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SECOND INFORMAL REPORT ON ACTIVITIES IN PROGRESS AT THE EPRI M&D CENTER

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CONTENTS

SUMMARY

In support of the ORNL Advanced Diagnostic Engineering Research and Development Center (ADEC), motor current signature analysis (MCSA) has been used to monitor a variety of motor-driven devices at the Philadelphia Electric Company's Eddystone Generating Station as part of a program conducted by the EPRI M&D Center. The purpose of this project is to demonstrate the ability of MCSA to monitor degradation in aging power plant equipment.

The focus of this work has been the development and demonstration of an on-line, automated data acquisition system that has, for the last several months, provided motor current signature information on eight motor-operated valves (MOVs) that are a part of the unit 2 turbine steam extraction system.

Since October 1989, over 1200 MOV actuations have been recorded and analyzed. The work carried out thus far has resulted in the discovery of undesirable MOV operational characteristics and the identification of other signature trends that will be closely monitored over the next few months. In order to improve data analysis capabilities, an automated data analysis program has been developed that significantly reduces the time required to extract diagnostic information from the MOV motor current signatures.

This report provides the results from the analyses of extraction valve motor current signatures that were acquired during the period November, 1989 through January, 1990 and is thus intended to serve as a companion to the first progress report that covered the month of October, 1989.

1. INTRODUCTION

1.1 Background

Motor current signature analysis (MCSA), a machinery monitoring technology developed by the Oak Ridge National Laboratory (ORNL), has been used to monitor the performance of a variety of motor-driven devices at the Philadelphia Electric Company's Eddystone Generating Station as part of a program conducted by the EPRI M&D Center. The focus of the work has been the development and demonstration of an on-line, automated data acquisition system that has, since October, 1989, provided motor current signature information on eight motor-operated valves (MOVs) located in the unit 2 turbine steam extraction system. The function of these valves is to allow steam extraction from various turbine sections. This steam is routed through eight individual feedwater heaters (5A, 6A, 7A, 8A, 5B, 6B, 7B, and 8B) to preheat the boiler feedwater. According to Eddystone, it is imperative that these extraction valves close if a significant feedwater heater tube leak occurs in order to avoid water induction back into the turbine sections.

This work supports the Advanced Diagnostic Engineering Research and Development Center (ADEC) which was established by the Oak Ridge National Laboratory (ORNL) in 1989 in order to play a key role in the area of diagnostic engineering. ADEC is an organized multi-disciplinary diagnostics research program that brings together experts in many fields in order to develop and apply new diagnostic technologies, especially within the power generating industry.

One of the long-term goals of ADEC is to trend key motor current signature features (from both the time and frequency domains) that track the progression of aging and service wear so that (a) maintenance can be performed only as needed and (b) unexpected failures can be minimized or avoided. This report provides several trend plots that are potentially useful for these purposes.

An initial analysis of Unit 2 extraction valve motor current signals was carried out during the month of October, 1989. The results from this analysis were presented to EPRI and Eddystone plant personnel on November 21, 1989 and reported in an informal progress report [1]. This report provides selected results from the analyses of extraction valve motor current data that were acquired during November (1989), December (1989), and January (1990).

This report is intended to serve as a companion to the first progress report, and together, they provide motor current signature information for Unit 2 extraction valves over a 4-month time period. By continuing to analyze and document MOV motor current signatures over the next few months, it is hoped that several trends in motor current signature parameters will emerge and will thus reflect service wear (aging) effects. Several notable trends have already been observed and are presented in this report. The continuation (or alteration) of these trends will become evident over the next few months and will be discussed in a future report.

1.2 ORNL On-Line Monitoring System: General Method of Operation

The ORNL-developed system is shown schematically in Figure 1. MOV motor current signals are acquired non-intrusively by 400:1 ratio toroidal current transformers, located near the motor control center. The ac current signals supplied by the secondary side of the current transformers are transmitted via coaxial cables to the first-floor data acquisition room, where they are connected to signal processing equipment developed especially for this application. At this location, each coaxial cable is terminated by a load resistor and the resulting voltages are summed prior to undergoing signal conditioning (amplification, filtration, etc.).

During an MOV actuation, the signal processing equipment provides two outputs, one suitable for time-domain (waveform) analysis and one suitable for frequency-domain (spectral) analysis. In addition to the two analog signals, a digital signal is also generated by the signal processing equipment that reflects the identity of the MOV being actuated. The three analog and one digital signal are carried by cables to the upstairs data display room where they are monitored continuously by an IBM AT-based data acquisition system.

A general system operation flowchart is presented in Figure 2, and illustrates that the process of MOV signature development is presently a four step process which includes data acquisition, data transfer, database construction, and data analysis elements. It is recognized that future system developments may ultimately streamline this process to the point where all necessary functions are carried out at Eddystone by M&D Center personnel.

1.3 Computer Program for Automated Data Analysis

Until recently, all data analyses were done manually, that is, by displaying a selected signature using a commercial data plotting program, determining the type of run (normal or abnormal) by examining the signature for the existence of specific features, and measuring all desired signature parameters via cursors (pointers) provided by the plotting program. This method of data analysis required considerable time from a person having MCSA expertise.

In order to reduce the time required for determination of run type and measurements of selected motor current signature features for trending purposes, and to provide accurate signature analysis capabilities to those unskilled in MCSA, an automated data analysis program was developed. This program, called "RESOLVE", has proved very capable at distinguishing between normal and abnormal MOV motor current signatures. RESOLVE can also identify several types of transients (motor startup, motor trip, motor operator hammerblow) that are present in normal MOV signatures. For normal actuations, RESOLVE presently determines the following information:

(a) Valve stroke time
(b) Average running current
(c) Maximum running current
(d) Minimum running current
(e) Current peak values for transients
(f) Probable valve stroke direction
(open-close, or close-open)

Changes are presently being made to RESOLVE that will provide improved diagnostic capabilities and more "user-friendly" operation.

2. UNIT 2 STEAM EXTRACTION VALVES: MONTHLY TREND PLOTS

Average running currents and stroke times were determined for each "normal" valve actuation carried out during November (1989), December (1989), and January (1990). These two performance parameters are plotted against time in Figures 3 through 62, as summarized in Table 1 below.

Table 1 Monthly Plots of Motor Current and Stroke Time

Month	Parameter Plotted	Valves	Figure Numbers
November, 1989	Motor Current	5A-8B	3 - 10
"	"	All "A" Train Valves	11 - 12
"	"	All "B" Train Valves	13 - 14
"	Stroke Time	5A-8B	15 - 22
December, 1989	Motor Current	5A-8B	23 - 30
"	"	All "A" Train Valves	31 - 32
"	"	All "B" Train Valves	33 - 34
"	Stroke Time	5A-8B	35 - 42
January, 1990	Motor Current	5A-8B	43 - 50
"	"	All "A" Train Valves	51 - 52
"	"	All "B" Train Valves	53 - 54
"	Stroke Time	5A-8B	55 - 62

It is noted that valve stroke direction was determined by the automated data analysis program by referencing the measured stroke time for a given actuation to a table of stroke time ranges for each valve and for both stroke directions (recall that valve identity, but not stroke direction, is known from the digital signal transmitted from the signal conditioning electronics to the data acquisition computer). This table of expected stroke times was determined from previous analyses of motor current signatures acquired with the on-line system and with portable MCSA equipment, and from discussions with plant personnel.

Considerable day-to-day variations in MOV running current and stroke time measurements were observed during these three months. Figure 63 provides a statistical analysis of valve stroke times for December, 1989. This Figure illustrates that, for the month of December, valves 7A, 8A, 7B, and 8B showed the greatest overall variation in stroke times relative to their mean values. This likely reflects the fact that these valves experience the greatest absolute variations in line pressure (between shut-down and full power operation) as a result of their locations in the steam extraction system.

Common-mode trends (i.e., trends observed for several valves during the same time period) were also seen, likely indicating times when significant changes in line voltage and/or pressure were encountered. These trends are discussed in detail later in the report.

3. UNIT 2 STEAM EXTRACTION VALVES: FOUR-MONTH TRENDS

Month-to-month trends in running currents and stroke times have also been observed that may be a result of valve and/or motor operator degradation. These trends, discussed in the following sections, will be closely monitored over the next few months.

3.1 Average Motor Current Trends

Figures 64 and 65 compare the average motor current (by month) for each valve during the four-month period following the installation of the ORNL on-line monitoring system. The general trends in motor current are summarized in Table 2 below.

Table 2 General Trends Observed in Average Motor Current Measurements During the Period October, 1989 to January, 1990

Valve	Stroke	Trend Observed
5A	Open-Close	Significant increase (0.25 A) over the last 3 months, following abrupt decrease between Oct. & Nov.
	Close-Open	No obvious trend
6A	Open-Close	No obvious trend
	Close-Open	No obvious trend
7A	Open-Close	No obvious trend
	Close-Open	No obvious trend
8A	Open-Close	Slight increase (0.08 A) over the last 3 months
	Close-Open	Significant increase (0.22 A) over the last 3 months
5B	Open-Close	No obvious trend
	Close-Open	No obvious trend
6B	Open-Close	No obvious trend
	Close-Open	Slight decrease (0.10 A) over the last 3 months
7B	Open-Close	No obvious trend
	Close-Open	No obvious trend
8B	Open-Close	Erratic, but no obvious trend
	Close-Open	Slight decrease (0.11 A) over the last 3 months

It is recognized that changes in motor current can simply reflect changes in line voltage; thus, these trends in motor running current may simply reflect trends in average line voltage during valve actuations. However, we believe that these variations in running current more likely reflect true changes in running load. This belief is based on the observation that only four valves (5A, 8A, 6B, and 8B) showed running current trends over the last three months. If voltage alone was responsible for these trends, other valves should have exhibited similar trends. These trends in running current will be closely monitored over the next few months, since changes in running loads can reflect valve and/or motor operator degradation.

3.2 Average Stroke Time Trends

Figures 66 and 67 compare the average stroke time (by month) for each valve during the four-month period following the installation of the ORNL on-line monitoring system. The general trends in stroke time are summarized in Table 3 below.

Table 3 General Trends Observed in Stroke Time Measurements During the Period October, 1989 to January, 1990

Valve	Stroke	Trend Observed
5A	Open-Close	Slight decrease (0.12 sec, 0.14 %) over the last 3 months
	Close-Open	No obvious trend
6A	Open-Close	Large but unvarying difference between open → close and close → open stroke times
	Close-Open	Large but unvarying difference between open → close and close → open stroke times

Valve	Stroke	Trend Observed
7A	Open-Close	Significant decrease (0.15 sec, 0.66 %) over the last 3 months
	Close-Open	No obvious trend
8A	Open-Close	Significant decrease (0.26 sec, 0.85 %) over the last 3 months
	Close-Open	Significant increase (0.18 sec, 0.61 %) over the last 3 months
5B	Open-Close	Slight increase (0.23 sec, 0.39 %) over the last 4 months
	Close-Open	Slight decrease (0.12 sec, 0.20 %) over the last 3 months
6B	Open-Close	Extremely consistent performance; no trend
	Close-Open	Extremely consistent performance; no trend
7B	Open-Close	No obvious trend
	Close-Open	No obvious trend
8B	Open-Close	Significant increase (0.84 sec, 2.9 %) over the last 4 months
	Close-Open	Unvarying (No obvious trend)

Changes in MOV stroke time can result from either a change in motor speed or a change in valve stroke (distance). Assuming that limit switches on all valves have remained at the same setting since October, 1989, the valves should travel the same stroke, thus the trends in stroke time likely represent actual changes in motor speed that can result from either changes in line voltage or running load. Since changes in running load may be a result of valve and/or motor operator degradation, these stroke time trends will be monitored closely over the next few months.

