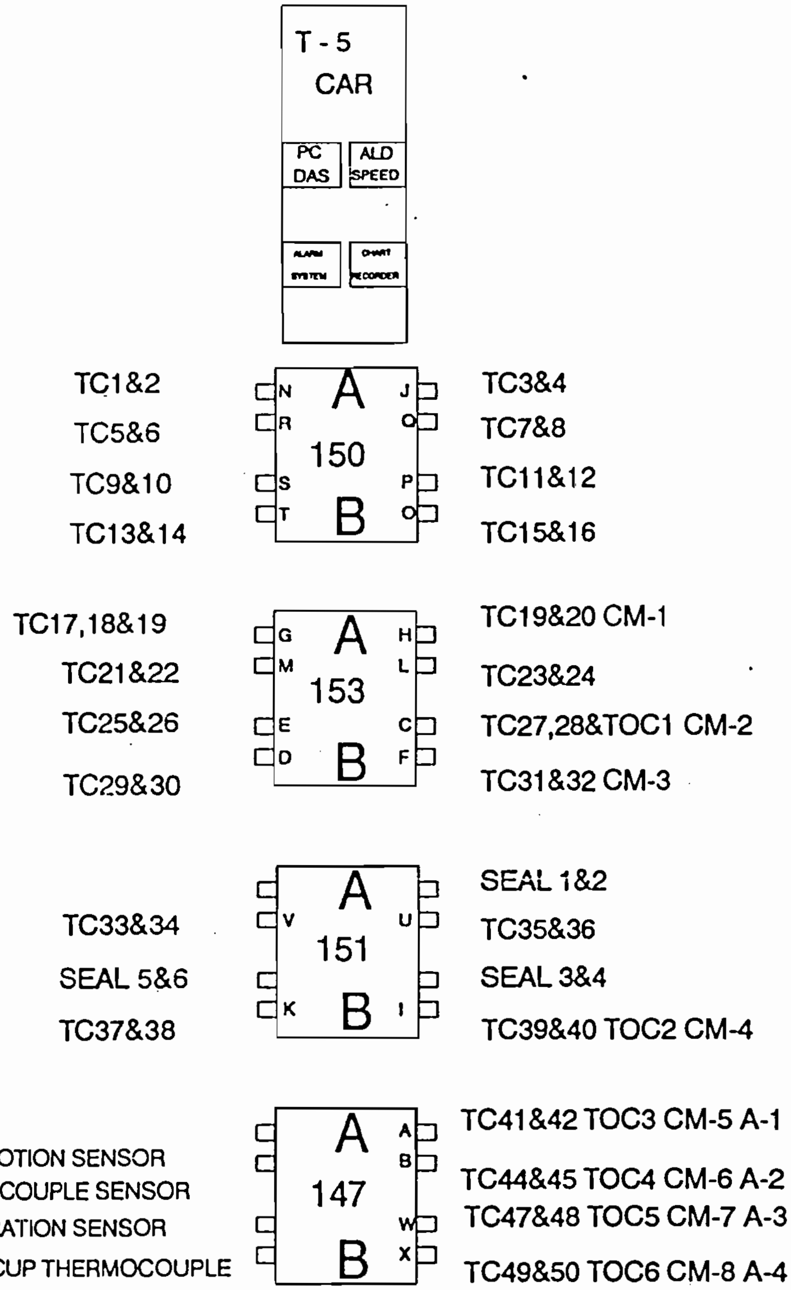
DEFECTIVE BEARING SPECIMENS & CONSIST INSTRUMENTATION

The range of cone bore/axle interference fit tolerances and end clamp loads for the specimen bearings, and the location of the specimen bearings in the test train consist, are shown in the attached chart.

The bearings were instrumented with thermocouples, cone motion sensors, and accelerometers. Sensor outputs were monitored and recorded during train operation.

The Advanced Development System, along with other HBD's at the Committee F site, and another HBD on the RTT near the HTL monitored bearing heat.

Bearings A and B in an 'as found' condition have grooved axles (i.e., loose, turning cone) and additional defects not noted on the chart. The loose cone on bearing A (Brenco 20825) is on the outboard end. The associated cone and cup raceways and rollers have severe spalls. The loose cone on bearing B (Brenco 27828) is on the inboard end. Again, the associated cone, cup and roller surfaces have defects, but not as severe as those on bearing A.



CM = CONE MOTION SENSOR
TC = THERMOCOUPLE SENSOR
A = ACCELERATION SENSOR
TOC = TOP OF CUP THERMOCOUPLE
SEAL = SEAL CASE THERMOCOUPLE

CLAMP	INTERFERENCE FIT					
	GROOVED	ZERO	0.00075	0.0015	0.002	0.0045
ZERO			G,H	L,M		U,V
AS FOUND	A,B					
10-TON		C,D	I,J	N		
SPEC		E,F	K	P,Q		
SPEC				R,S	O,T	

PROGRAM SCHEDULE - SIGNIFICANT EVENTS & OBSERVATIONS
(5,000 Mile Test - 10 March 1989 through 7 April 1989)

Due to delays in acquiring the specimen bearings and in assembling and instrumenting the consist, field activity at TTC did not begin until the first week of March 1989.

Servo personnel completed the installation of the Advanced Development System on the RTT at the Committee F site on March 2 and 3, 1989 and were ready for train operation on Monday, 6 March 1989.

Intermittent preliminary train operation and debugging of consist instrumentation occupied most of the week of 6 March. Meaningful train operation and gathering of data began on Friday, 10 March.

Almost immediately on Friday, 10 March, bearing B began to exhibit abnormal heat, while emitting a very small amount of acoustical noise (DATAGRAPH charts 1, 2, 3 and 4). All of the other bearing specimens operated normally.

NOTE

> *In reading DATAGRAPH charts, the top group of signatures represent those for the far rail train side, and the bottom group, those for the near rail side. Axle locations are determined from the axle pulses on the top trace.*
>
> *Normal direction around the RTT is counter-clockwise or Eastbound with severely defective bearings A and B outboard around curves and with signatures recorded on the lower group of the DATAGRAPHs. For the Westbound direction, locations are reversed.*

After a few passes around the RTT, bearing B tripped hot box alarms without emitting any significant acoustical noise. Bearing A, although hot as measured by on-board instrumentation, did not trip hot box alarms and was quiet. All of the other bearings behaved normally.

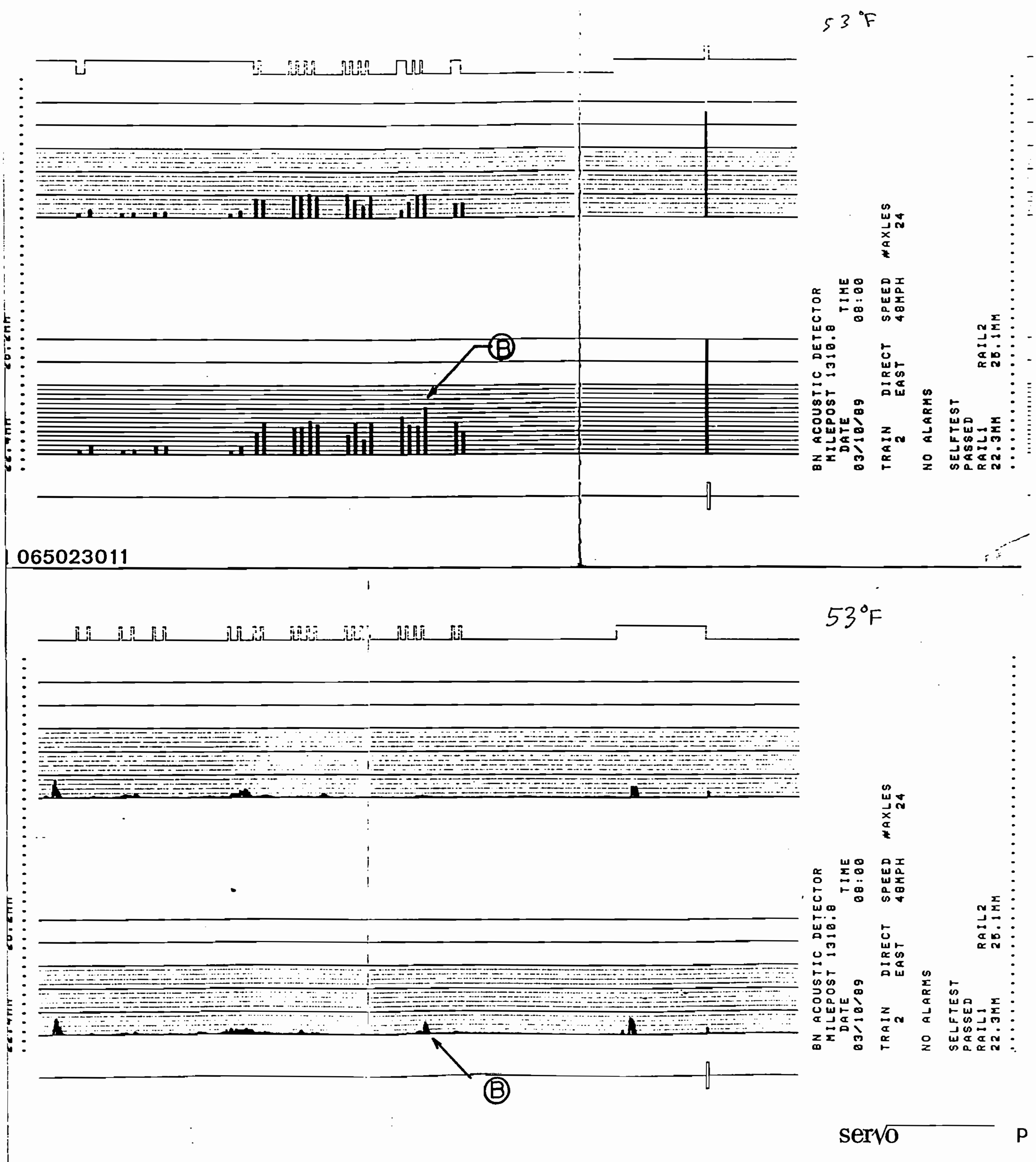
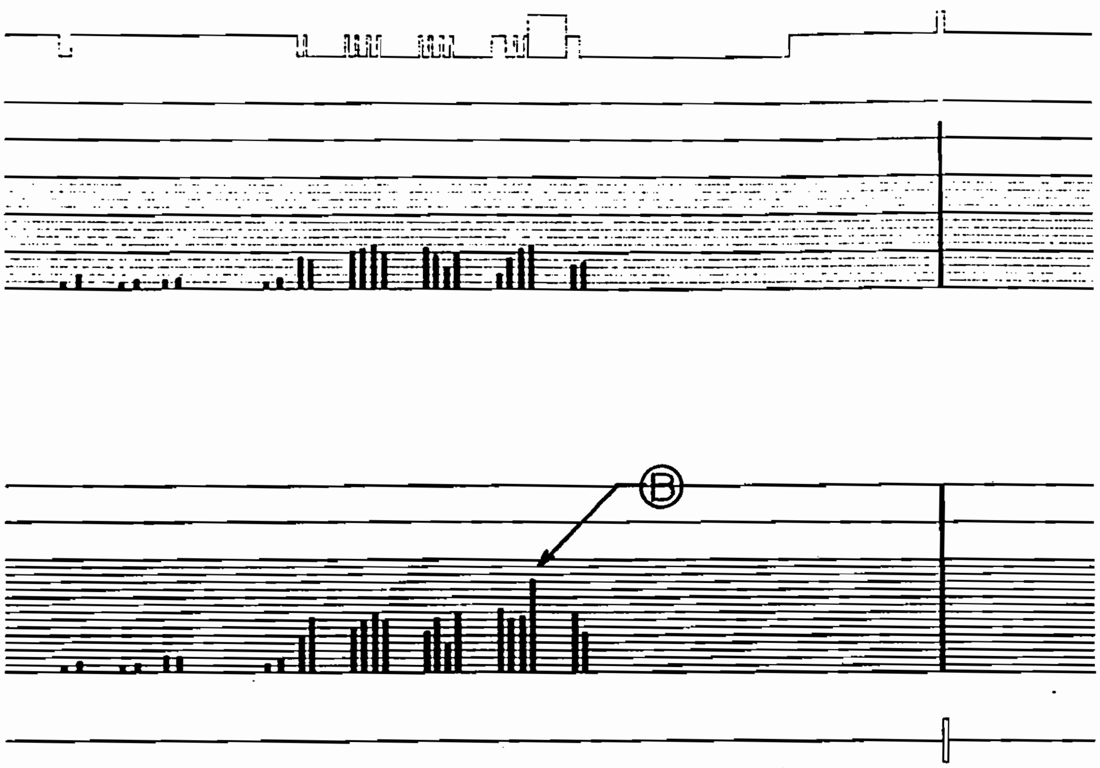

53°F
B
BN ACOUSTIC DETECTOR
MILEPOST 1318.8
DATE 03/18/89
TIME 08:00
TRAIN 2
DIRECT EAST
SPEED 48MPH
#AXLES 24
NO ALARMS
SELFTEST PASSED
RAIL1 22.3MM
RAIL2 25.1MM
065023011
53°F
B
BN ACOUSTIC DETECTOR
MILEPOST 1318.8
DATE 03/18/89
TIME 08:00
TRAIN 2
DIRECT EAST
SPEED 48MPH
#AXLES 24
NO ALARMS
SELFTEST PASSED
RAIL1 22.3MM
RAIL2 25.1MM
servo
P

CHART 1

60°F



BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE TIME
03/10/89 08:32

TRAIN DIRECT SPEED #AXLES
3 EAST 50MPH 24

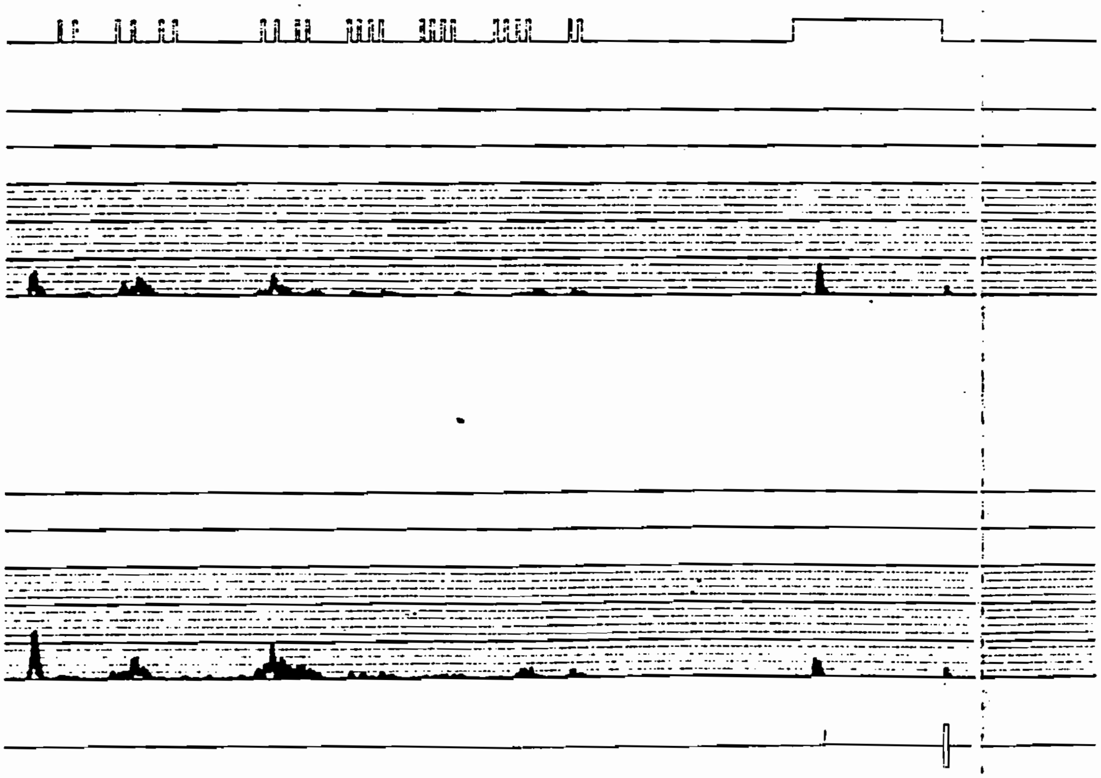
AXLE-COUNT-FROM-HEAD-
ALARM TYPE HEAT RL# AXLE#

HOT BEARING 12.0MM 2 22

SELFTEST
PASSED
RAIL1 RAIL2
21.6MM 25.2MM

servo P/N 065023011

60°F



BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE TIME
03/10/89 08:32

TRAIN DIRECT SPEED #AXLES
3 EAST 50MPH 24

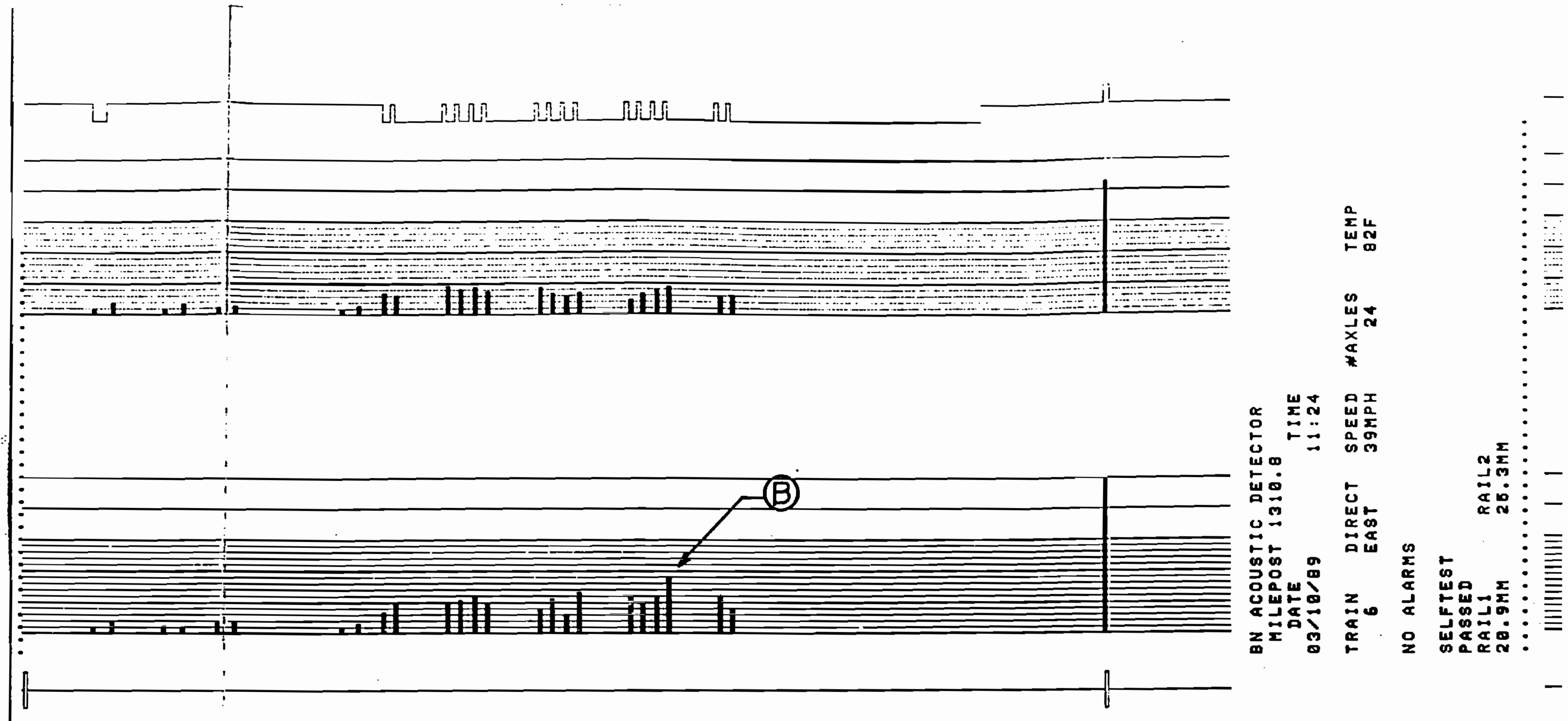
AXLE COUNT FROM HEAD
ALARM TYPE HEAT RL# AXLE#

HOT BEARING 12.0MM 2 22

SELFTEST
PASSED
RAIL1 RAIL2
21.6MM 25.2MM

P/N 065023011

CHART 2



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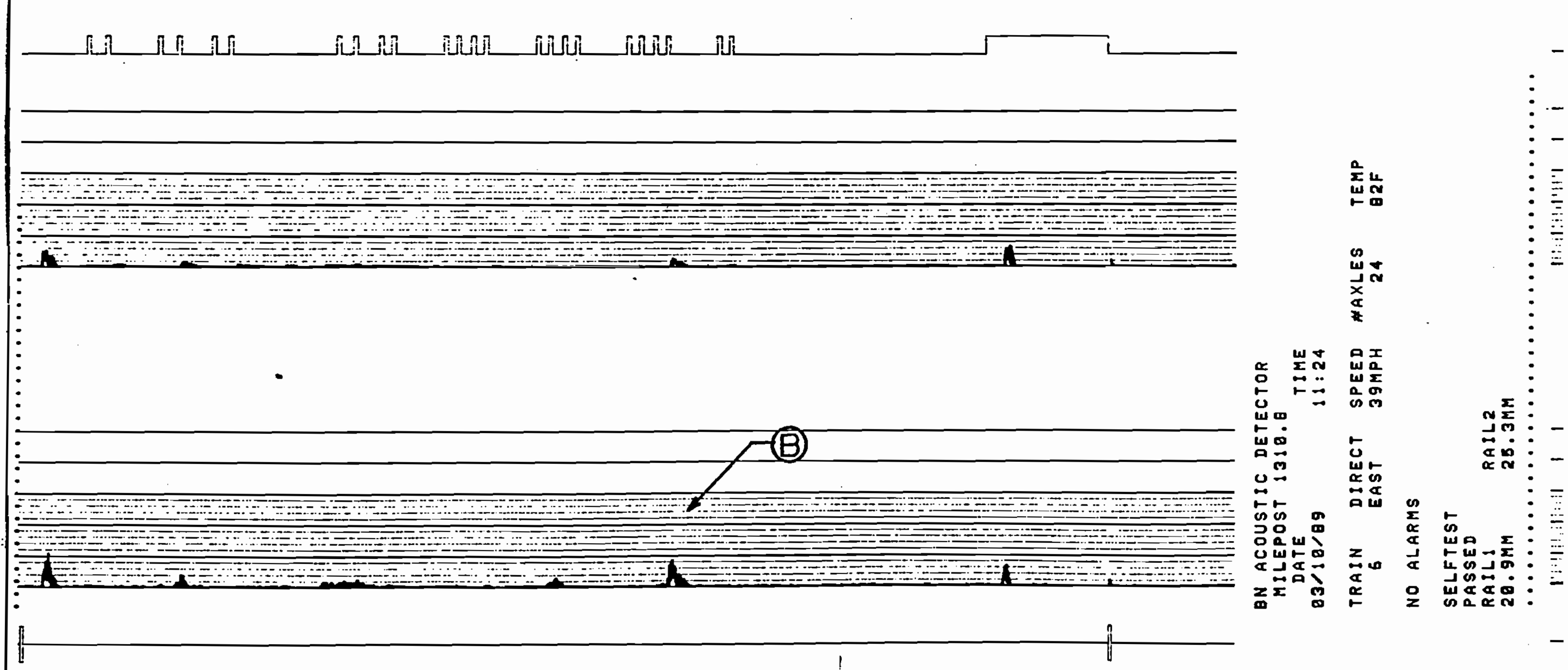

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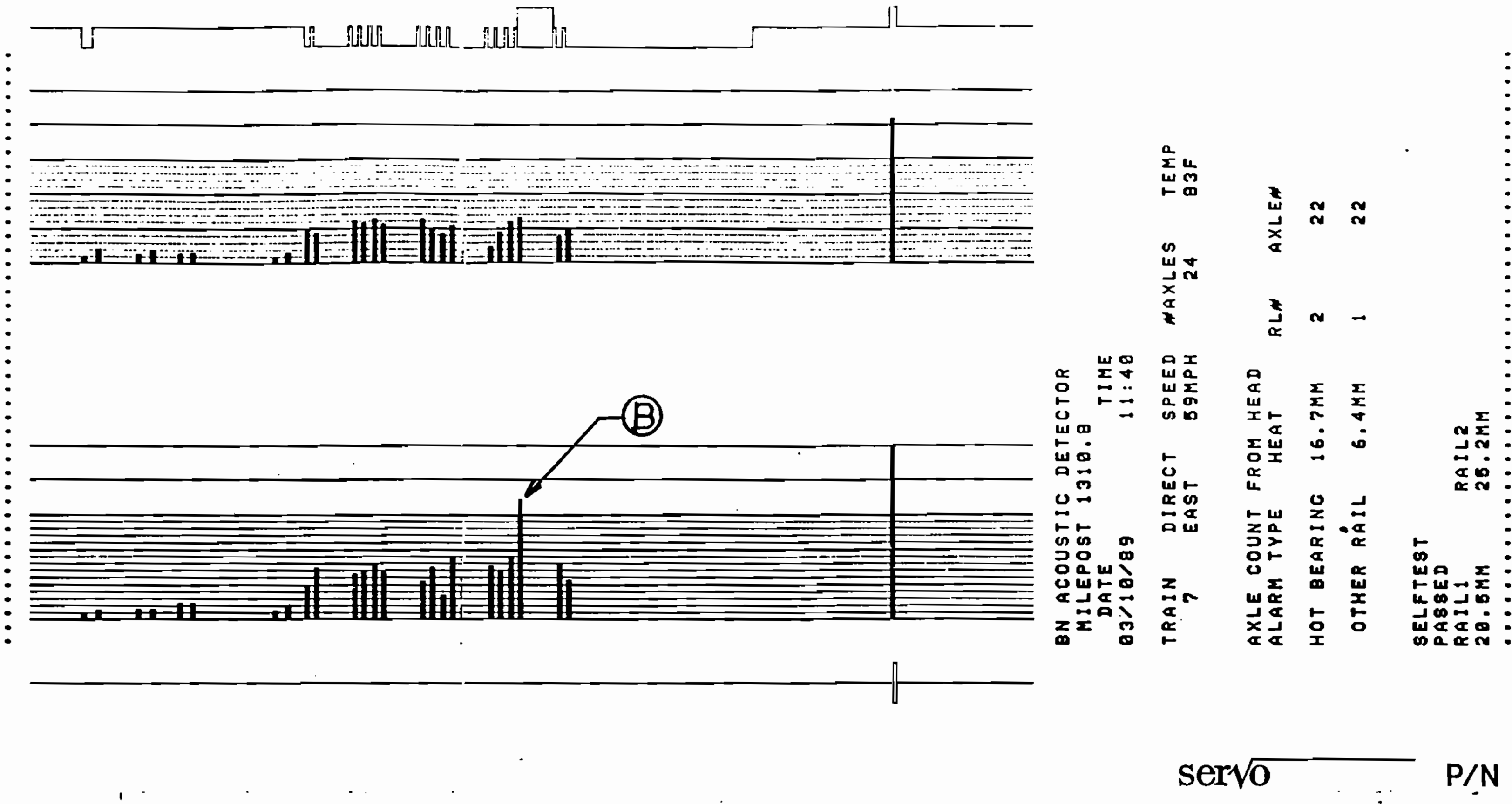

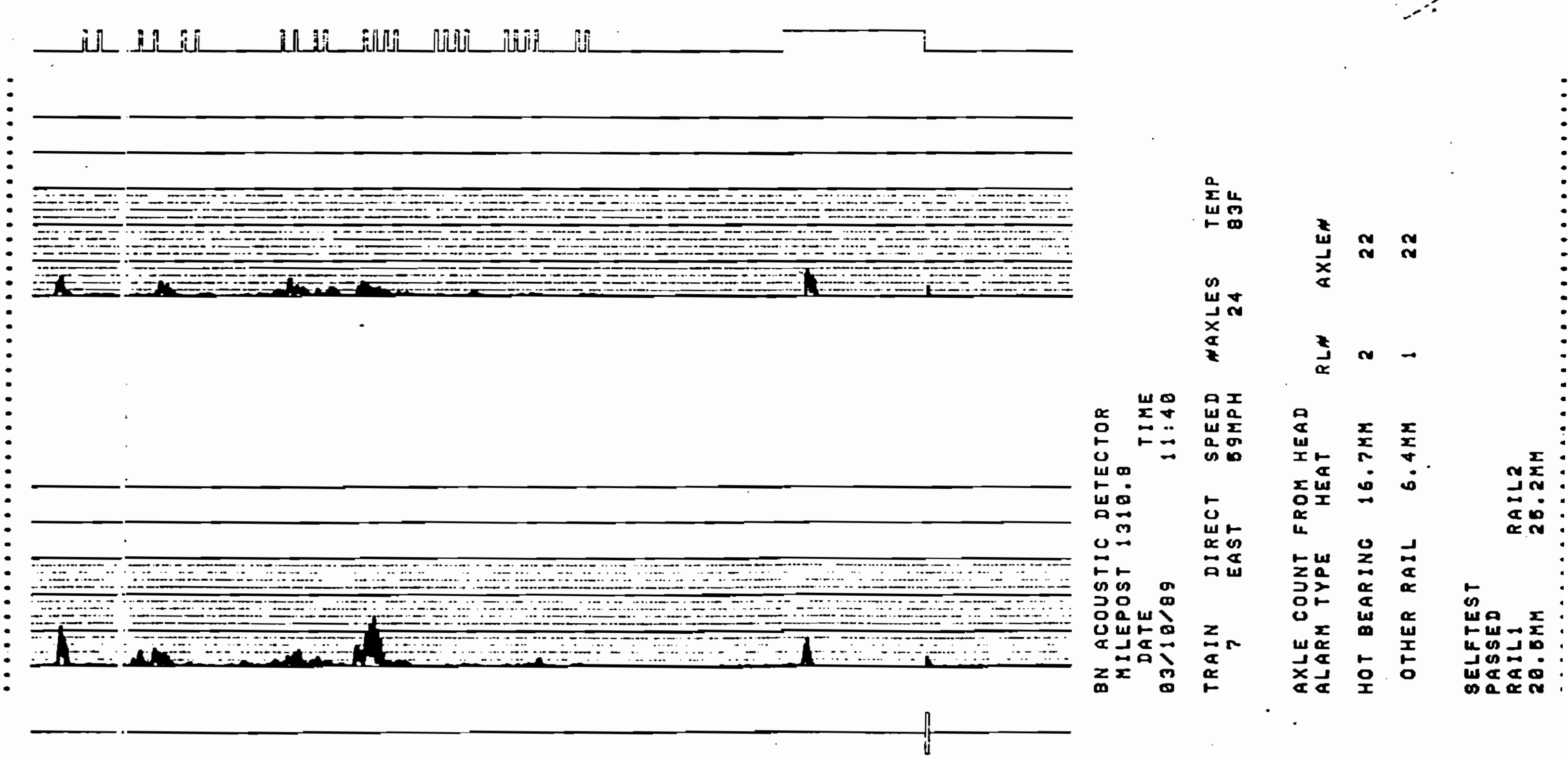

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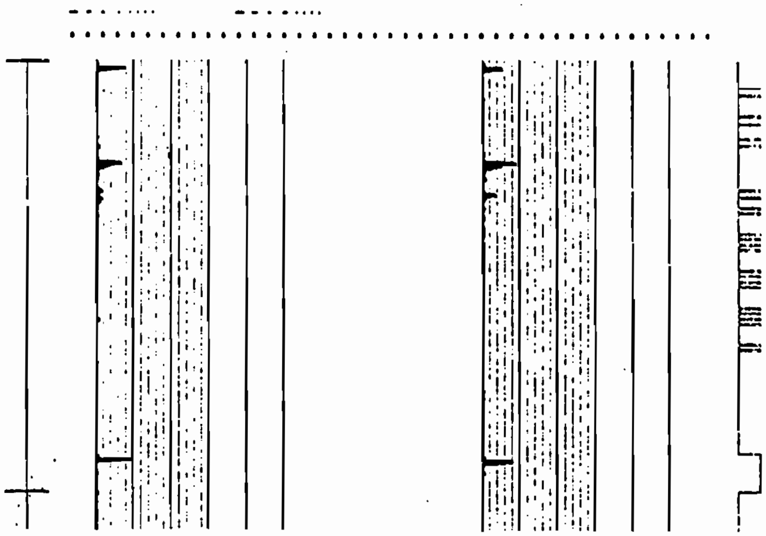
CHART 4

During the week of 13 March, the same behavior was repeated until finally both bearing A and B triggered hot box alarms without emitting significant acoustical noise (DATAGRAPH charts 5, 6, 7, and 8).