4. UNIT 2 STEAM EXTRACTION VALVES: TRENDS OF SIGNATURE TRANSIENTS

A motor-operated gate valve motor current signature may include momentary increases in current (transients) due to short-lived increases in running load resulting from motor operator hammerblow, gate seating, and gate unseating events. Since it is known that all eight Unit 2 extraction valves being monitored do not fully close [1], it is unlikely that gate seating or unseating transients would ever be observed in the motor current signatures. Other motor current transients have been observed, however, that apparently result from motor-operator hammerblow and valve differential pressure loads. These transients, seen occasionally during the open-close strokes of valves 7A, 8A, and 8B, are described during the next few sections and will be closely monitored during the next few months for any trends that may develop that would be indicative of valve and/or motor operator degradation.

4.1 Valve 7A Motor Operator Hammerblows

Hammerblow transients were observed in open-close motor current signatures for valve 7A on twenty-one occasions during November, December, and January. A typical valve 7A hammerblow transient (open-close stroke) is shown in Figure 68. The transient begins approximately 0.64 seconds after the motor is energized and results in a momentary rise in current of approximately 0.5 A. The rise in current reflects the additional motor torque required to initiate the motion of the motor operator drive sleeve. As shown in Figure 69, the hammerblow current rise for valve 7A has varied considerably over the last three months; however, no consistent trend is evident.

4.2 Valve 8A Motor Operator Hammerblows

For the same time period, hammerblow transients were also observed infrequently on valve 8A (only six times); however, on two occasions the beginning of the open-close stroke was also seen to include additional features that deserve mention. Figure 70 illustrates a typical valve 8A motor operator hammerblow transient. The hammerblow begins approximately 0.73 seconds after the motor is energized and results in a momentary current rise of approximately 0.2 A. On November 7 and December 11, 1989, additional signature features were observed and are shown in Figure 71, along with a more recent (January 24, 1990) hammerblow transient for comparison. As shown in the figure, on November 7, 1989, a short-lived (approximately 0.4 second) period of anomalously low running current (3.7 A) was seen at the beginning of the open-close stroke and on December 11, 1989, two 0.6 A transients were seen at the beginning of the open-close stroke, indicating two separate momentary load increases. It is presently not known what resulted in the unusual features shown in this figure; however, since these features are known to have occurred only once during the three-month period, it does not seem that their occurrence should warrant much concern, but they bear watching in the future.

4.3 Valve 8B Motor Operator Hammerblows

Figure 72 illustrates a motor-operator hammerblow transient observed on valve 8B on January 22, 1990 along with two separate occurrences (January 28 and January 31, 1990) of a two-transient feature at the beginning of the open-close stroke. This double peak characteristic, similar to that observed on valve 8A on December 11, 1989, is of unknown origin, but it will be looked for in future data, since its existence may indicate development of a valve and/or motor operator problem.

4.4 Other Transients

On several occasions, the motor current magnitude of valves 7A and 5B increased near the end of the open-close stroke. Figures 73 and 74 illustrate the rise in current observed for valve 7A (on November 17, 1989 and January 31, 1990) and valve 5B (January 29, 1990) respectively. Since both valves deenergize on limit (as opposed to torque) switch actuation, a probable cause of this feature is an increase in valve internal friction resulting from increased differential pressure across the valve obturator as the valve nears its closed position.

To look for trends in this signature feature, the maximum current value (observed at the end of stroke) was plotted along with the average running current and the difference between the maximum and average values for those actuations having a current rise at the end of stroke. Figures 75 and 76 show no clear trend in the current rise at the end of the open-close stroke for valves 7A and 5B, respectively.

5. COMMON MODE TRENDS DURING DECEMBER

During December, 1989, motor running current magnitudes were seen to increase for several MOVs at the same time. A likely explanation for this "common mode" trend is a change in Unit 2 status (start-up, shut-down) that results in significant changes in line voltage (approximately 20 volts according to data provided by Eddystone) and pressures. These changes in voltage and pressure would affect all monitored MOVs and therefore would be observed in motor current signatures for all the MOVs actuated during those times. Figures 77 through 80 show four observations of motor current increases during December that were seen on several valves at the same time.

An attempt was made to correlate these common mode trends with the times of Unit 2 start-ups and shut-downs provided by Eddystone; however, a correlation was not found. Nevertheless, since several MOVs exhibited increases in current at the same time, it seems unlikely that these changes reflect MOV degradation.

6. DATA QUALITY: NORMAL AND ABNORMAL DATA

Examples of "normal" and "abnormal" MOV motor current signatures were presented and described in our earlier informal progress report. Ideally, if only one MOV is actuated at a time and thirty seconds are allowed to elapse between valve actuations, nearly all MOV actuations would be normal. In practice, however, abnormal runs (signatures) occur frequently. These abnormal runs are not analyzed since they represent, at best, only a segment of a MOV actuation and, at worst, they contain confusing signature features that result from the combined effects of two or more MOVs running at the same time.

6.1 Influence of Valve Actuation Technique

Figure 81 illustrates that for December, 1989, only 45.8% of the valve actuations recorded by the ORNL on-line system were normal, and thus were analyzable. Most abnormal runs (81.7%) were the result of starting another valve stroke too soon after one had ended, or of actuating more than one valve at a time. A significant percentage of the abnormal runs (18.3%) were the apparent result of terminating a valve stroke manually (i.e., before motor operator switch trip).

It should be noted that the percentage of normal runs acquired, and thus the percentage of valve actuations analyzable, could be increased significantly simply as a result of more careful valve actuation technique.

6.2 Four-Month Trend

Figure 82 shows that over the four-month period October, 1989 through January, 1990, the majority (53.4 %) of the valve actuations have been abnormal. In other words, approximately 650 valve actuations were not analyzed due to the manner in which they were carried out. On the positive side, over 560 normal motor current signatures have been acquired and analyzed, and for the last month (January, 1990), the fraction of total runs that were normal exceeded 50%.

6.3 Reliability of Automated Data Analysis Computer Program

As mentioned early in the report, a computer program was developed by ORNL that provides automated analysis of Unit 2 MOV motor current signatures. Before the program was used to analyze the data acquired during the months of November (1989), December (1989), and January (1990), the data from December, 1989 had been analyzed manually. Therefore, to determine its effectiveness and reliability, the program was initially used to analyze this same set of data. Figure 84 illustrates that the initial version of "RESOLVE" differentiated between normal and abnormal runs in a manner comparable to a manual analysis. This program is presently being upgraded to increase its effectiveness and accuracy.

7. MCSA TESTS PERFORMED NOVEMBER 22, 1989

On November 22, 1989, ORNL acquired motor current data on two air compressors, a Unit 3 MOV (VP6), a Unit 2 MOV (5A), and a fixed resistor (dummy load) at the Eddystone Plant using portable MCSA equipment. A discussion of significant findings from these tests is presented in the sections below.

7.1 Air Compressors

Descriptive specifications for the two tested compressors are provided by Table 4 below.

Table 4 Air Compressors Tested by ORNL on November 22, 1989 at the Eddystone Power Plant

Compressor	Motor
Manufacturer : Ingersoll-Rand	Manufacturer : General Electric
Type : XLE	Horsepower : 200
Size : 17x10x7	Voltage : 460, three phase
RPM : 585	Rated Current : 253 A
Discharge Pressure : 115 psi	RPM : 585

Compressor No.	Serial Number	Comments
1	JH-7183	Recently refurbished
2	JH-7181	Not recently refurbished

Figure 84 illustrates motor current time waveforms for the two compressors and shows that the recently refurbished compressor (#1) actually draws more current than the compressor that had not been refurbished. The running current magnitudes for both machines were found to vary considerably (averaging from approximately 140 A to 270 A) during compressor operation. Subtle features seen in both time waveforms likely represent actual running load characteristics common to both machines.

Figure 85 provides a frequency spectrum comparison between the two machines. As shown in the figure, both machines exhibit almost identical spectral characteristics. This is interpreted to mean that both machines are in similar operational condition.

The data acquired on these compressors on November 22, 1989 represent baseline signatures against which future data may be compared.

7.2 Unit 3 motor-operated valve VP6

Motor current data were acquired on valve VP6 at its motor control center. It is noted that Unit 3 was on line at the time the valve test was carried out. Two complete valve cycles were carried out from an initially closed position. The motor current signatures obtained from these actuations are presented in figures 86 through 89. As shown in the figures, both close-open strokes resulted in normal motor current signatures; however, extreme variations in current magnitudes were observed approximately mid-way through both open-close actuations. Relay chatter was also audible during this time, thus identifying the source of the observed extreme motor current variations.

7.3 Valve 5A/Dummy Load

Motor current data were also acquired on valve 5A at its motor control center. It is noted that Unit 2 was shut down at the time this test was carried out. In addition, the current through a dummy load resistor was acquired concurrent with the MOV current acquisition. Figure 90 shows that the dummy load current signature is void of the power line frequency components (2, 4, 6... Hz) that are observed when the Unit is on line. Therefore, these power line frequencies are likely caused by Unit 2 equipment that is operational only when the Unit is on line. As shown in the figure, when the power line frequencies are absent, the MOV current spectrum features may be more clearly viewed. The major peaks in the valve 5A spectrum are tentatively identified (see Figure 90).

8. PLANS FOR FUTURE WORK

Emphasis will be placed on continued monitoring of the eight Unit 2 MOVs using the on-line data acquisition system. Trends in motor current signature features (discussed in this report) will be closely monitored during the next few months for signs of continuance or discontinuance. The automated MOV signature analysis computer program "RESOLVE" will be upgraded to improve its diagnostic capabilities. In addition, there are other areas worthy of future work, including:

1. Continued testing of other equipment with portable MCSA equipment (e.g., previously tested pumps, fans, mills, compressors, and Unit 3 MOVs) in order to look for any signature changes that may indicate equipment degradation.
2. Investigating the possibility of data coloration attributable to the acquisition of motor

current signals in the Eddystone control room on the secondary (meter) side of the Eddystone current transformers.

3. Making improvements in the on-line MOV monitoring system including :
   (a) Improvement of MOV frequency domain information through identification and removal of power line noise
   (b) Upgrading Eddystone-resident programming such as improving real-time screen display, adding trend plot capabilities, and automated diagnostics.
4. Planning for the eventual "phase-out" of ORNL and the possible "phase-in" of a MCSA licensee to continue motor current signature analysis activities at the Eddystone plant.

The timetable for this work is not clear; however, with continued interaction with M&D Center personnel, priorities can be established, based on the relative importance of each task to the objectives of ORNL/ADEC, EPRI,and the Eddystone plant.

9. SUMMARY AND INTERIM CONCLUSIONS

Motor current signature analysis (MCSA) has been used to monitor a variety of motor-driven devices at the Philadelphia Electric Company Eddystone Generating Station as part of a program conducted jointly by the ORNL Advanced Diagnostic Engineering Research and Development Center (ADEC) and the EPRI M&D Center. The purpose of this project is to demonstrate the ability of MCSA to monitor degradation in aging power plant equipment.