The wheelsets containing bearings A and B were replaced by normal wheelsets with no defects for the remaining weeks of the test. All survived to the 5,000 mile limit that was reached on Friday, 7 April. All bearings operated quietly without emitting significant acoustical signatures. Except for bearing U that triggered HBD alarms on 21, 23 and 28 March, all others operated with normal heat (DATAGRAPH charts 9, 10, 11, 12 and 13).



BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE TIME
03/13/89 10:29

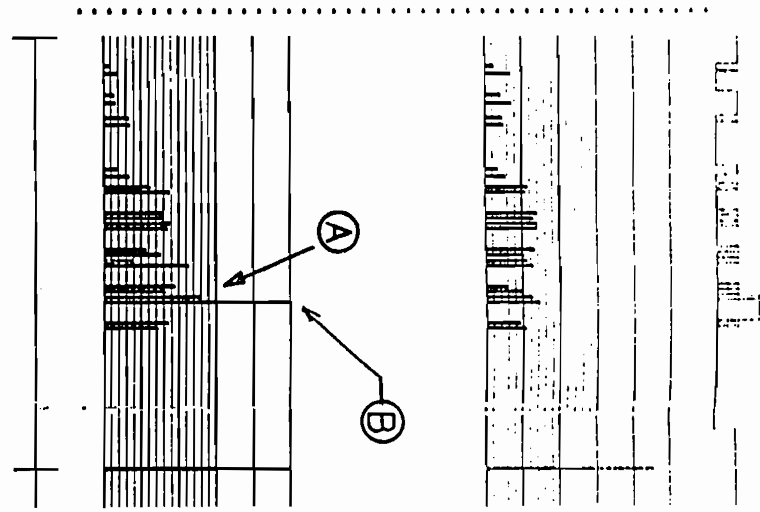
TRAIN	DIRECT	SPEED	#AXLES	TEMP
9	EAST	29MPH	24	58F

AXLE COUNT FROM HEAD

ALARM TYPE	HEAT	RL#	AXLE#
HOT BEARING	12.6MM	2	21
HOT BEARING	25.1MM	2	22
OTHER RAIL	7.1MM	1	22

SELFTEST
PASSED

RAIL1	RAIL2
22.2MM	25.1MM



BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE TIME
03/13/89 10:29

TRAIN	DIRECT	SPEED	#AXLES	TEMP
9	EAST	29MPH	24	58F

AXLE COUNT FROM HEAD

ALARM TYPE	HEAT	RL#	AXLE#
HOT BEARING	12.6MM	2	21
HOT BEARING	25.1MM	2	22
OTHER RAIL	7.1MM	1	22

SELFTEST
PASSED

RAIL1	RAIL2
22.2MM	25.1MM

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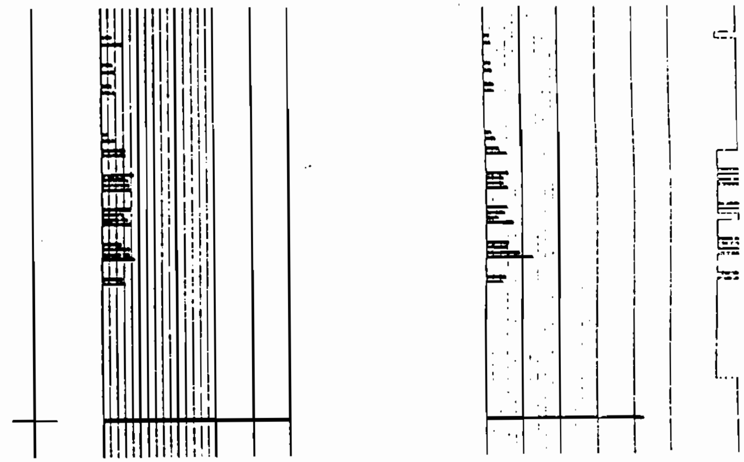
CHART 5



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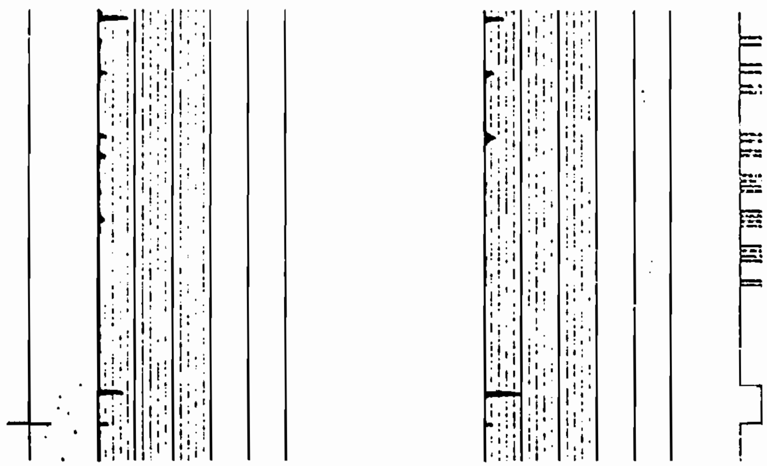
 MILEPOST 1310.8
  DATE              TIME
03/13/89           11:39

TRAIN   DIRECT   SPEED   #AXLES    TEMP
  10     WEST    30MPH      24      65F

NO ALARMS

SELFTEST
PASSED
RAIL1       RAIL2
20.8MM      25.3MM
```

/N 065023011



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BN ACOUSTIC DETECTOR
 MILEPOST 1310.8
  DATE              TIME
03/13/89           11:39

TRAIN   DIRECT   SPEED   #AXLES    TEMP
  10     WEST    30MPH      24      65F

NO ALARMS

SELFTEST
PASSED
RAIL1       RAIL2
20.8MM      25.3MM
```

/N 06

CHART 6

BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE 03/15/89 TIME 19:14

TRAIN	DIRECT	SPEED	#AXLES	TEMP
9	EAST	57MPH	26	44F

AXLE COUNT FROM HEAD

ALARM TYPE	HEAT	RL#	AXLE#
HOT BEARING	15.0MM	2	24
OTHER RAIL	6.7MM	1	24

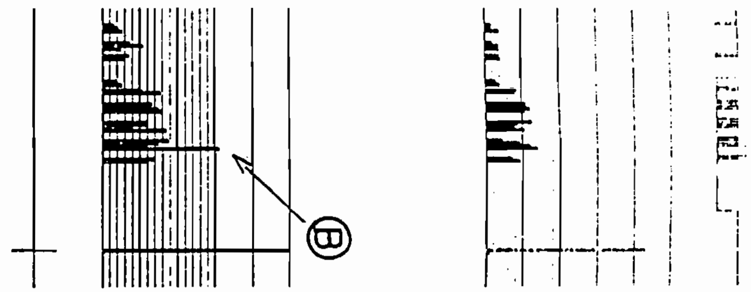
SELFTEST
PASSED

RAIL1	RAIL2
21.1MM	25.1MM

P/N 0650230

servo

P/N 06502:



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MILEPOST 1310.8
DATE 03/15/89 TIME 19:14

TRAIN	DIRECT	SPEED	#AXLES	TEMP
9	EAST	57MPH	26	44F

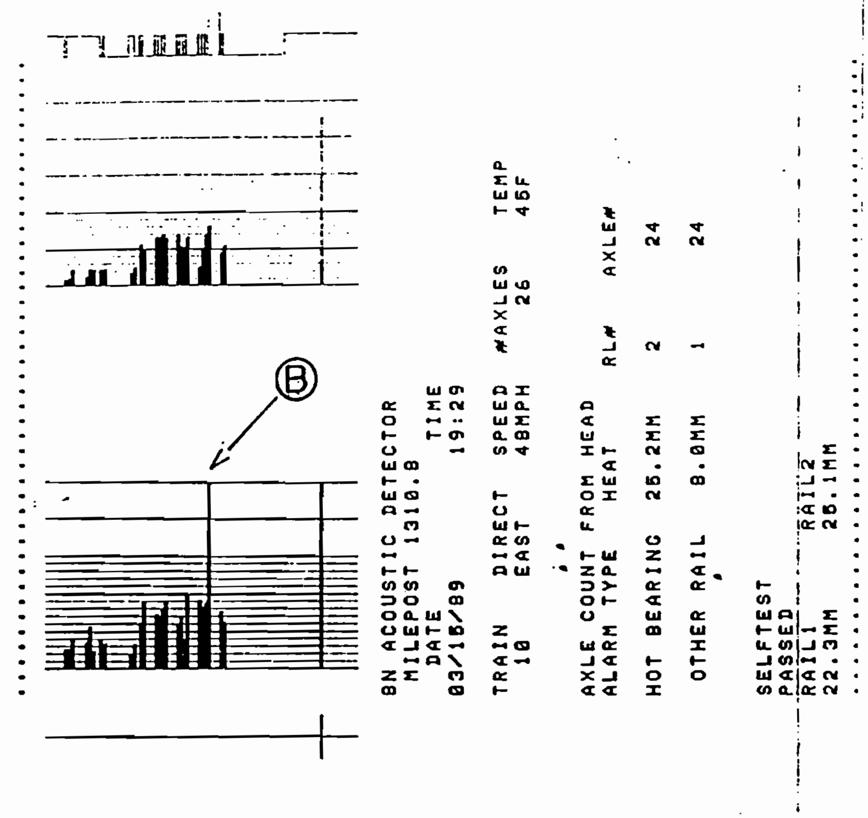
AXLE COUNT FROM HEAD

ALARM TYPE	HEAT	RL#	AXLE#
HOT BEARING	15.0MM	2	24
OTHER RAIL	6.7MM	1	24

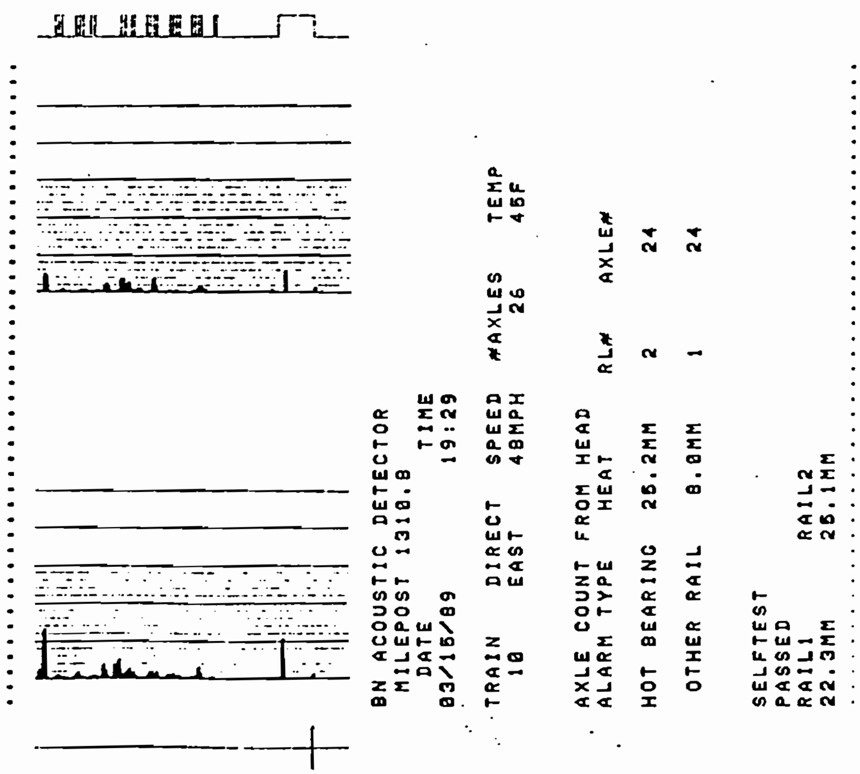
SELFTEST
PASSED

RAIL1	RAIL2
21.1MM	25.1MM

CHART 7


B
BN ACOUSTIC DETECTOR
MILEPOST 1310.8
DATE TIME
03/15/89 19:29
TRAIN DIRECT SPEED #AXLES TEMP
10 EAST 48MPH 26 45F
AXLE COUNT FROM HEAD
ALARM TYPE HEAT RL# AXLE#
HOT BEARING 25.2MM 2 24
OTHER RAIL 8.0MM 1 24
SELFTEST
PASSED
RAIL1 RAIL2
22.3MM 25.1MM

3011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MILEPOST 1310.8
DATE TIME
03/15/89 19:29
TRAIN DIRECT SPEED #AXLES TEMP
10 EAST 48MPH 26 45F
AXLE COUNT FROM HEAD
ALARM TYPE HEAT RL# AXLE#
HOT BEARING 25.2MM 2 24
OTHER RAIL 8.0MM 1 24
SELFTEST
PASSED
RAIL1 RAIL2
22.3MM 25.1MM

CHART 8

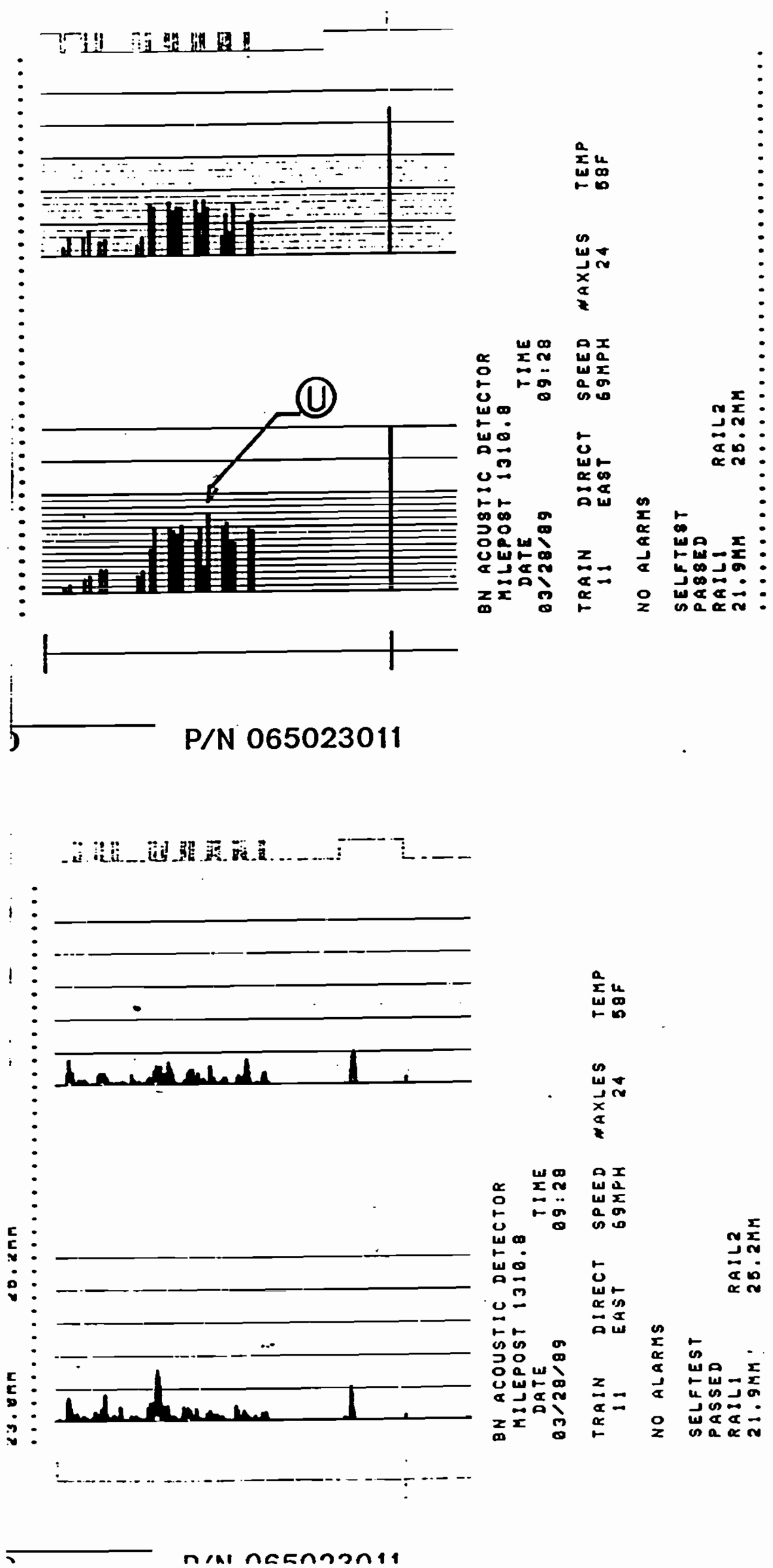
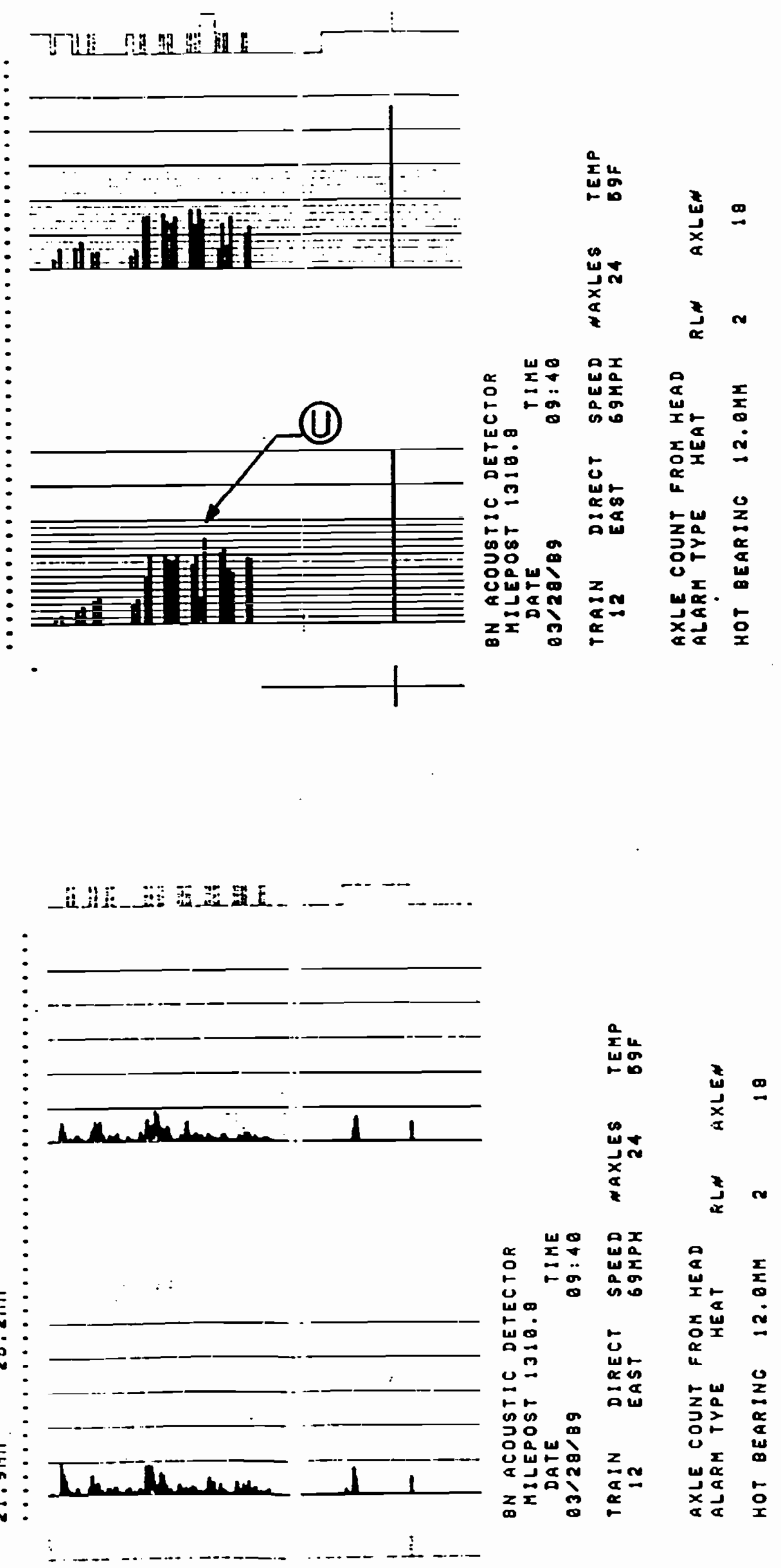


CHART 9



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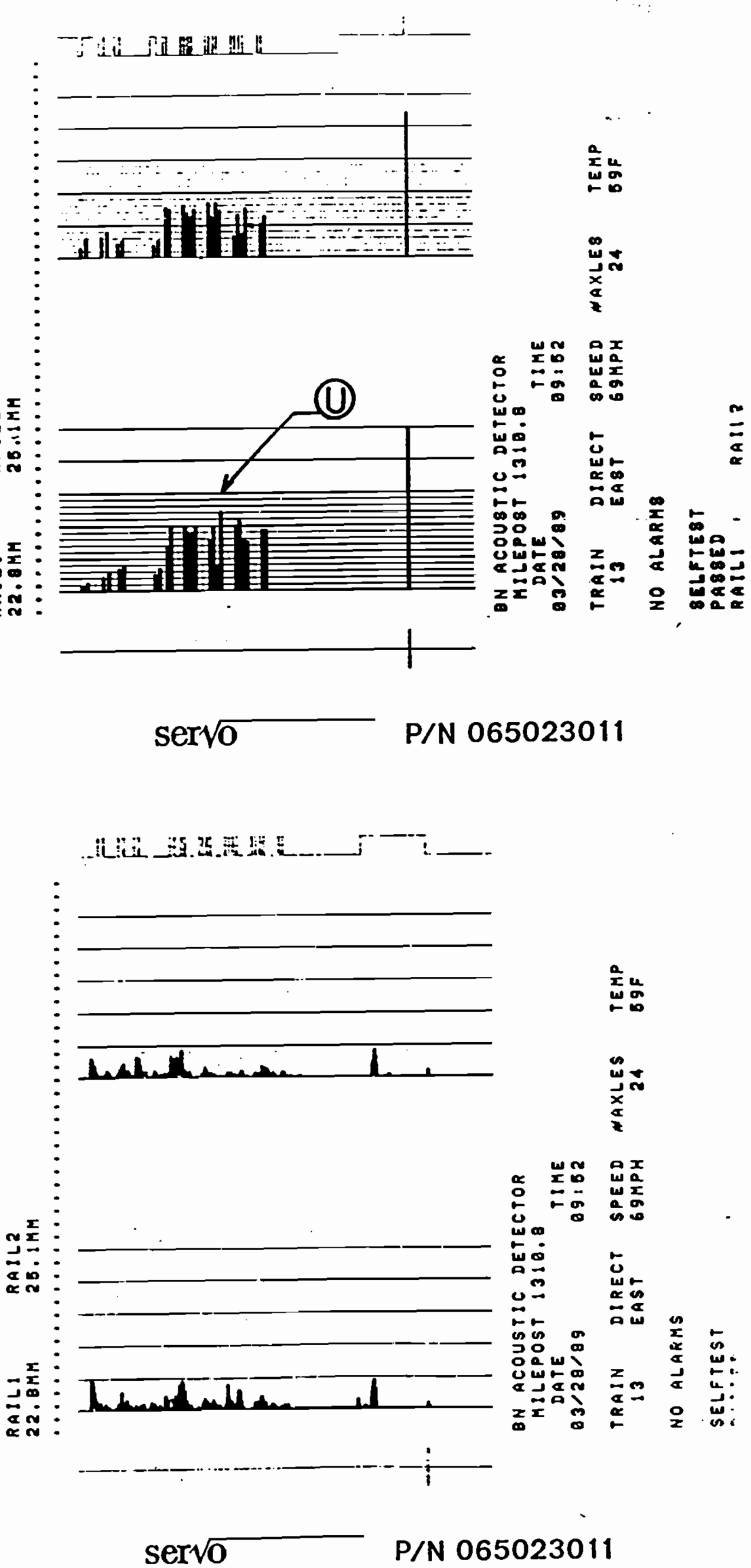

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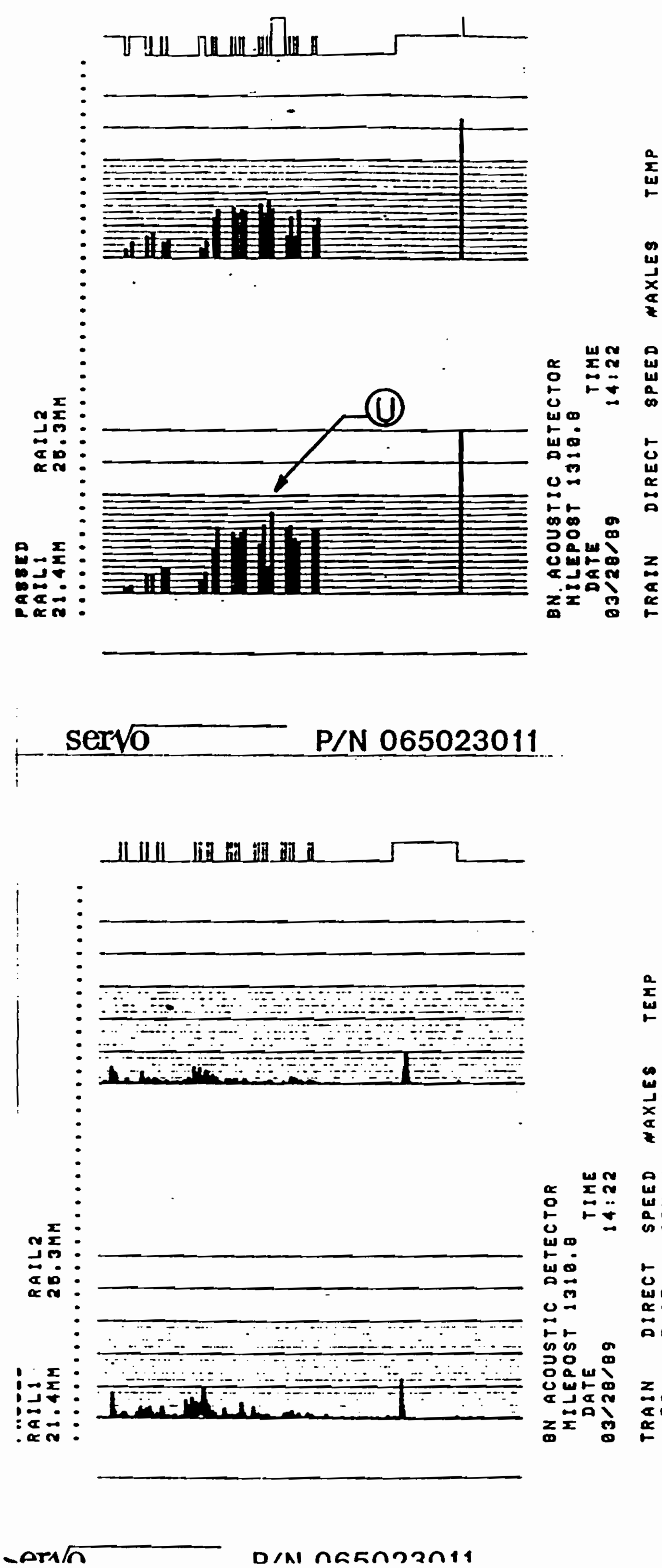

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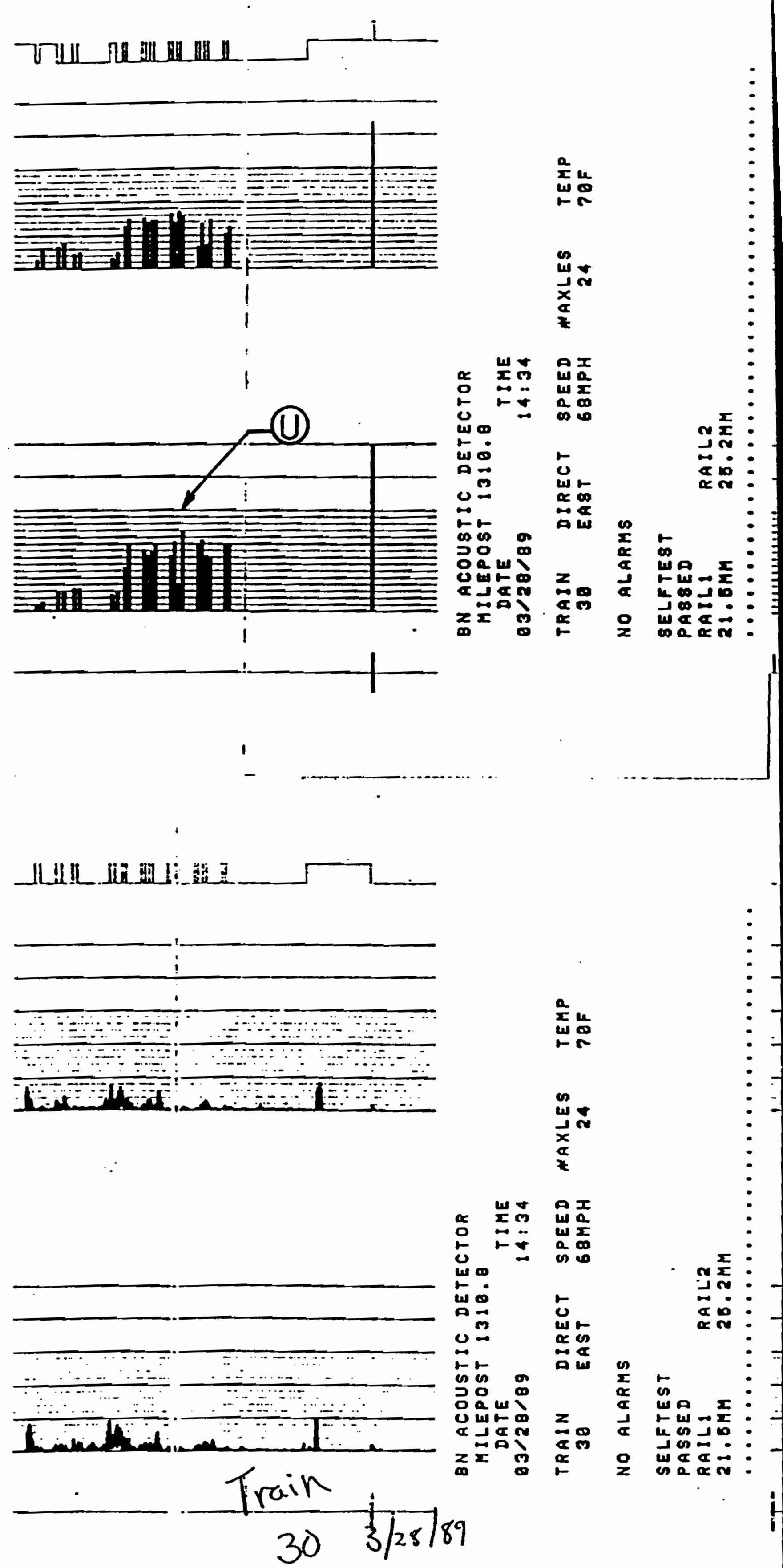