During the period October, 1989 through January, 1990, eight MOVs that are a part of the Unit 2 turbine steam extraction system have been monitored using an on-line data acquisition system developed by ORNL. To date, this system has acquired motor current signatures for over 1200 MOV actuations that have now been recorded, analyzed, and documented in two informal progress reports.

The results of this work include the discovery of certain undesirable MOV operational characteristics and the identification of other signature trends, possibly reflecting early stages of MOV degradation, that will be closely monitored over the next few months.

In order to improve data analysis capabilities, an automated data analysis program was developed that reduces significantly the time required to extract diagnostic information from the MOV motor current signatures.

At this point in the program, MOV aging and service wear has yet to be substantiated, although several trends in motor current features have been observed that suggest that changes in operational condition of several MOVs may have occurred. It is expected that during the next few months of MOV actuations, these trends will either continue (providing strong indication of MOV degradation) or terminate (suggesting that no degradation has in fact, occurred).

REFERENCE

[1] H.D. Haynes, R.C. Kryter, C. Lacombe, and C.P. Stafford, "Informal Report on Activities in Progress at the EPRI M&D Center," ADEC-P1, November 10, 1989.

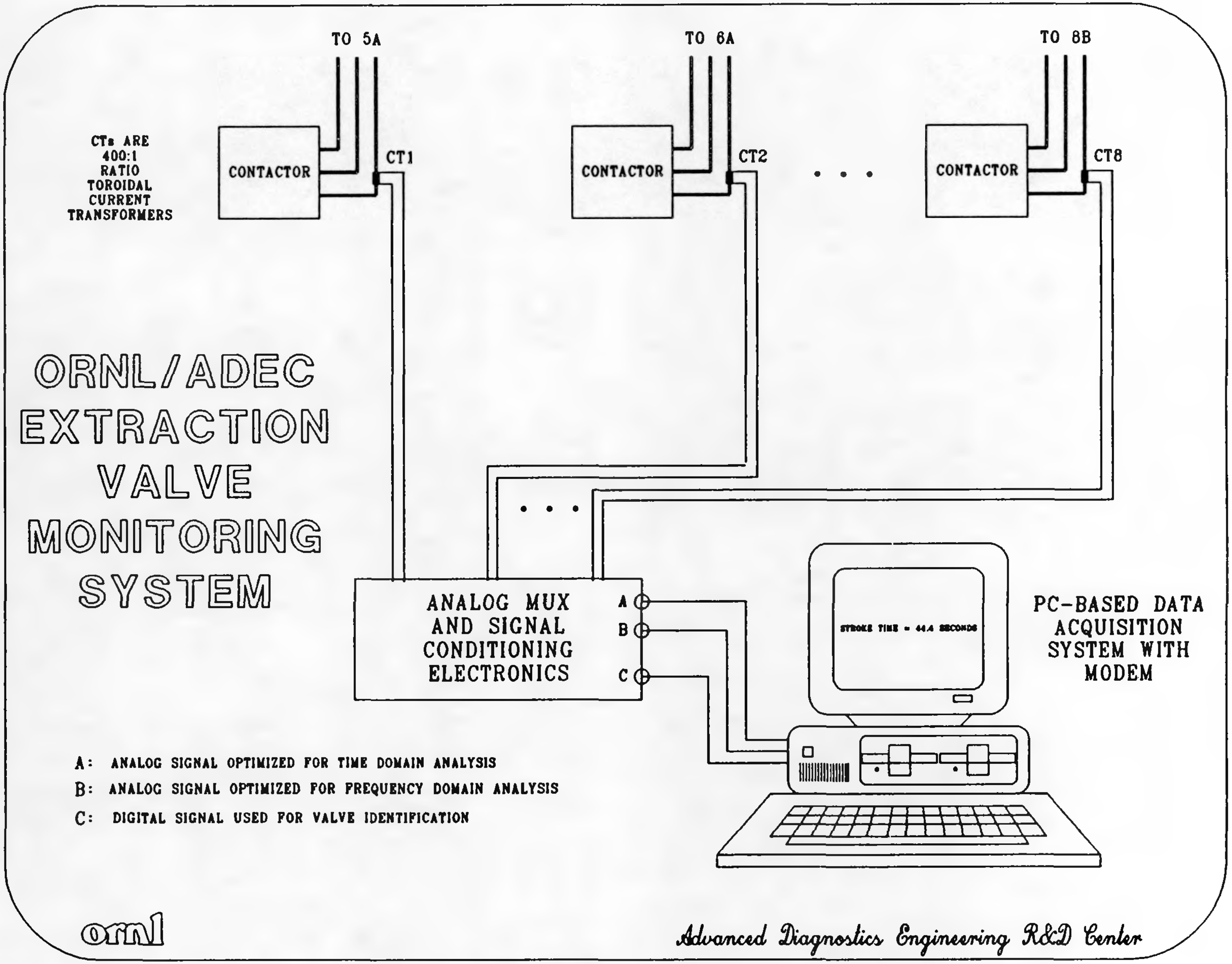
TO 5A
TO 6A
TO 8B
CTs ARE 400:1 RATIO TOROIDAL CURRENT TRANSFORMERS
CONTACTOR
CT1
CONTACTOR
CT2
CONTACTOR
CT8
ORNL/ADEC EXTRACTION VALVE MONITORING SYSTEM
ANALOG MUX AND SIGNAL CONDITIONING ELECTRONICS
A
B
C
STROKE TIME = 44.4 SECONDS
PC-BASED DATA ACQUISITION SYSTEM WITH MODEM
A: ANALOG SIGNAL OPTIMIZED FOR TIME DOMAIN ANALYSIS
B: ANALOG SIGNAL OPTIMIZED FOR FREQUENCY DOMAIN ANALYSIS
C: DIGITAL SIGNAL USED FOR VALVE IDENTIFICATION
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 1

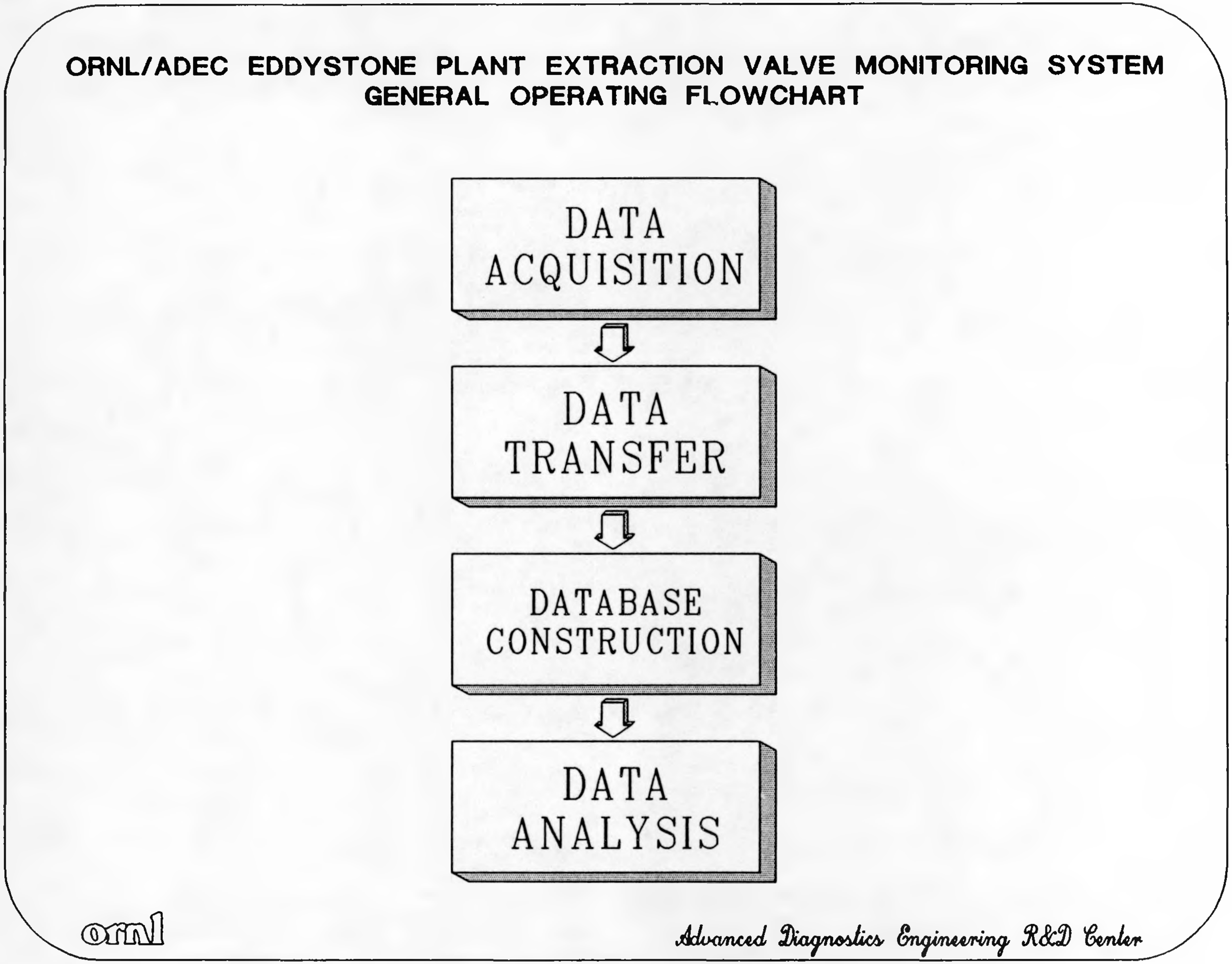
ORNL/ADEC EDDYSTONE PLANT EXTRACTION VALVE MONITORING SYSTEM
GENERAL OPERATING FLOWCHART
DATA ACQUISITION
DATA TRANSFER
DATABASE CONSTRUCTION
DATA ANALYSIS
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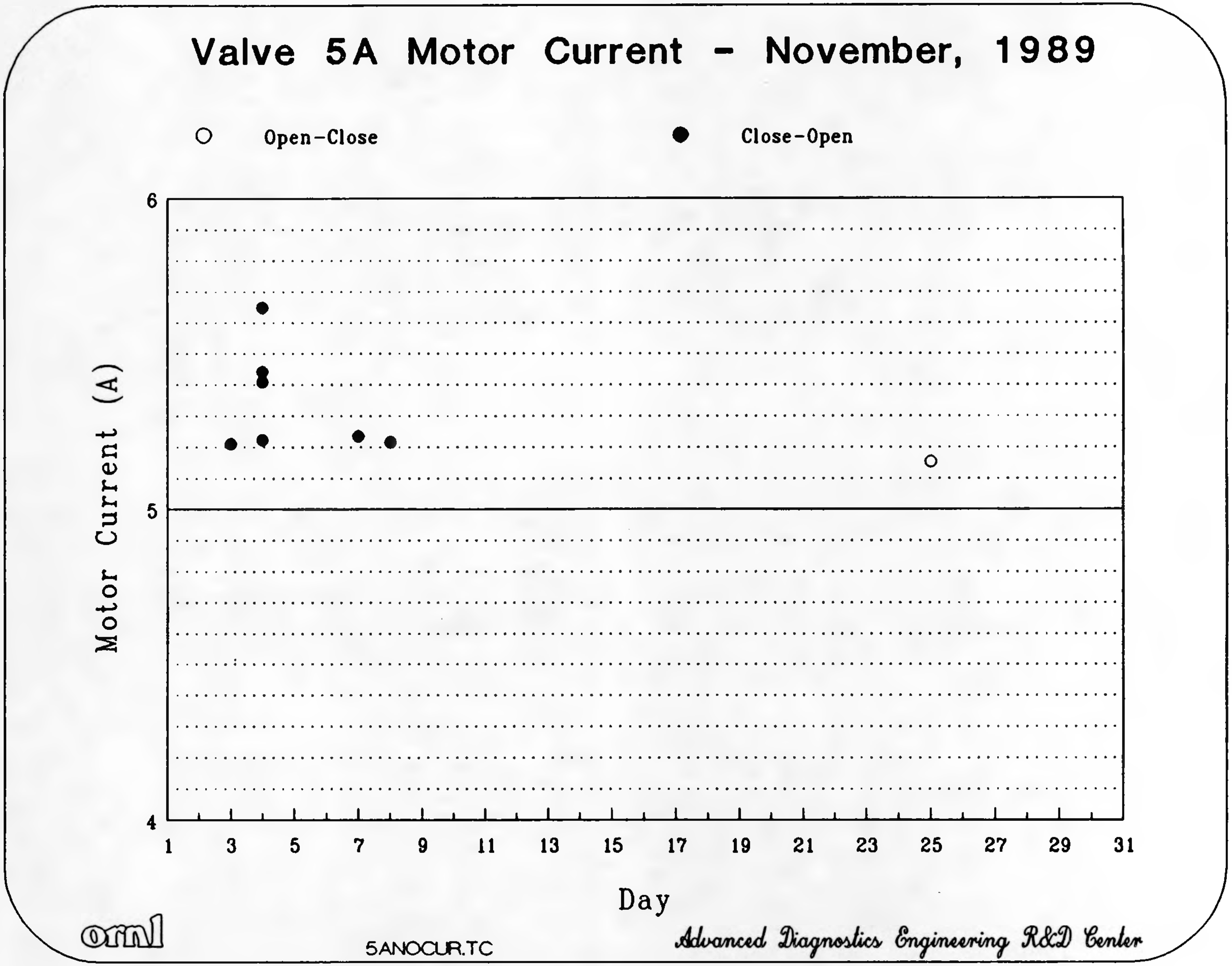
FIGURE 2



Valve 5A Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
6
5
4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
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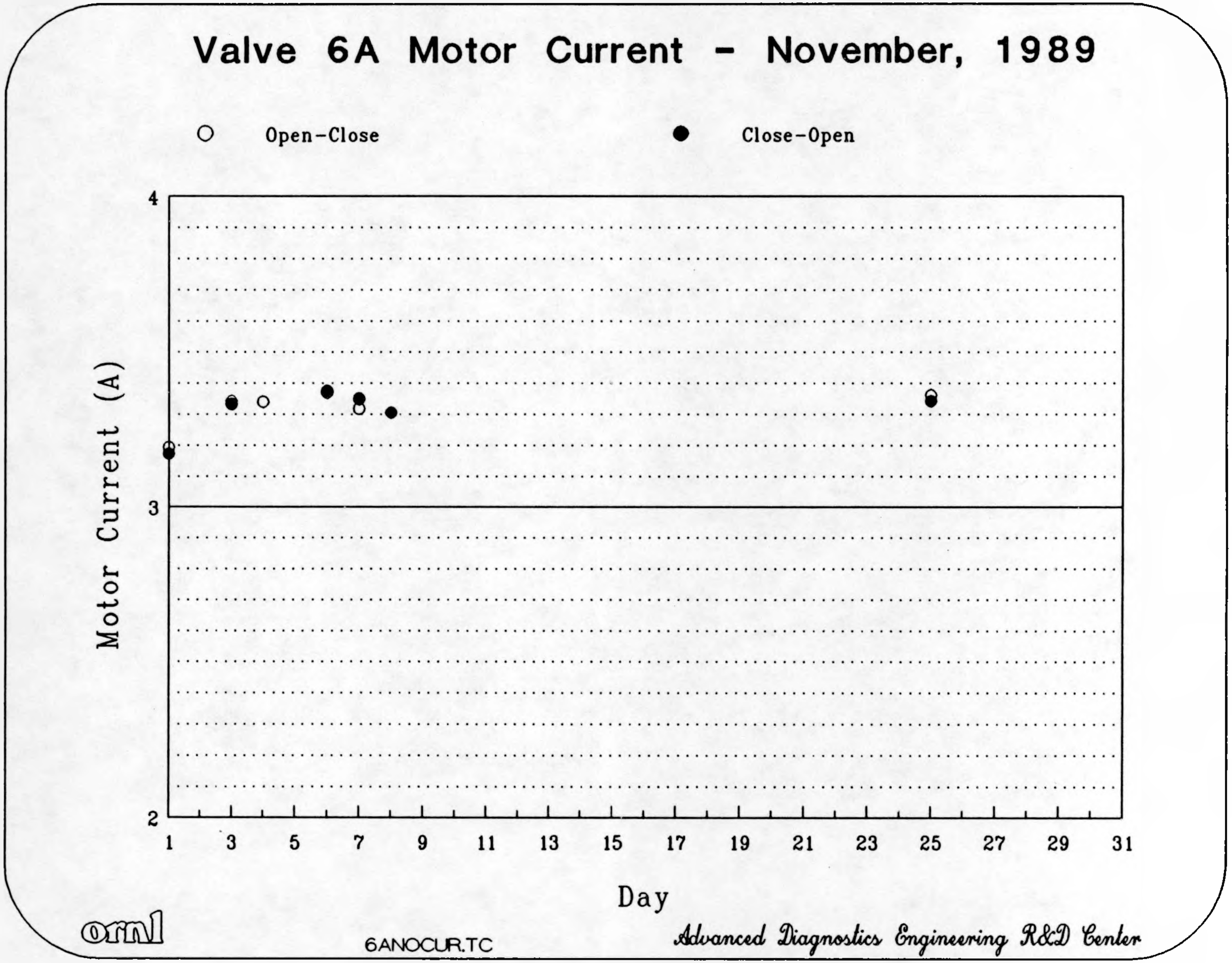
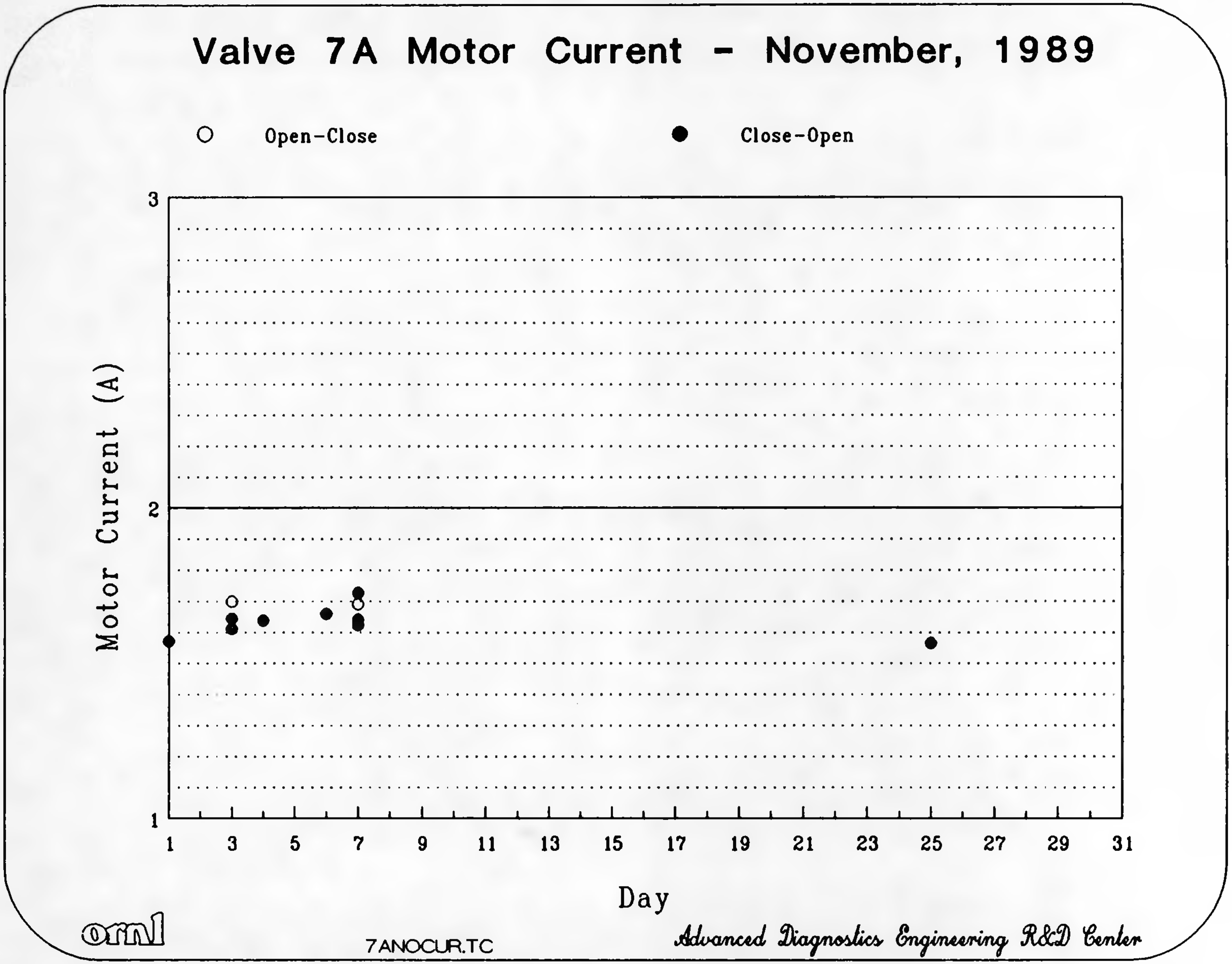
5ANOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 3



Valve 6A Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6ANOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 4