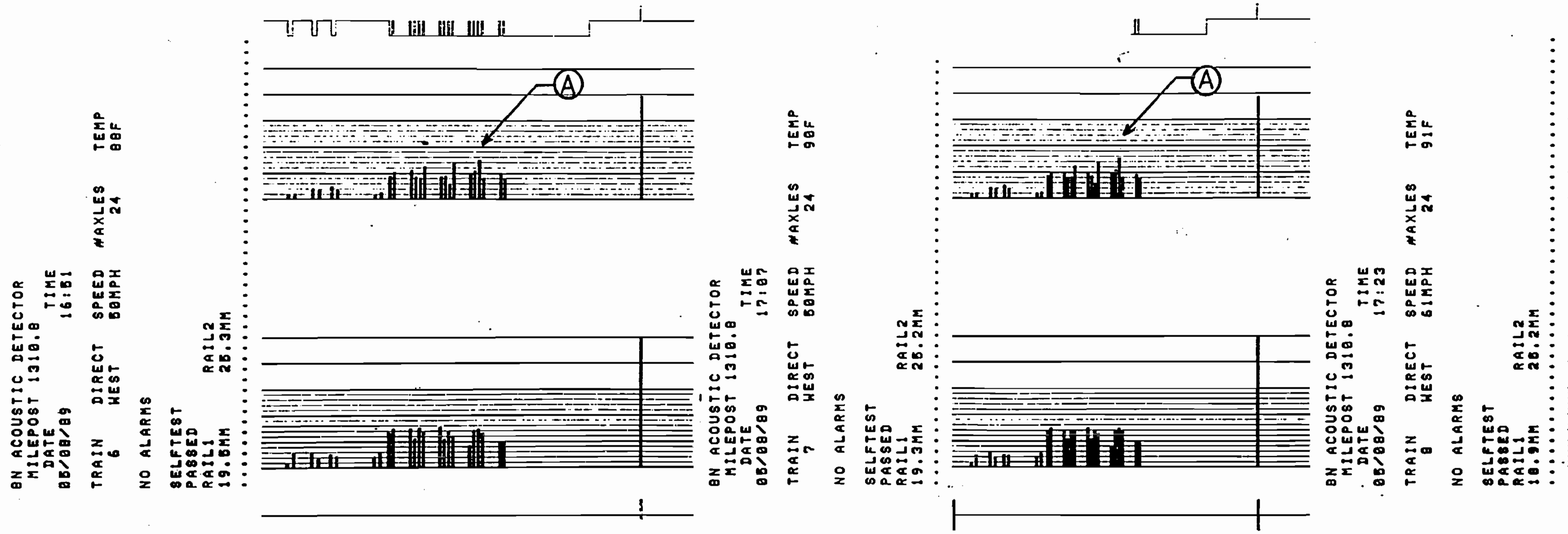
CHART 13

SUPPLEMENTAL TEST
(800 Miles - 4 May 1989 through 9 May 1989)

Only the wheelset with bearing A was re-installed in its original location on the last car of the consist and the consist was operated an additional 800 miles.

With the exception of bearing A, this time, all bearings operated quietly without emitting significant heat or acoustical noise.

Bearing A emitted discernible acoustical noise prior to generating excessive heat. Subsequently, bearing A triggered HBD alarms, and the acoustical signature essentially disappeared (DATAGRAPH charts 14, 15, 16, 17, 18 and 19).



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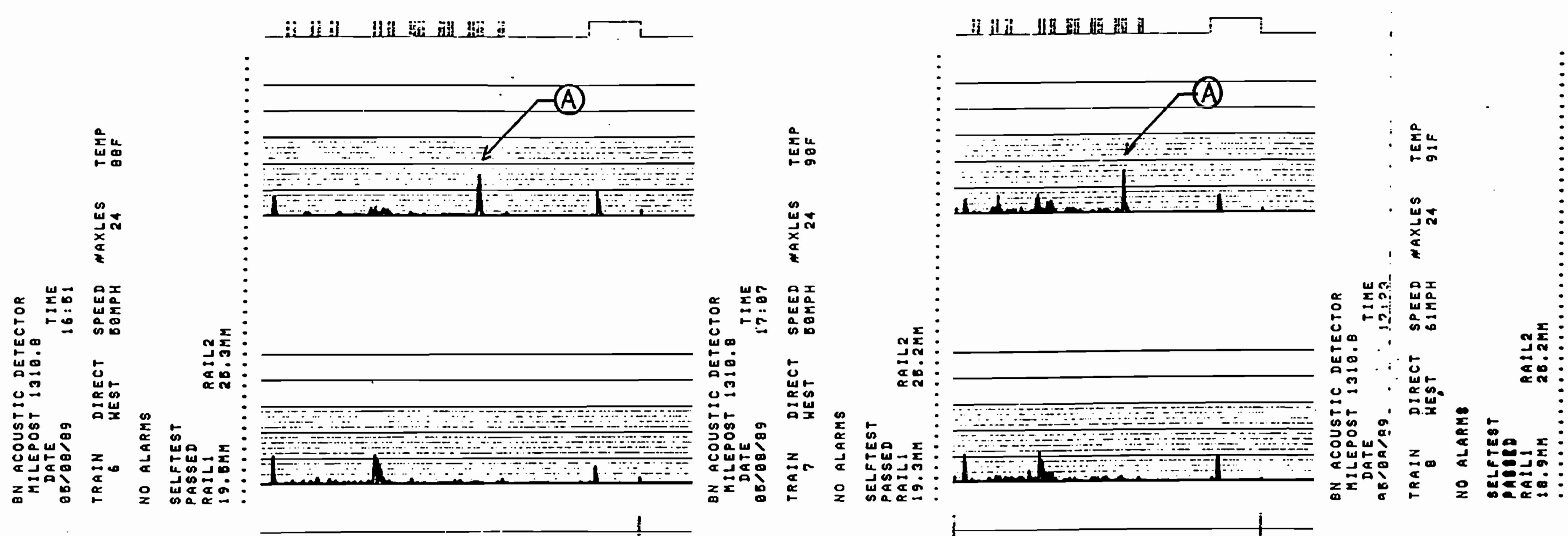
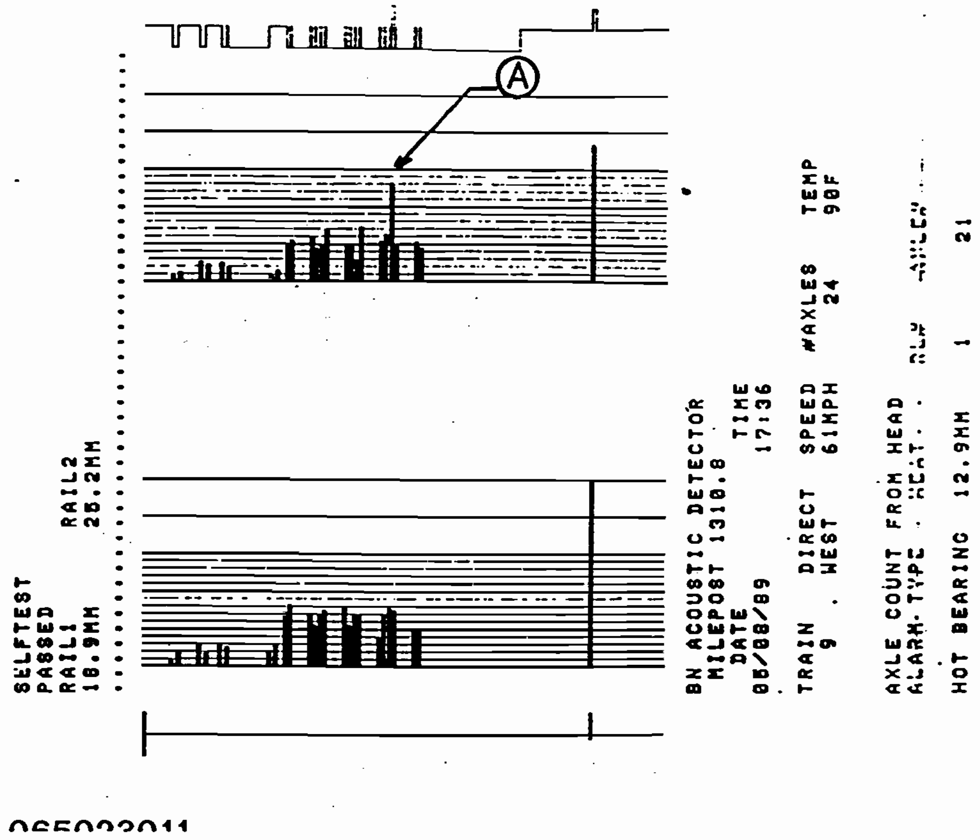
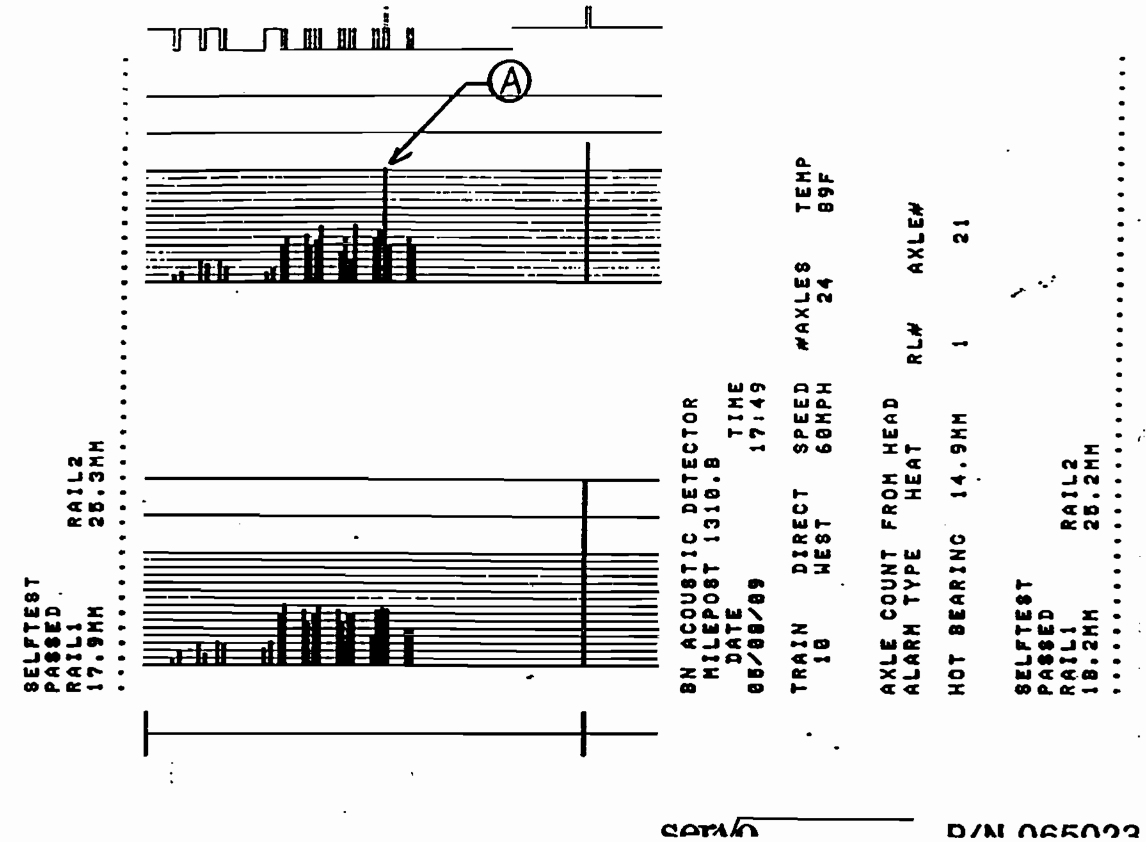
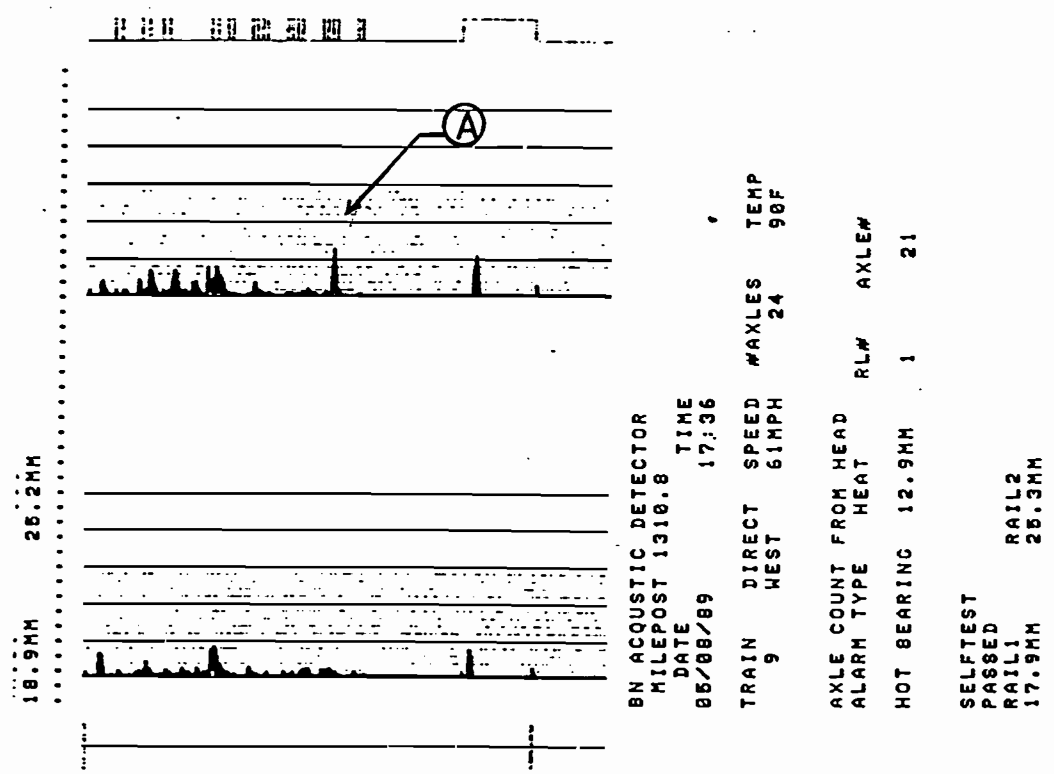


CHART 14

CHART 15







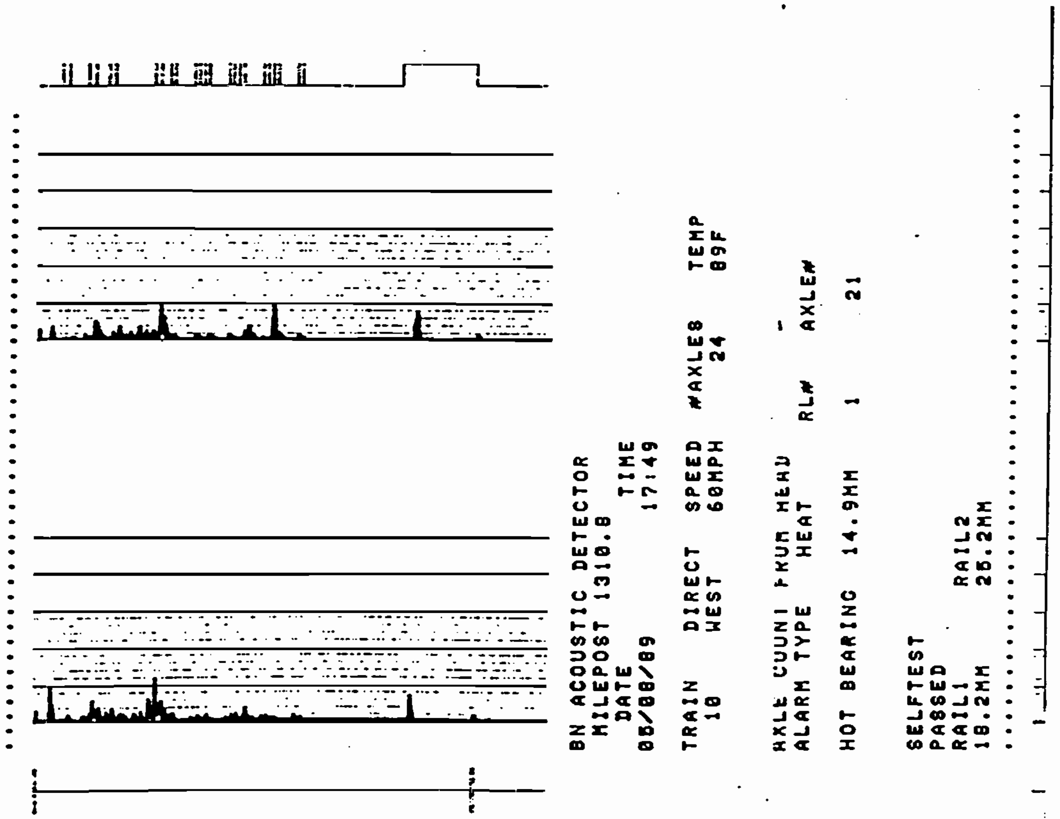


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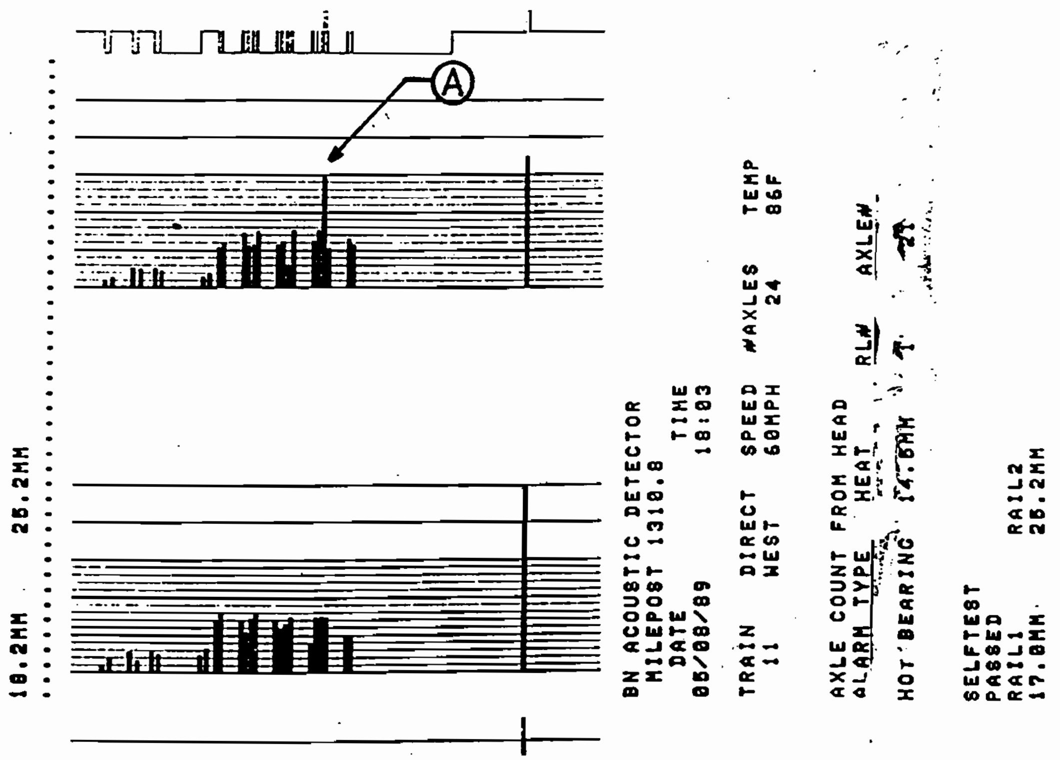
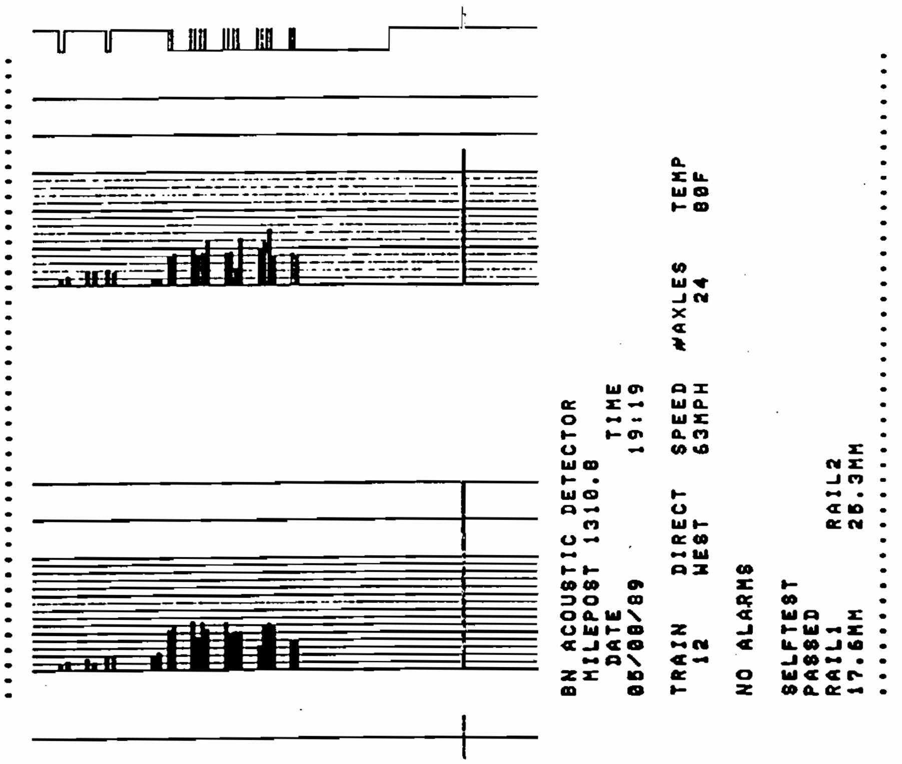
CHART 16

CHART 17





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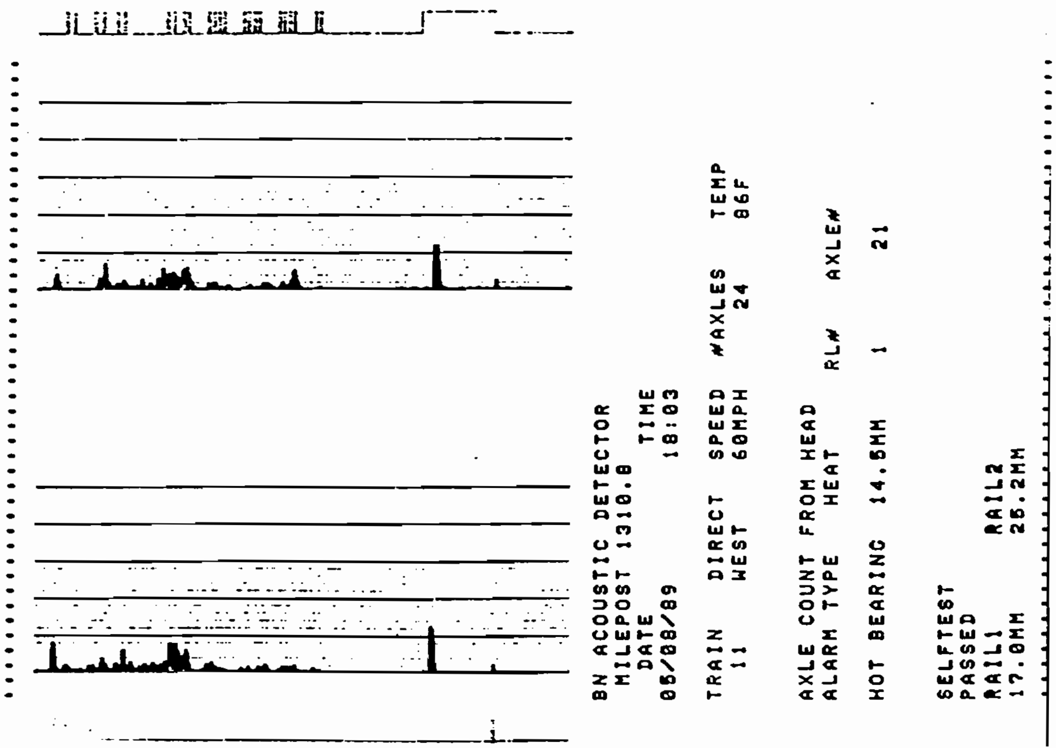
servo P/N



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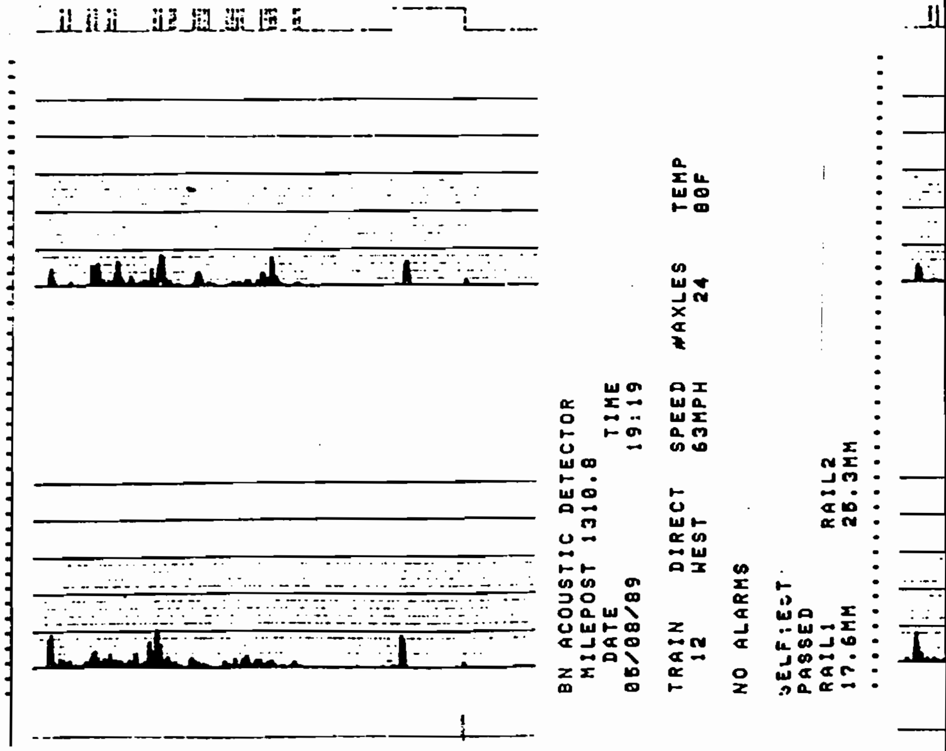

CHART 19

CONCLUSIONS & COMMENTS

From one point of view, the Short Term Test was disappointing. Except for bearings A and B with multiple defects, the remaining bearings with only bearing retention anomalies refused to cooperate and degrade rapidly over 5,000 miles of operation.

From another point of view, the results are encouraging in that bearing retention anomalies do not by themselves appear to cause bearings to degrade rapidly and exhibit distress over 5,000 miles of operation. Bearing U (zero clamp, 0.0045 interference fit) that triggered occasional HBD alarms may be an exception. However, its mate, bearing V, with the same anomaly behaved normally.

At the beginning of the 5,000 mile test, bearing B emitted a small amount of acoustical noise, generated excessive heat, and soon triggered HBD alarms. Bearing A did not emit acoustical noise but ultimately triggered HBD alarms.

In the supplemental 800 mile test, bearing A emitted discernible acoustical noise, generated heat, and triggered HBD alarms. Bearing U did not generate excessive heat.

Here again we have another documented case where defective bearings can play a 'cat-and-mouse' game with wayside defect detectors.

With regard to bearings A and B with multiple defects, it is interesting to ask, which occurred first in real life, retention anomalies or cup and cone raceway and roller defects. Hopefully continued long-term operation of the specimens with only retention anomalies on the HTL will provide some answers.

ACOUSTICAL DETECTION OF DEFECTIVE ROLLER BEARINGS

Joseph E. Bambara, Vice-President
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SERVO CORPORATION OF AMERICA
Hicksville, New York

April 1988

ACOUSTICAL DETECTION OF DEFECTIVE ROLLER BEARINGS

Joseph E. Bambara, Vice-President
Corporate Advanced Development
SERVO CORPORATION OF AMERICA
Hicksville, New York

ABSTRACT

The acoustical detection of defective freight car roller bearings has progressed from exploratory shop and field measurements, with laboratory instruments and laboratory processing of data, to the deployment of advanced development wayside systems that automatically pick up and process acoustical bearing defect signatures in real time, to generate alarms for major bearing defects.

After presenting the basic principles of a stand-alone wayside acoustical detector, the configuration and features of an advanced development system are described. The system combines and integrates acoustical signature detection and hot box detection technology. Deployment of these systems has demonstrated that defective bearings can be detected automatically by the noise they emit. Early acoustical detection by wayside systems facilitates cost-effective follow-up corrective action at yard locations. Integration of an acoustical detector with a hot box detector provides a back-up warning of imminent bearing failure.

INTRODUCTION

Servo's efforts in acoustical detection R&D began a few months after the AAR bearing conference in Urbana in April 1986. Since that time, in about two (2) short years, significant progress has been achieved.

We have progressed from exploratory shop and field measurements, with laboratory instruments and laboratory processing of data, to the deployment of advance development wayside systems that automatically pick up and process acoustical bearing defect signatures in real time, to generate alarms for major bearing defects.

SERVO/SHAKER TEAM & CONRAIL TEST

At the 1986 Urbana conference, Richard Smith of the Shaker Research Division of Mechanical Technologies Inc., (MTI) presented a paper(1) on Acoustical Signatures of Various Roller Bearing Defects. Within a few months, a team association was formed whereby Servo has sponsored Shaker Research for R&D support activities involving acoustical technology.

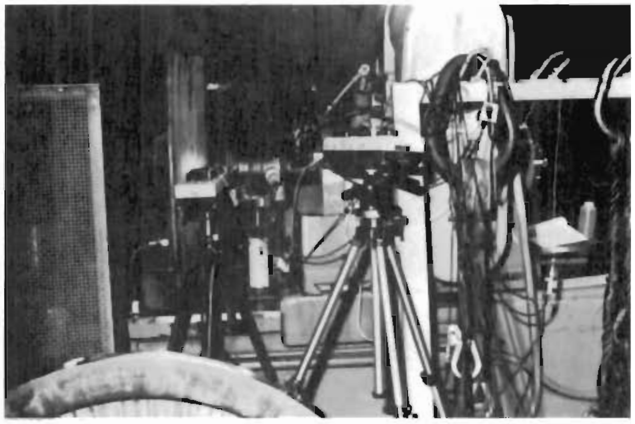
In September 1986, with the cooperation of ConRail, we recorded our first wayside acoustical and accelerometer signals of passing trains at the ConRail test site at Leonardsburg, Ohio. We found what we expected; a high level of background noise associated with rail joints, flat wheels and wheel flange rubbing. Clearly our task was formidable. We had to develop techniques to extract useful bearing signatures from that background noise.

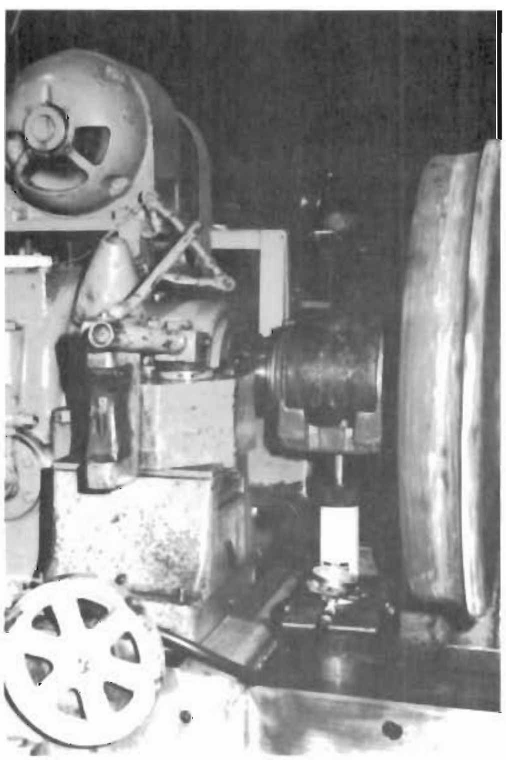
LEONARDSBURG TEST SITE
September 1987

UNION PACIFIC CONTROLLED TESTS

Before the Urbana conference, the personnel of the Union Pacific Mechanical R&D Lab had established a pilot acoustical detection program at the Bailey Yard in North Platte, Nebraska. They had also attended the Urbana conference, and almost immediately after the Leonardsburg test, the Servo/Shaker team was invited to participate along with Brenco in a series of controlled tests using the known noisy defective bearings acquired at the Bailey Yard.