Valve 7A Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
3
2
1
1
3
5
7
9
11
13
15
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19
21
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25
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29
31
Day
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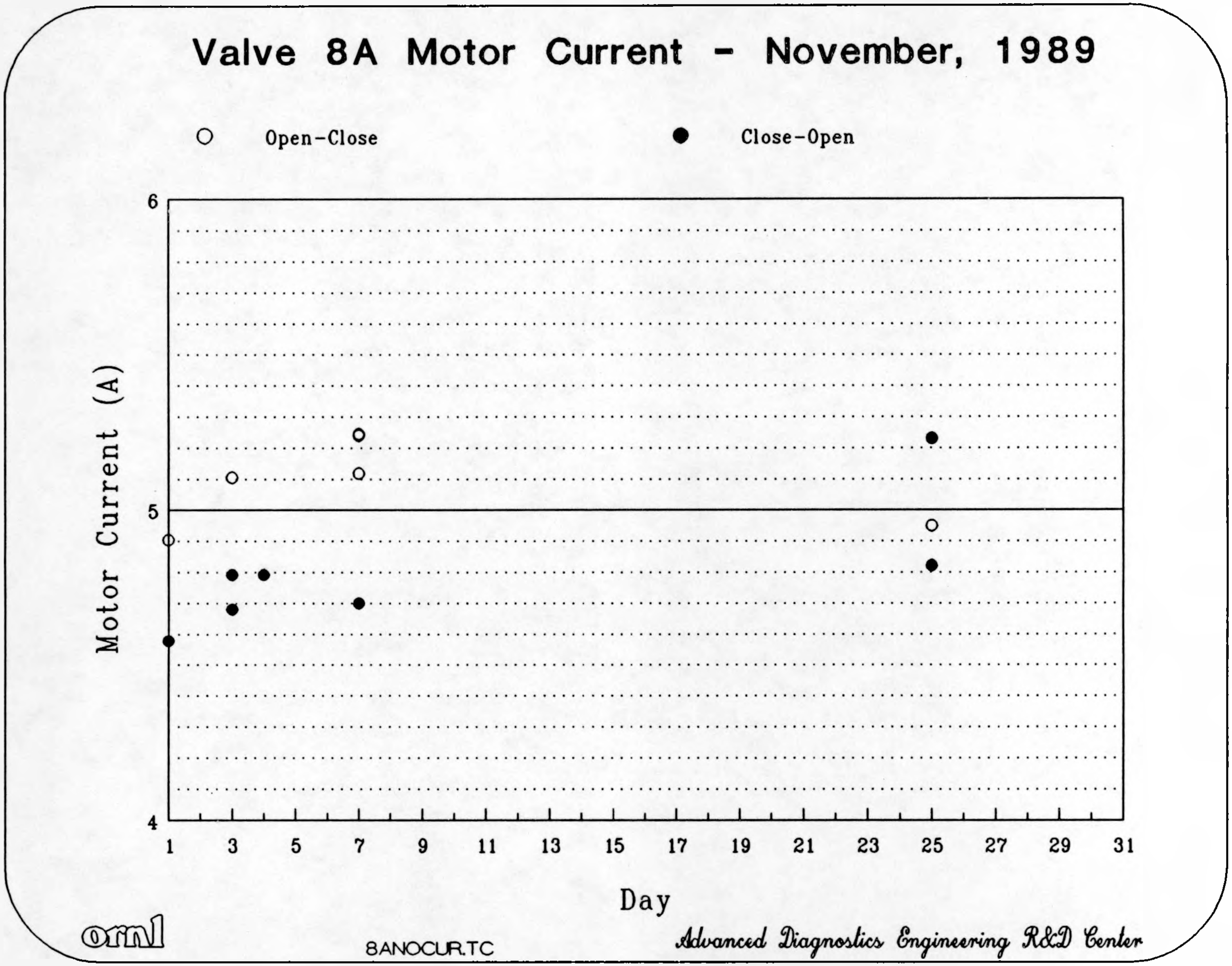
7ANOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 5



Valve 8A Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
6
5
4
1
3
5
7
9
11
13
15
17
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21
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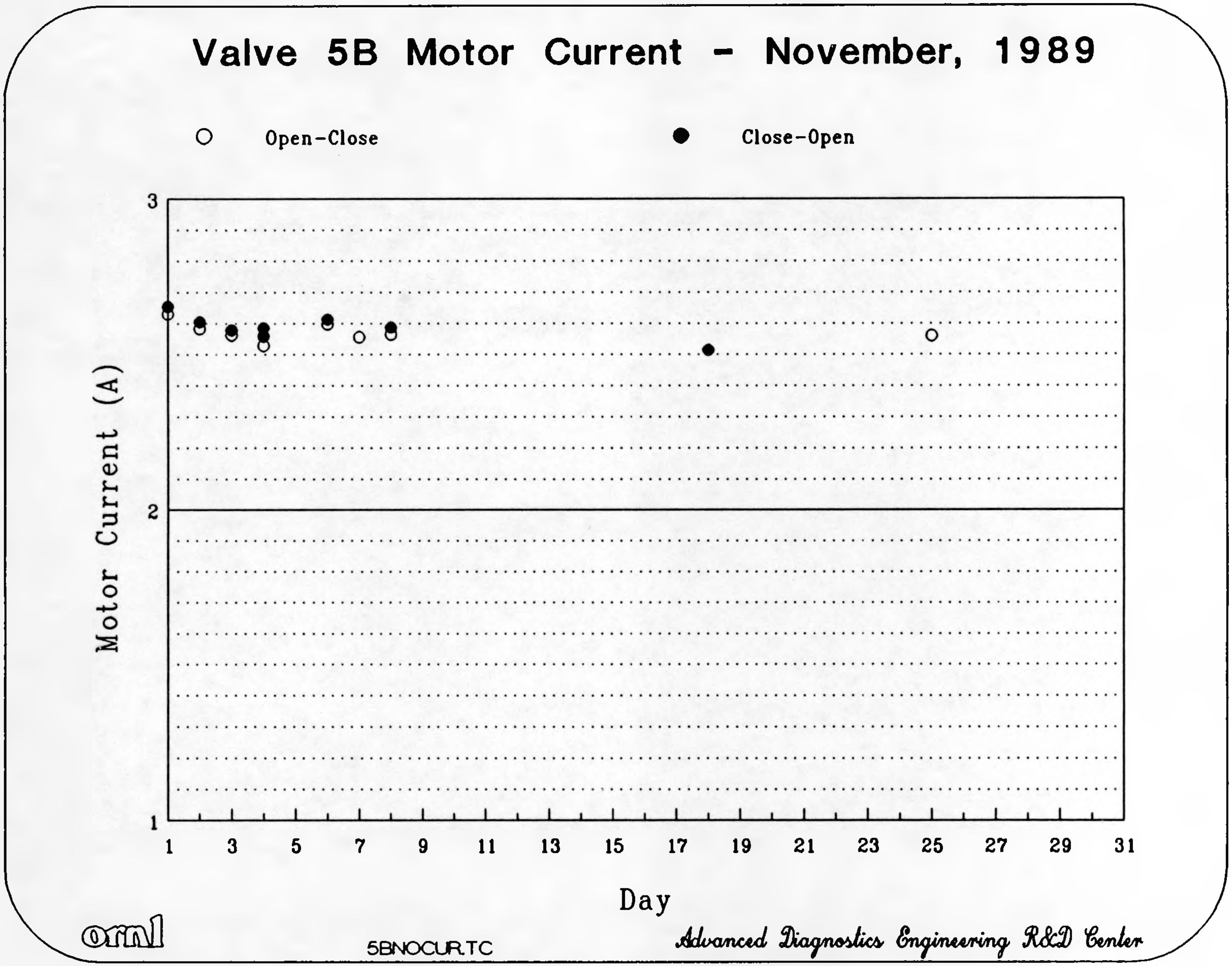
25
27
29
31
Day
ornl
8ANOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 6



Valve 5B Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BNOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 7

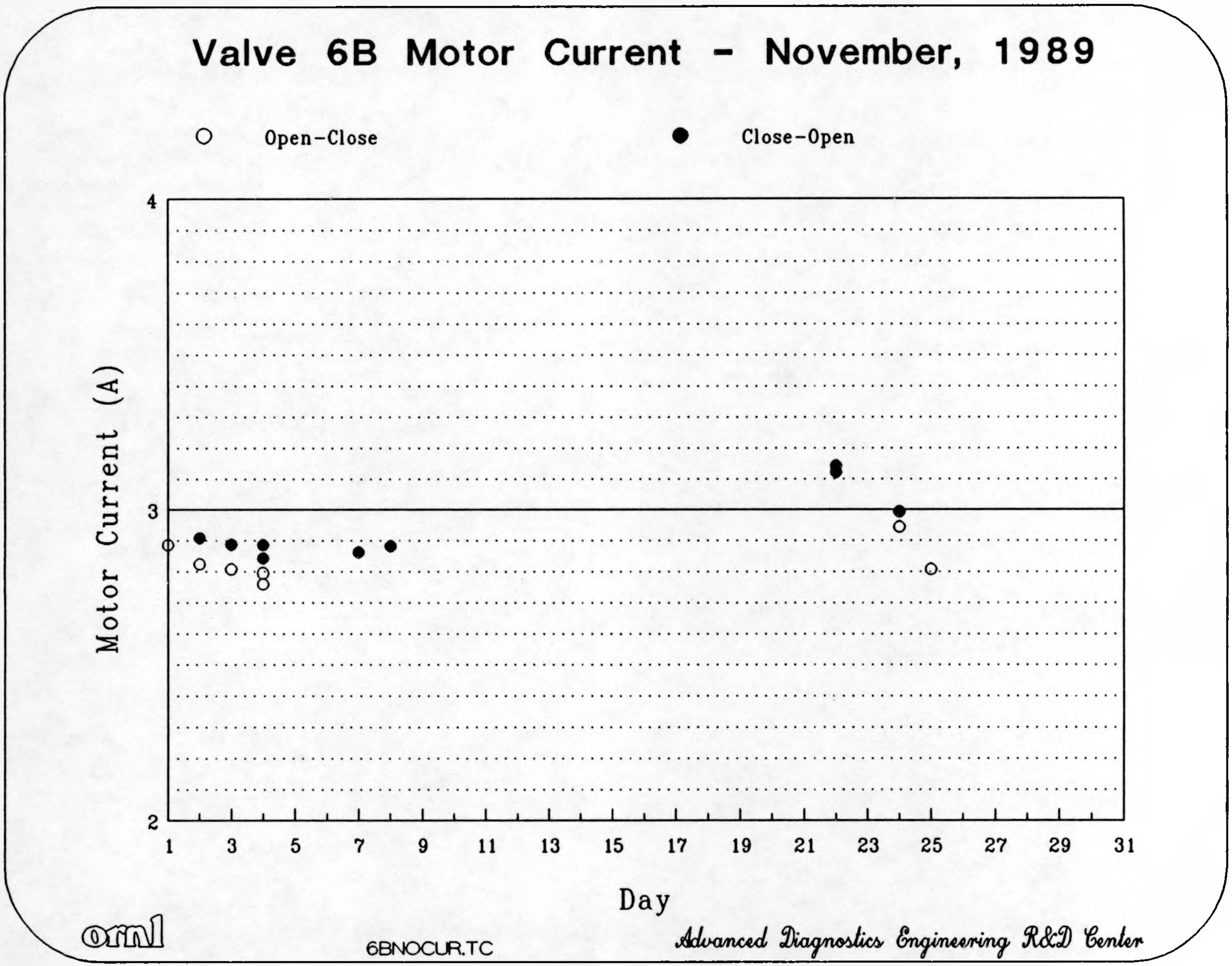
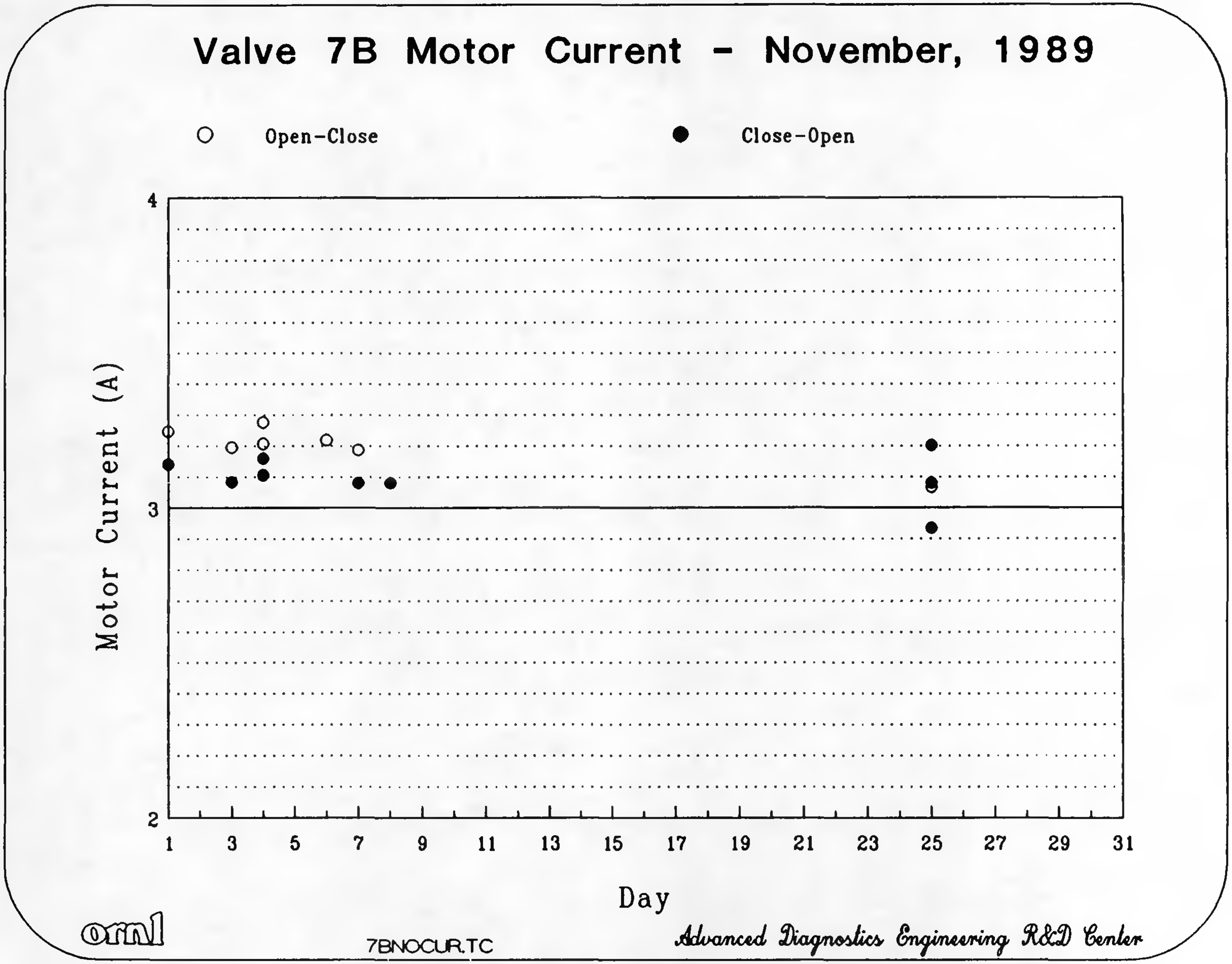

Valve 6B Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6BNOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 8



Valve 7B Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BNOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 9

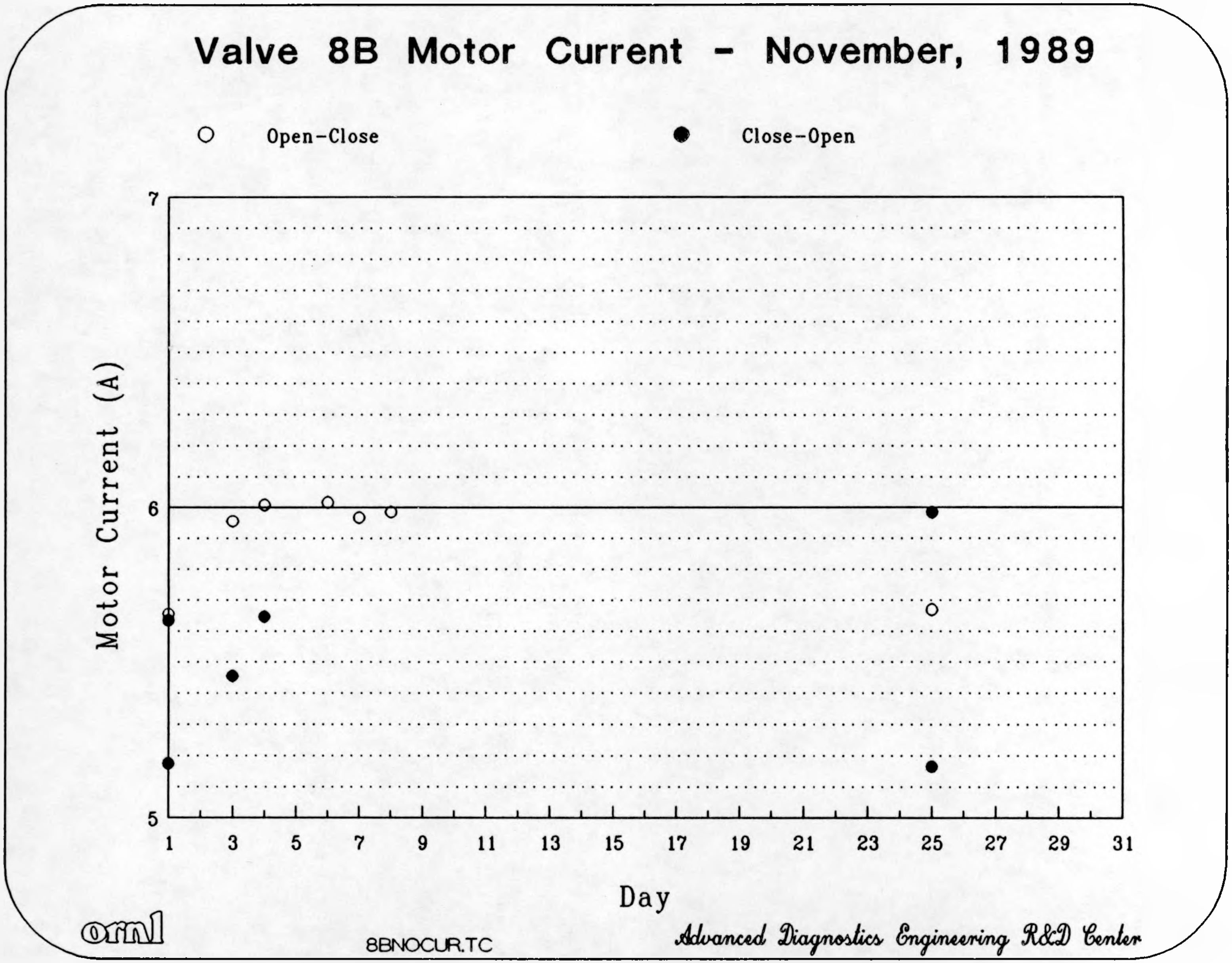

Valve 8B Motor Current - November, 1989
Open-Close
Close-Open
Motor Current (A)
7
6
5
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8BNOCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 10

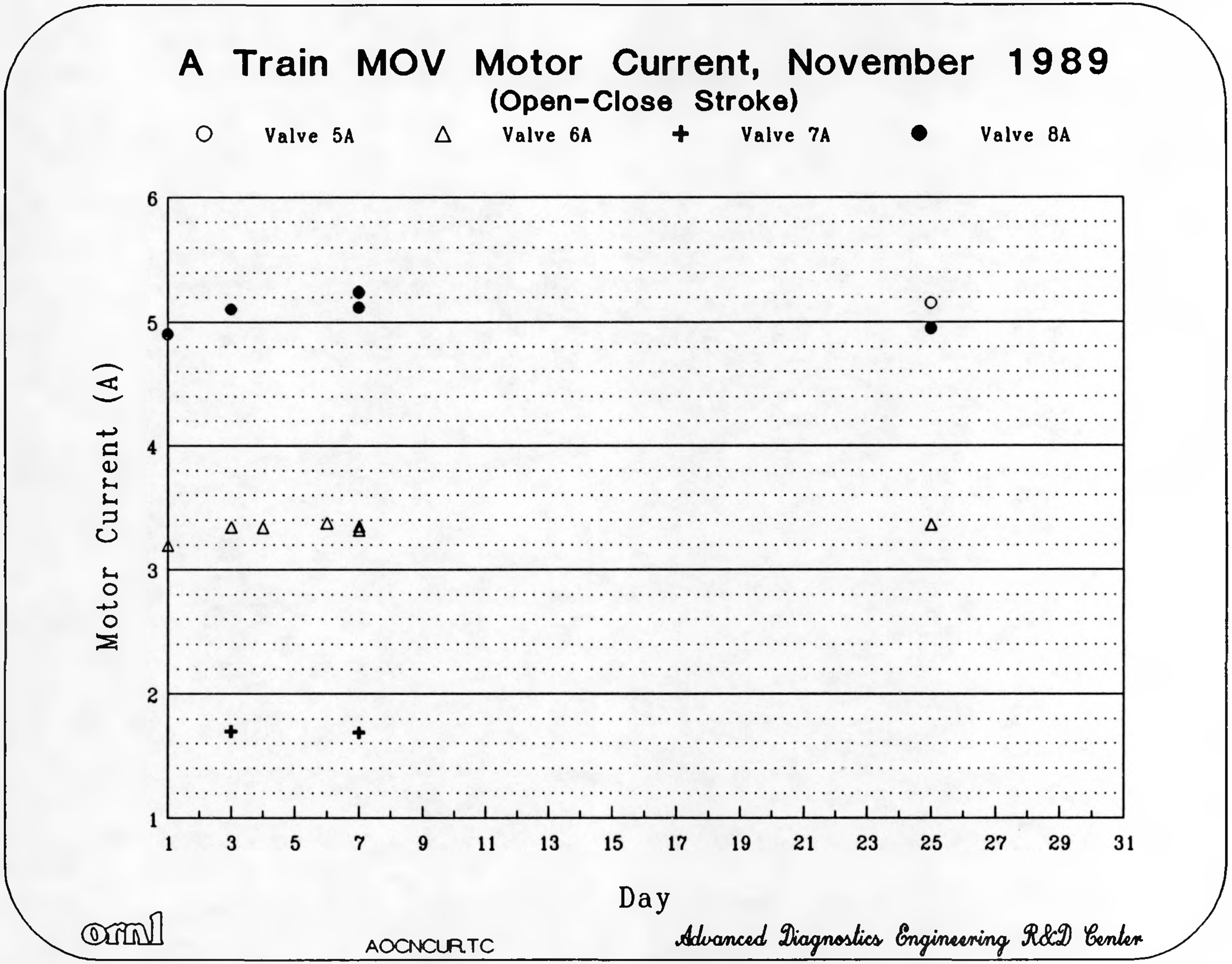

A Train MOV Motor Current, November 1989
(Open-Close Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
AOCNCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 11