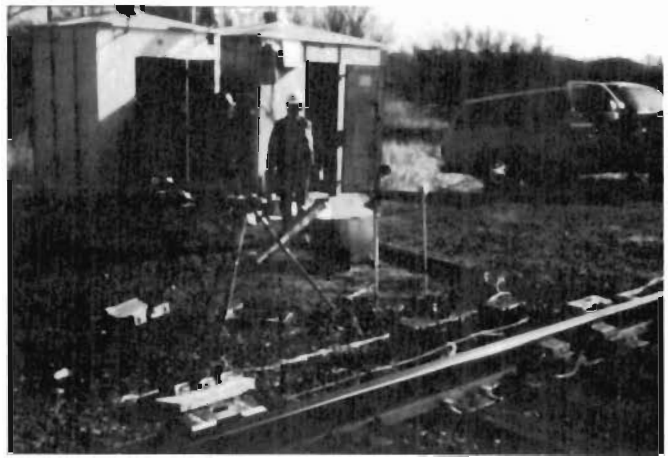
The controlled tests were conducted on Union Pacific property at the Omaha Wheel Shop and the Hot Box Detector (HBD) site at Elkhorn, Nebraska from January through March 1987. The tests performed, and the results obtained, are described in detail in a paper (2) authored by Bob Florom (formerly of the UP R&D Lab, now TTC, Pueblo), along with Richard Smith (MTI/Shaker), Tony Hiatt (formerly of UP R&D Lab) and myself. The paper was published by the ASME and presented at their annual convention in December 1987.

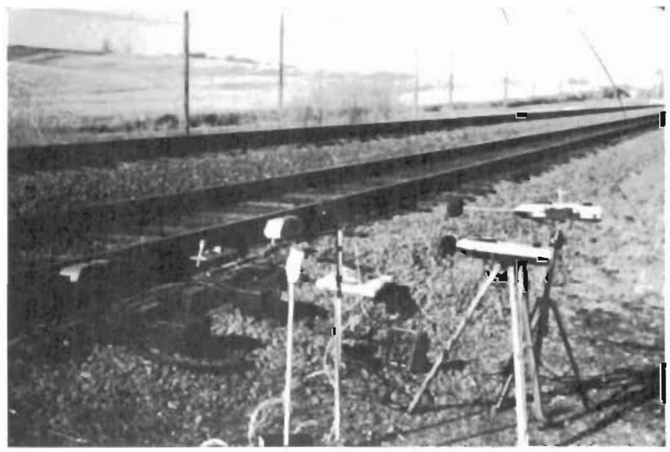




OMAHA WHEEL SHOP
January 1987

The controlled tests, especially the test train loaded and unloaded car sequences, over speeds of about 5mph up to 50mph, at the Elkhorn, Nebraska test site, where an array of acoustical and accelerometer sensors was deployed, demonstrated, after processing of the recorded data, that we could identify defective bearings with sufficient reliability to warrant expanding our efforts into a new phase.





ELKHORN TEST SITE
March 1987

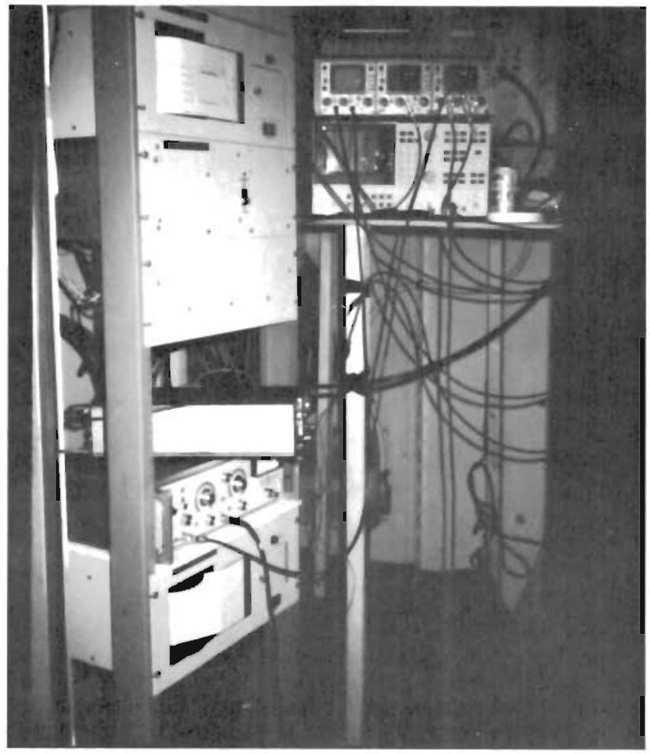
NORTH PLATTE TEST SITE

In June 1987, early engineering prototype equipment was installed on the North Platte Subdivision of the Union Pacific to operate with a Servo SYSTEM 9000 HBD. Several types of acoustical sensors used at Elkhorn were again deployed in a variety of positions with respect to the rails. Accelerometers and velocity sensors were also attached to the rails. Simultaneous multi-track magnetic tape recordings of the sensor signals and the wheel gate and heat pulses from the HBD were made for laboratory analysis at Shaker. Optimum sensor configuration and location were determined from the processed data.

A few weeks later, in July, a pilot prototype system was installed to process and record acoustical signals for both the north and south rails in real time. Defects were located by trainside and axle count. The first automatic acoustical detection of a defective bearing occurred on 14 July 1987. The defective bearing was on a loaded eastbound 109-car unit coal train moving at 40mph. The wheel set was removed at the Bailey Yard. Subsequent dis-assembly and inspection revealed a deep Brinell in the cup raceway.

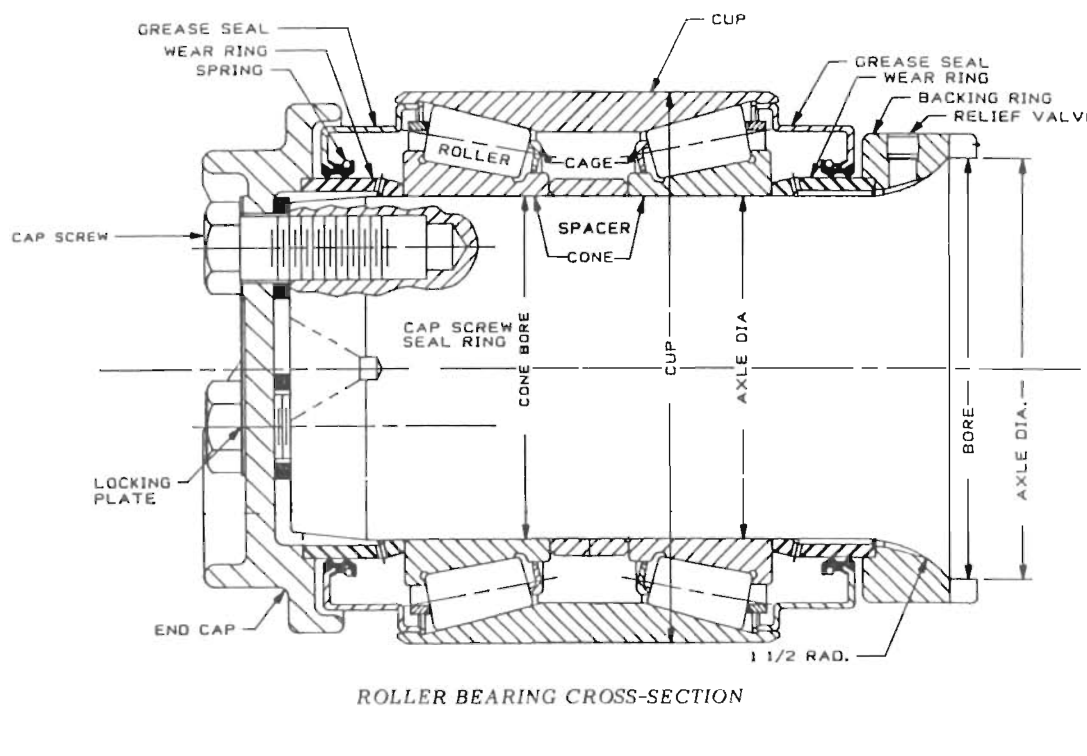
NORTH PLATTE SUBDIVISION
June 1987

Over a period of three (3) days (from 14 to 16 July), we inspected 21 unit coal trains, each with at least 110 100-ton cars and were able to identify acoustically eleven (11) defective bearings. Of the eleven (11), several alarms occurred in the wee hours of the morning while the site was unmanned and communication with yard personnel could not be maintained. As a result, cars with four (4) defective bearings passed through the yard before wheel sets could be set out. Similarly, because coordination with yard personnel was less than perfect, the wrong truck and the wrong axle involving three (3) detected defects were set out. Of the remainder, as I have noted before, the first had a deep cup Brinell, and three had condemnable cup spalls. One of the last three apparently was a reworked bearing with some minor residual spalls on the cup raceway.



NORTH PLATTE SUBDIVISION
June 1987

Our activities at North Platte uncovered a fundamental and pervasive problem of how to reliably communicate the location of detected defects for validation and corrective action.



ROLLER BEARING CROSS-SECTION

For those who are interested, additional detail on activities up to this point in time is covered in a paper I presented at the AAR C&S Annual Meeting in October 1987(3).

BEARING DEFECT SIGNATURES
SIGNAL PROCESSING

At this point, I will review some of the basics involved with the acoustical detection of bearing defects.

Because of the planetary kinematics of the roller bearing, defects on the cup and cone raceways, and those on the rollers have distinctive characteristic impact repetition rates that are a function of bearing geometry and the rotational rate of an axle, which in turn depends on wheel diameter and train speed.

For train speeds of 40mph, computed impact repetition frequencies for commonly encountered wheel diameter and bearing size combinations are shown in Fig. 'X'.

CAR LOAD BEARING SIZE WHEEL DIAMETER	100 TON F(6-1/2 X 12) 36 INCH	70 TON E(6 X 11) 33 INCH	70 TON E(6 X 11) 28 INCH
CONE	79.0	89.5	105.5
CUP	64.1	73.5	86.6
ROLLER	(58.4) 29.2	(67.7) 33.9	(79.8) 39.9
WHEEL	6.22	6.79	8.00

FIG. 'X'.

Cone raceway defects have the highest characteristic frequencies. Cup raceway defects are slightly lower than for cone defects. Roller defects have the lowest frequencies.

Two (2) roller defect frequencies for each wheel/bearing combination are shown. The lower frequency of each pair is the roller fundamental rotational rate. The higher frequency of each pair is the second harmonic of the fundamental.

Either or both may exist in a given situation. If the sound emitted when a roller defect impacts the cup raceway is greater than for the cone, or vice versa, the fundamental is dominant. When the sound emitted by cup and cone impacts are essentially equal, the higher frequency is dominant.

As can be seen in Fig. 'X', the roller defect fundamental frequency is nearly the 5th harmonic of the wheel/axle rate, while the cup defect frequency is nearly the 10th harmonic of the wheel/axle rate. Therefore, other bearing defects such as a loose end cap, a loose backing ring, or a loose cone, may have impact spectral components in the vicinity of these wheel/axle harmonics.

The noise sound level emitted by a bearing defect is related to the severity of the defect, the operating speed and the load. Defective bearings emit more noise when cars are loaded compared to unloaded. Defective bearings emit more noise at higher train speeds. Empty cars emit more random background noise at higher train speeds.

Real time signal processing for a stand-alone acoustical defective bearing detector is illustrated in the simplified block diagram of Fig. 'Y'. Signal processing extracts the electrical signals related to the metallic sound signatures picked up by the wayside sensors. Processing includes bandpass filtering, demodulation and spectrum analysis. The spectrum analysis function is pre-programmed to recognize the characteristic bearing defect frequencies for each of the commonly encountered wheel diameter and bearing size combinations. The spectrum analysis function is controlled dynamically by train speed information derived from two (2) wheel presence transducers. Acoustical signatures are correlated with axle count.

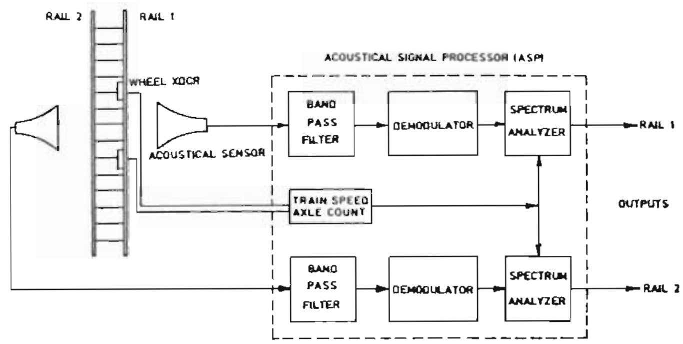


FIG. 'Y'

When a characteristic frequency is recognized within a narrow bandpass tolerance band, an output corresponding to the defect sound level is generated. Alarms for outputs exceeding preset levels can be generated separately for each defect type. Defects are located by trainside and axle count. A separate alarm for a severe roller defect is desirable since that type is potentially dangerous and can lead to a sudden and catastrophic burn-off. When acoustical detection is correlated with hot box detection, an acoustically-detected bearing defect with abnormal heat can indicate the bearing is near failure; an acoustically-detected defect with no abnormal heat can provide early detection where corrective action can be taken when economically convenient at a yard location.

ADVANCED DEVELOPMENT SYSTEM - PHASE I,

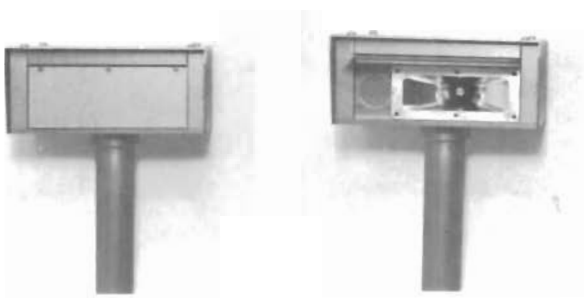
Toward the end of the summer of 1986, we began the engineering design of an advanced development system. We chose to add the acoustical detector functions to those of the Servo SYSTEM 9000 HBD to utilize advantageously all of the extensive automatic features of that microprocessor-based system. We added and integrated two (2) Trackside Acoustical Sensors, an Acoustical Signal Processor and a DATAGRAPH Chart Recorder/Printer for acoustical data.

Trackside Acoustical Sensors (TAS)

The acoustical sensor assemblies are located about four (4) feet from gage on each side of the track along the transverse reference center-line midway between the A and B HBD wheel gate transducers. The horizontal acoustical axis of each sensor is adjusted to be about fourteen (14) inches above the top of the rail(s).

FIELD INSTALLATION
ADVANCED DEVELOPMENT SYSTEM

Each sensor has a directivity pattern that is approximately $\pm 30^{o}$ in a horizontal plane and $\pm 10^{o}$ in a vertical plane. The horizontal directivity captures bearing signatures over a 4-1/2-foot span that are uniquely related both spacially and temporally to the wheel gate of a passing wheelset. The vertical directivity pattern emphasizes bearing signatures, while attenuating wheel/rail noise, flange/rail squeal, and carbody noise.



TRACKSIDE ACOUSTICAL SENSOR
Left - Shutter Closed; Right - Shutter Open

Each assembly has a gain-stabilized preamplifier and a solenoid-actuated aperture shutter that is opened during train presence by control signals from the SYSTEM 9000 HBD. A thermostatically controlled heater is included to melt snow and keep the internal components dry. A small loudspeaker and driver amplifier is also included for calibration and system integrity tests.

Acoustical Signal Processor (ASP)

The Acoustical Signal Processor is a nineteen (19) inch card cage with a self-contained power supply module and plug-in cards.

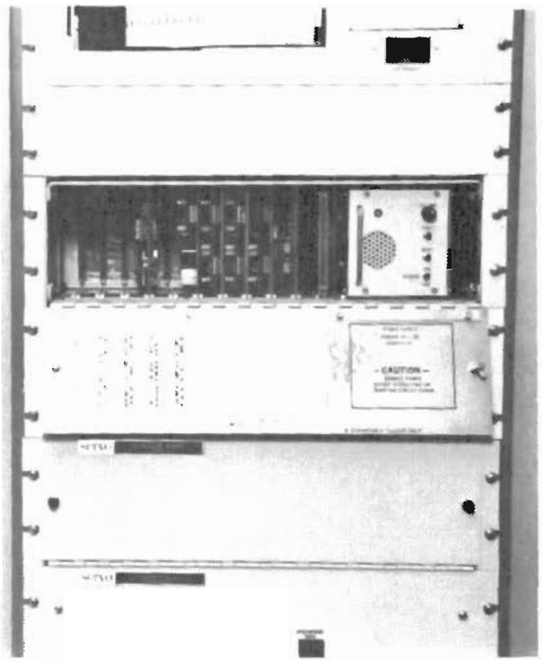


PHOTO - RACK ASSEMBLY

The acoustical signal from each trackside sensor is processed by proprietary circuitry. After bandpass filtering and demodulation, the signal amplitudes corresponding to cup, cone and roller defect frequencies are extracted in plug-in cards individually dedicated to the 36-inch wheel & Class F (6-1/2 x 12) 100-ton bearing, the 33-inch wheel & Class E (6 x 11) 70-ton bearing, and the 28-inch wheel & Class E (6 x 11) 70-ton bearing.

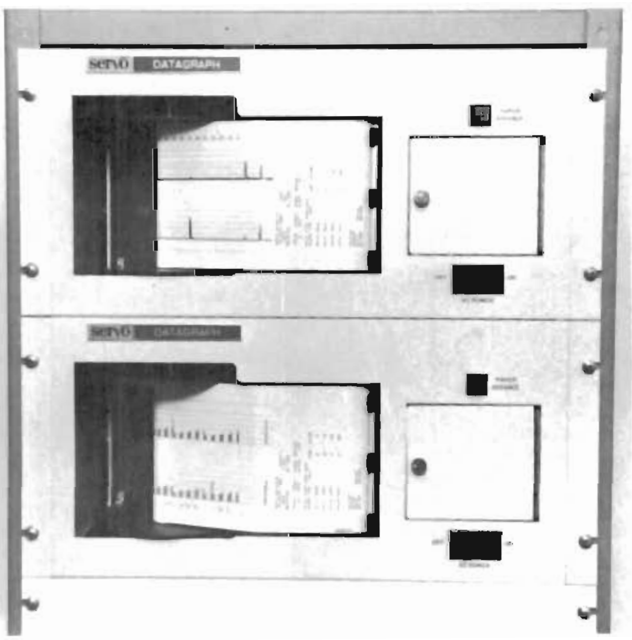
Similarly, a single plug-in card is provided to extract the amplitudes of the wheel defect frequencies for the 36, 33 and 28-inch wheels.

As noted before, all of these defect frequencies are proportional to the angular velocity of the wheelset and therefore to train speed. Train speed is derived from the time duration of the SYSTEM 9000 HBD wheel gate pulse and applied to these dedicated cards to effectively 'tune' them dynamically.

Since the acoustical noise emitted by defects increases with train speed, system sensitivity is automatically reduced with increasing train speed. Also, since the defect noise may be louder with loaded cars, and since the coal or ore cars travel full from a mine and empty toward a mine, an optional feature is provided to automatically adjust system sensitivity according to train direction obtained from the HBD.

The output amplitudes for the detected defect frequencies are available for recording. They are also applied to alarm circuits with thresholds that can be varied. To simplify the recording and display of data, the cup, cone and roller analog outputs for all of the wheel/bearing combinations of the Rail 1 track side are combined and applied to the Rail 1 analog input of the DATAGRAPH dedicated for acoustical information. A corresponding arrangement is provided for Rail 2.

Similarly, alarms for Rail 1 and Rail 2 are combined and applied in parallel to three event tracks of both DATAGRAPHs. Combined cup and cone raceway alarms are applied to one event track, roller alarms to a second, and wheel defects to a third.



DATAGRAPHs
Acoustical & HBD

The cup/cone alarms, and the roller alarms for each rail are applied to the SYSTEM 9000 DPU for correlation with axle count and trainside location and storage in the non-volatile memory.

Since the exceptionally loud noise emitted from a pounding, earth-shaking flat wheel is picked up over a large longitudinal span very nearly equally by the Rail 1 and Rail 2 acoustical sensors, it is difficult to identify the trainside location of a flat wheel and the exact axle location. Therefore, the flat wheel alarms for Rail 1 and Rail 2 are combined and applied to the SYSTEM 9000 for correlation and storage, where flat wheel alarms are identified as NEAR AXLE without including trainside.

Both the acoustical and HBD DATAGRAPHs are operated automatically from the recorder START/STOP control output of the SYSTEM 9000. The RS-232-C digital ports of both DATAGRAPHs are connected in parallel with the RS-232-C port of the SYSTEM 9000 to simultaneously print ASCII data at the end of each train scan and during system testing.

Non-Volatile Memory & Digital Access

The extended memory module, located in the SYSTEM 9000 DPU, stores train data for a maximum of 28,000 axles - OR- 127 trains. When the maximum capacity is reached, the oldest data is automatically erased and replaced by new data.

For each train, all acoustical alarms and all hot box alarms located by trainside and axle count from the head end are stored along with heat values. Diagnostic system performance data is also stored.

Trains are identified by site milepost, time and date, and train number beginning at midnight. A directory of all trains held in memory that includes a brief summary of data for each train, and another directory of the last five (5) trains with alarms simplifies access. All of the stored data is accessed through the SYSTEM 9000 DPU RS-232-C digital port.

DEPLOYMENT AND PERFORMANCE

At the present time, we have fabricated and deployed three (3) PHASE I Advance Development Systems. Installation of the first on the Union Pacific North Platte Subdivision was begun in December 1987 and completed in early January 1988. This system is operating continuously to monitor unit coal train traffic. The second was deployed in mid-January 1988 at the TTC, Pueblo, in conjunction with tests sponsored by the Burlington Northern. The third was installed in March 1988 on the Norfolk Southern north of Atlanta to monitor a mixture of revenue traffic. More systems are being manufactured for deployment in the near future.

BEARING INSPECTION SUMMARY
March 10, 1988

ACOUSTIC SIGNATURE AMPLITUDE mm	BEARING CONDITION CONDEMNABLE	DEFECTS / COMMENTS	
16	YES	CUP:	2 bar spall
			1 ea. 1/2 bar spall
		WHEEL:	code 75-shell tread
13	YES	CUP:	2 condemnable brinell
			4 brinell
			2 small spall
25	YES	ROLLER:	1 spall roller
		CUP:	35 small brinell
		WHEEL:	code 75-shell tread
14	YES	ROLLER:	1 split roller
		CUP:	1 bar spall ready to break out;
			2 repaired spalls
		WHEEL:	code 75-shell tread
20	YES	ROLLER:	1 seamed roller
		CUP:	2 ea. 1/2 bar spall
			3 bar spall
24	YES	CUP:	1 bar spall
			1 small spall
		CONE:	1 ea. 1/8" bar spall
12	YES	ROLLER:	1 spall roller
		CUP:	10 ea. 1/2 bar spalls
			heavy indentation
		CONE:	1 bar spall
14	YES	CUP:	1 bar spall, only 1/3 of which had completely broken out.

FIG. '7'

Optimum procedures for relaying acoustical alarms to yard personnel for validation and corrective action remain to be developed. As noted earlier, identification by axle count is frequently unreliable. Consist lists often are inaccurate, and counting axles on a long train is subject to human error. In a PHASE II Advanced Development System, we will be exploring television approaches to extract car owner and number and defect location from the 'B' end of the car.

CONCLUSION

By a reduction to practice, we have demonstrated that defective roller bearings can be detected automatically by wayside systems that use acoustical technology and electronic processing of signal spectra.

Early detection in stand-alone systems will reduce the probability of derailments due to the catastrophic failure of bearings. Early acoustical detection facilitates cost-effective follow-up corrective action at yard locations without unnecessary train stops.

Coupling and integrating an acoustical detector with a hot box detector provides a back-up warning of imminent bearing failure. The existence of both an acoustical defect signature and an abnormally hot bearing enhances the reliability of detecting defective bearings.

ACKNOWLEDGEMENTS

Several dedicated people contributed to the success of this program. Among them, the contributions and cooperation of Robert L. Florom (formerly of the Union Pacific now TTC, Pueblo) and Richard Smith and Jack Frarey (both Shaker/MTI) in the early phases, and subsequently those of Robert Vandeberg (Union Pacific) are gratefully acknowledged.

The efforts and skills of Ed Gellender as Project Engineer of the acoustical system and Luis Villar for the mechanical design of the trackside acoustical sensor at Servo deserve recognition and thanks.

REFERENCES:

(1) <u>Acoustical Signatures of Various Roller Bearing Defects</u>; Frarey, Jack; Smith, Richard; Paper presentation given at Conference sponsored by AAR and University of Illinois, April 15-16, 1986.

(2) <u>Wayside Acoustic Detection of Railroad Roller Bearing Defects</u>; Florom, R.L., Hiatt, A.R., Bambara, J.E., Smith, R.L.; Paper published by the ASME for their Annual Convention, December 1987.

(3) <u>The Detection of Acoustical Noise & Heat Signatures Generated by Defective Railroad Roller Bearings</u>; Bambara, J. E., Paper published and presented at the AAR C&S Convention in October 1987.

ADDENDUM
September 1988

ACOUSTICAL DETECTION OF DEFECTIVE ROLLER BEARINGS

Joseph E. Bambara, Vice-President
Corporate Advanced Development
SERVO CORPORATION OF AMERICA
Hicksville, New York

DEPLOYMENT & PERFORMANCE

At the present time, we have deployed three (3) Advanced Development Systems.

The first was installed on the Union Pacific near North Platte in December 1987. The site is unattended and is operating continuously to monitor unit coal train traffic at speeds of about 40mph. Defect data and diagnostic information are relayed to their R&D Lab by a telephone dial-up line.

On one special planned occasion, the site was manned when an unloaded unit coal train that was scheduled to be shopped for periodic maintenance passed the site. The system identified fifteen (15) bearing defects. When the train was shopped, eight (8) were determined to have defects by the AAR Hand Test. When they were taken apart, as shown in Fig. Z, all eight (8) had condemnable defects of various types including spalled, split and seamed rollers and spalls and Brinells on the cone and cup raceways. Three (3) of these bearings were associated with wheels that had shelled treads.

The seven (7) that were determined to have no defects by the AAR Hand Test were not taken apart. We believe most,if not all, would be verified as condemnable if disassembled.

Optimum procedures for relayed acoustical alarms to yard personnel for validation and corrective action remain to be developed. Identification by train side and axle count occasionally is unreliable. Consist lists often are inaccurate, counting axles and even cars on a long train is subject to human error, and sometimes a car is turned end-for-end before the truly defective wheelset is removed.

Defective bearing location errors are expected to be eliminated, or at least minimized by a 'frame capture' approach being developed by UP Lab personnel, to extract car owner and number and defect location relative to the "B" end of a car.

The second Advanced Development Systems was deployed at TTC, Pueblo, from January 1988 to May 1988 in conjunction with a test program sponsored by the Burlington Northern.

They had assembled a group of Class E (6 x 11) and Class F (6-1/2 x 12) bearings with a variety of known defects. These defective bearings were deployed in two separate test train consists; one composed of 70-ton TOFC/COFC cars, and another composed of 100-ton coal cars.

In separate test sequences, over a range of train speeds, these consists were operated unloaded and loaded, and for two different arrangements of the wheelsets with defective bearings.

The four (4) test sequences for the 70-ton consist and the four (4) for the 100-ton consist provided an opportunity to gather acoustical signature and background noise data, and an opportunity to check and adjust the real time performance of our system, over a very broad range of variables including some very bad weather.

We were able to identify many of the bearing defects such as cup, cone and roller defects, with reasonable consistency. Some others, such as loose backing ring and loose cone were only identified occasionally.

BEARING INSPECTION SUMMARY
March 10, 1988

ACOUSTIC SIGNATURE AMPLITUDE mm	BEARING CONDITION CONDEMNABLE	DEFECTS / COMMENTS	
16	YES	CUP:	2 bar spall 1 ea. 1/2 bar spall
		WHEEL:	code 75-shell tread
13	YES	CUP:	2 condemnable brinell 4 brinell 2 small spall
25	YES	ROLLER:	1 spall roller
		CUP:	35 small brinell
		WHEEL:	code 75-shell tread
14	YES	ROLLER:	1 split roller
		CUP:	1 bar spall ready to break out; 2 repaired spalls
		WHEEL:	code 75-shell tread
20	YES	ROLLER:	1 seamed roller
		CUP:	2 ea. 1/2 bar spall 3 bar spall
24	YES	CUP:	1 bar spall 1 small spall
		CONE:	1 ea. 1/8" bar spall
12	YES	ROLLER:	1 spall roller
		CUP:	10 ea. 1/2 bar spalls heavy indentation
		CONE:	1 bar spall
14	YES	CUP:	1 bar spall, only 1/3 of which had completely broken out.

FIG. 'Z'

At the completion of the test program, the second Advanced Development System was refurbished and updated, and is now being installed on the Burlington Northern at Alliance, Nebraska.

The third Advanced Development System was installed in March 1988 on the Norfolk/Southern north of Atlanta to monitor a mixture of revenue traffic at speeds in the 40 to 50 mph range.

Acoustical defective bearing alarms for southbound traffic, where cars can be set out at the Inmann Yard, are reported by telephone dial-up to a printer in the Atlanta office. Additionally, until a television identification system is installed, a wheel associated with an alarmed bearing is marked by a quick-response grease gun.

Three evaluation tests have been conducted so far.

The first was a preliminary evaluation in that our system had not been completely debugged, and the grease guns were not operating. For twelve alarms, we extracted five (5) confirmed defective bearings on tear-down and seven (7) 'nothing found'. One of the confirmed defective bearings was under a tank car.

On the second test, our score was better. For thirteen (13) defect alarms, three (3) associated with misfiring of the grease guns, were 'nothing found'. However, ten (10) with properly marked wheels were confirmed as defective.

Finally, for the third test conducted recently, of nineteen (19) bearings torn down, only one (1) associated with a severe wheel squeel was a 'nothing found' and eighteen (18) were bad bearings.

On one unit coal train included in the third test, we recorded seven (7) alarms for bearings that were later confirmed as condemnable. DATAGRAPH recordings for this train are shown in this slide. The acoustical signatures and alarms are on the lower portion and the corresponding heat signatures are on the upper portion.

All of the acoustically-detected defective bearings had normal Hot Bearing Detector heat values.

Alarmed bearings have been dis-assembled and inspected at Rail Bearing Service in Knoxville.

One of many spalled cups is shown in this slide. Multiple bar line spalls extend around one-third of the raceway circumference.

One of many spalled cone raceways is shown in this slide.

At this time, in three evaluation tests, we have eliminated thirty-three (33) bad bearings by automatic acoustical alarms.

Additionally, on tear-down, we have found a relatively high incidence of about one in four bad mate bearings on the opposite axle end of an alarmed bearing. Seven (7) such bad mate bearings have been removed.

Thus to date, at least forty (40) bad bearings with a variety of condemnable defects have been removed from service that otherwise would still be operating and awaiting an AAR 'Hand Test' associated with a wheel maintenance, or awaiting a hot bearing detection with associated train delays, or ultimately a 'burn-off'.