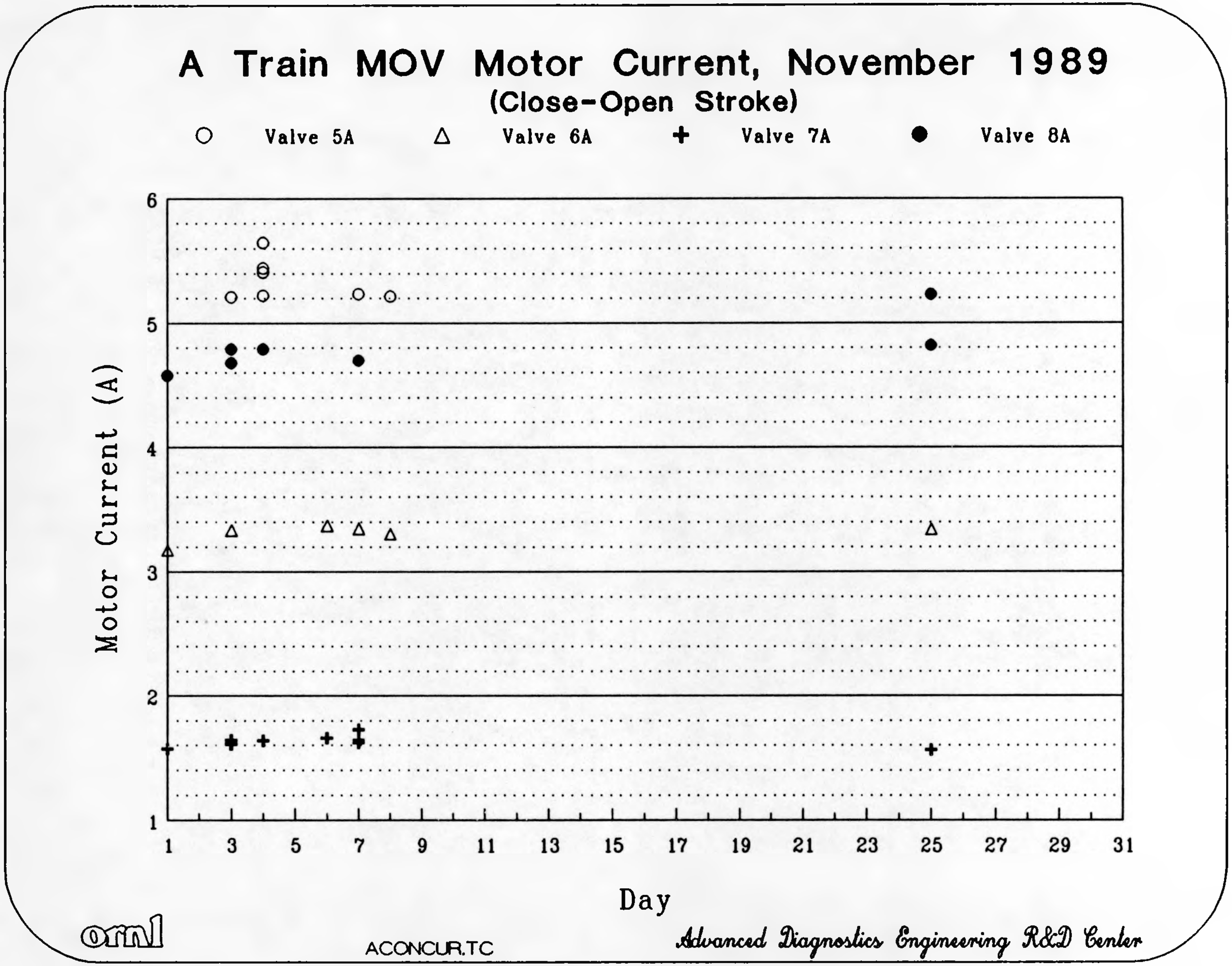

A Train MOV Motor Current, November 1989
(Close-Open Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
ACONCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 12

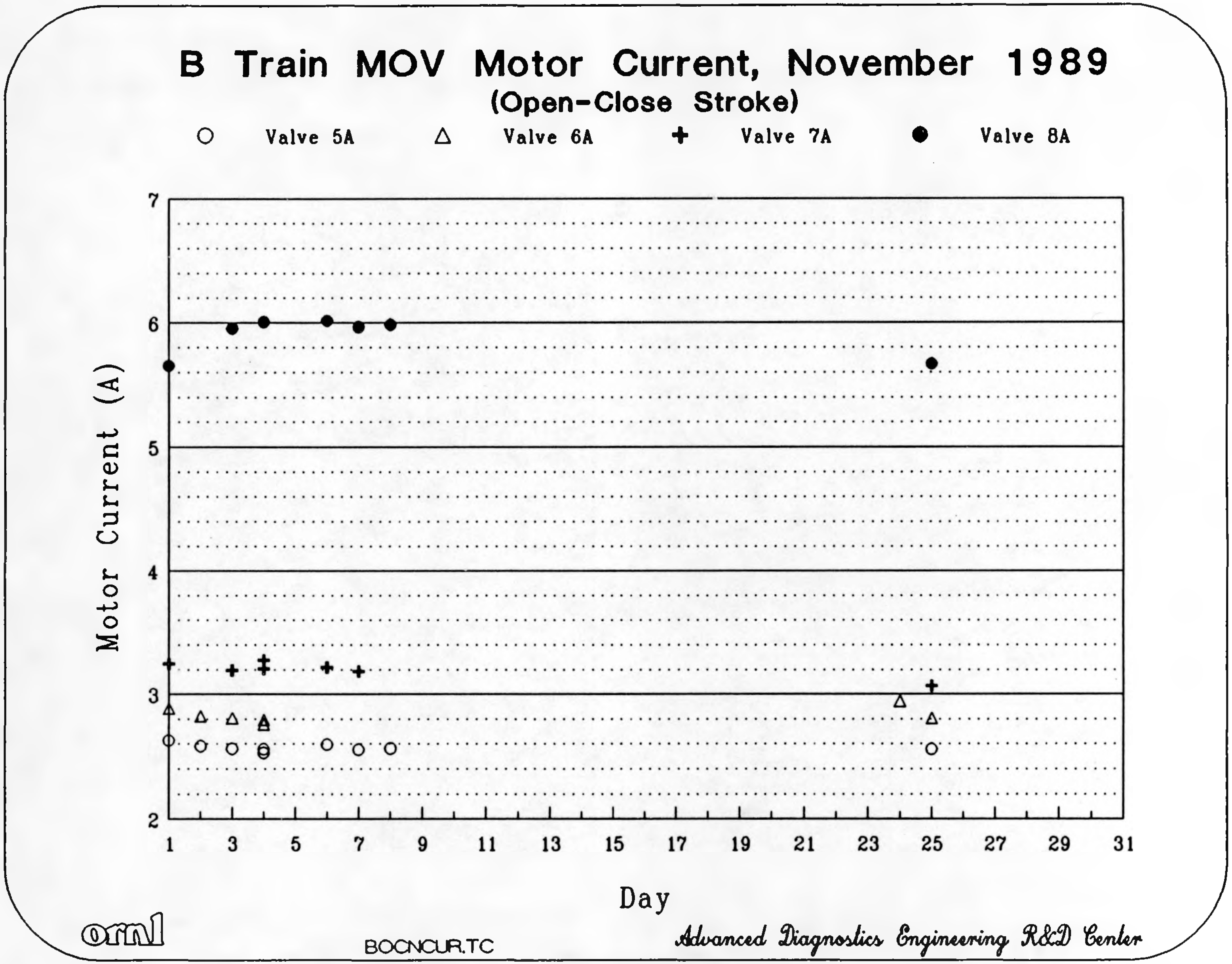
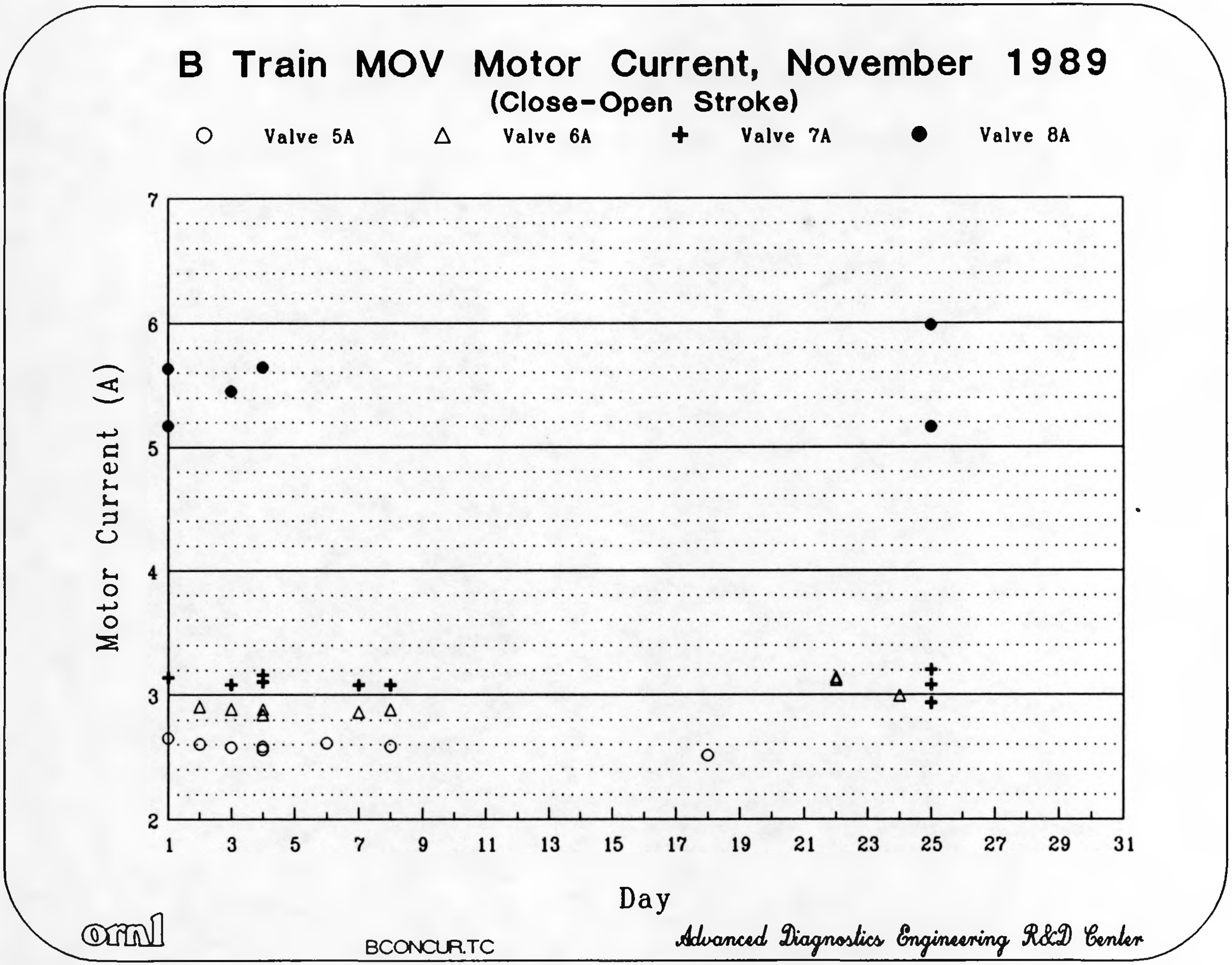

B Train MOV Motor Current, November 1989
(Open-Close Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BOCNCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 13



B Train MOV Motor Current, November 1989
(Close-Open Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BCONCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 14

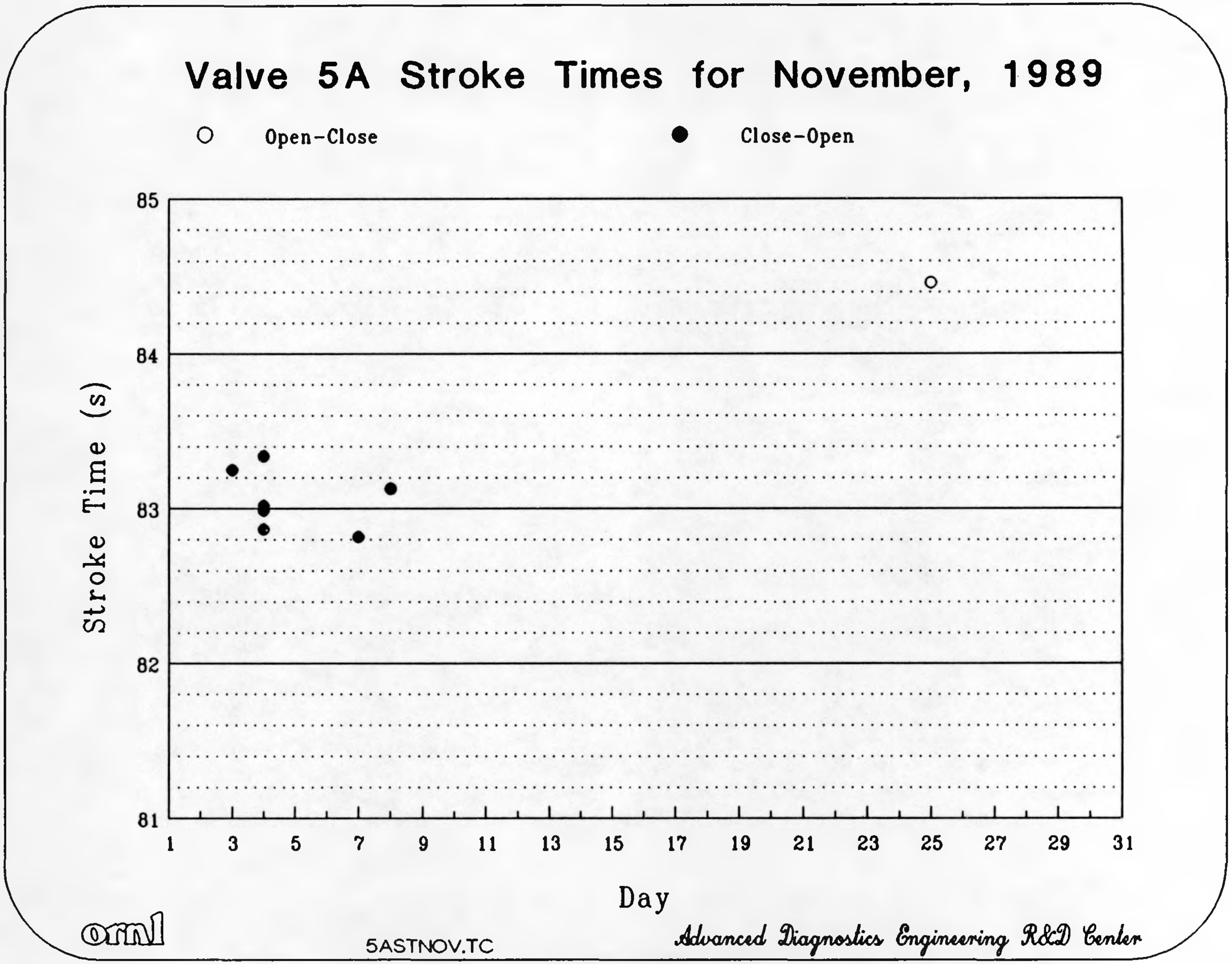

Valve 5A Stroke Times for November, 1989
Open-Close
Close-Open
85
84
83
82
81
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5ASTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 15

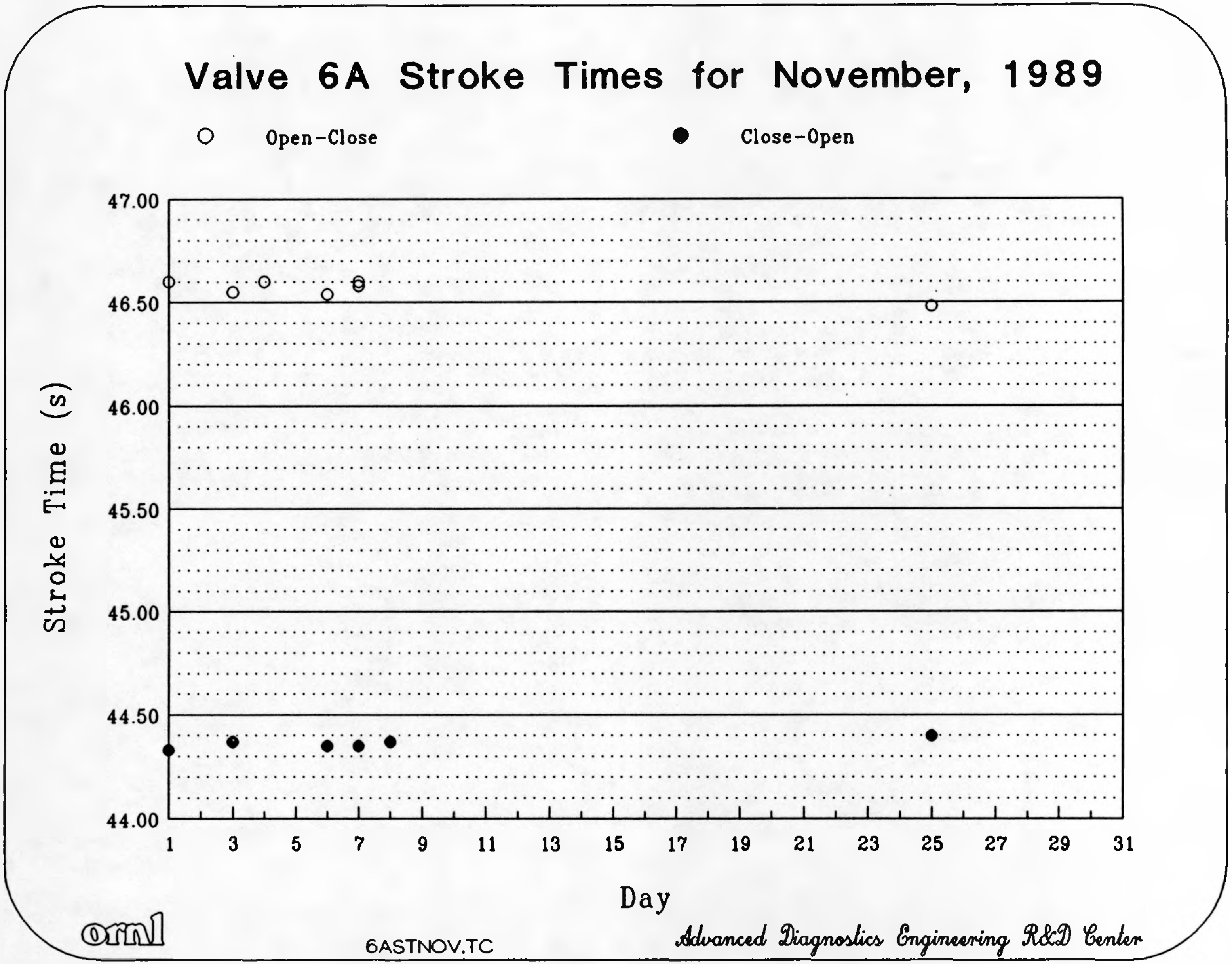
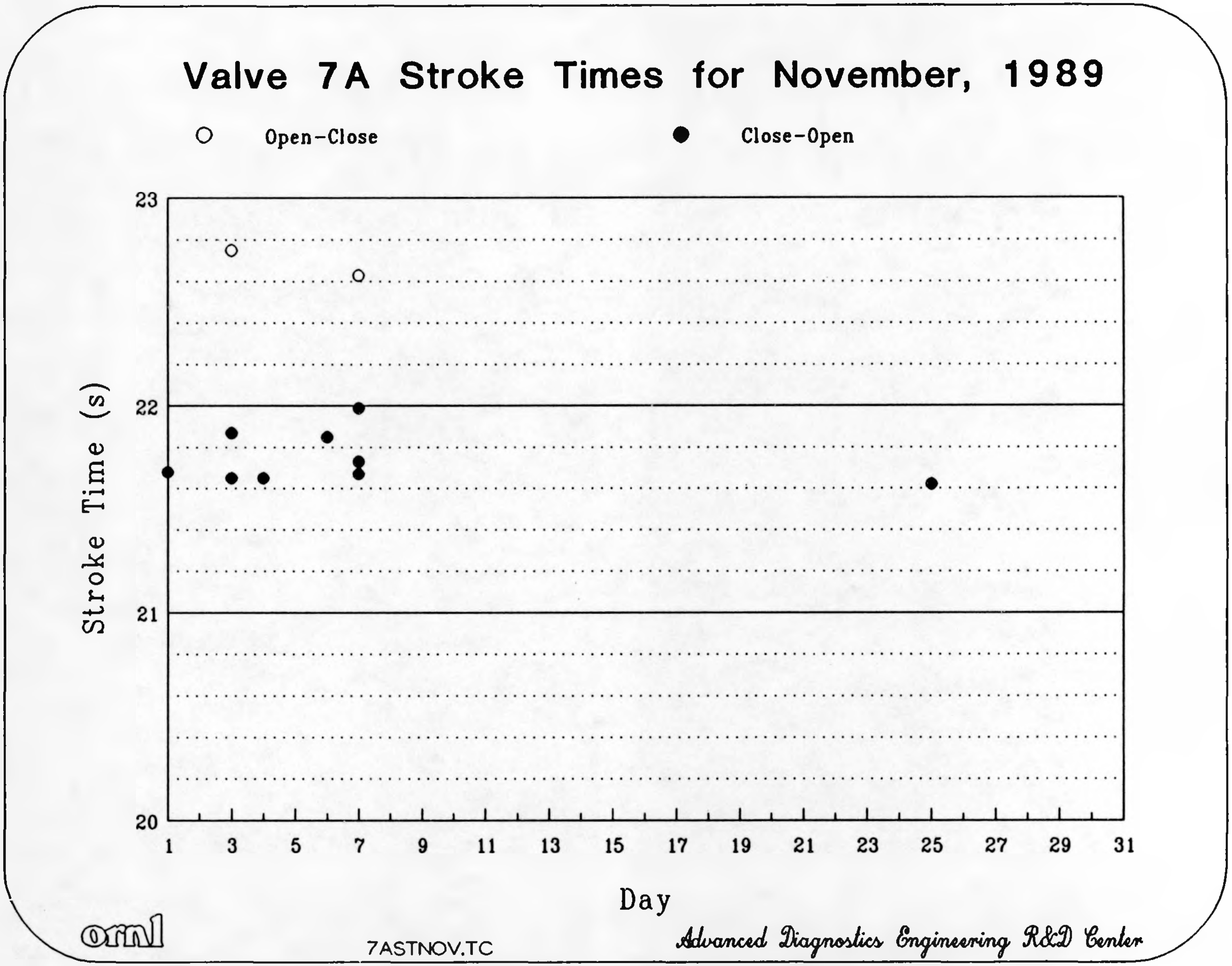

Valve 6A Stroke Times for November, 1989
Open-Close
Close-Open
47.00
46.50
46.00
45.50
45.00
44.50
44.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6ASTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 16



Valve 7A Stroke Times for November, 1989
Open-Close
Close-Open
Stroke Time (s)
23
22
21
20
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7ASTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 17

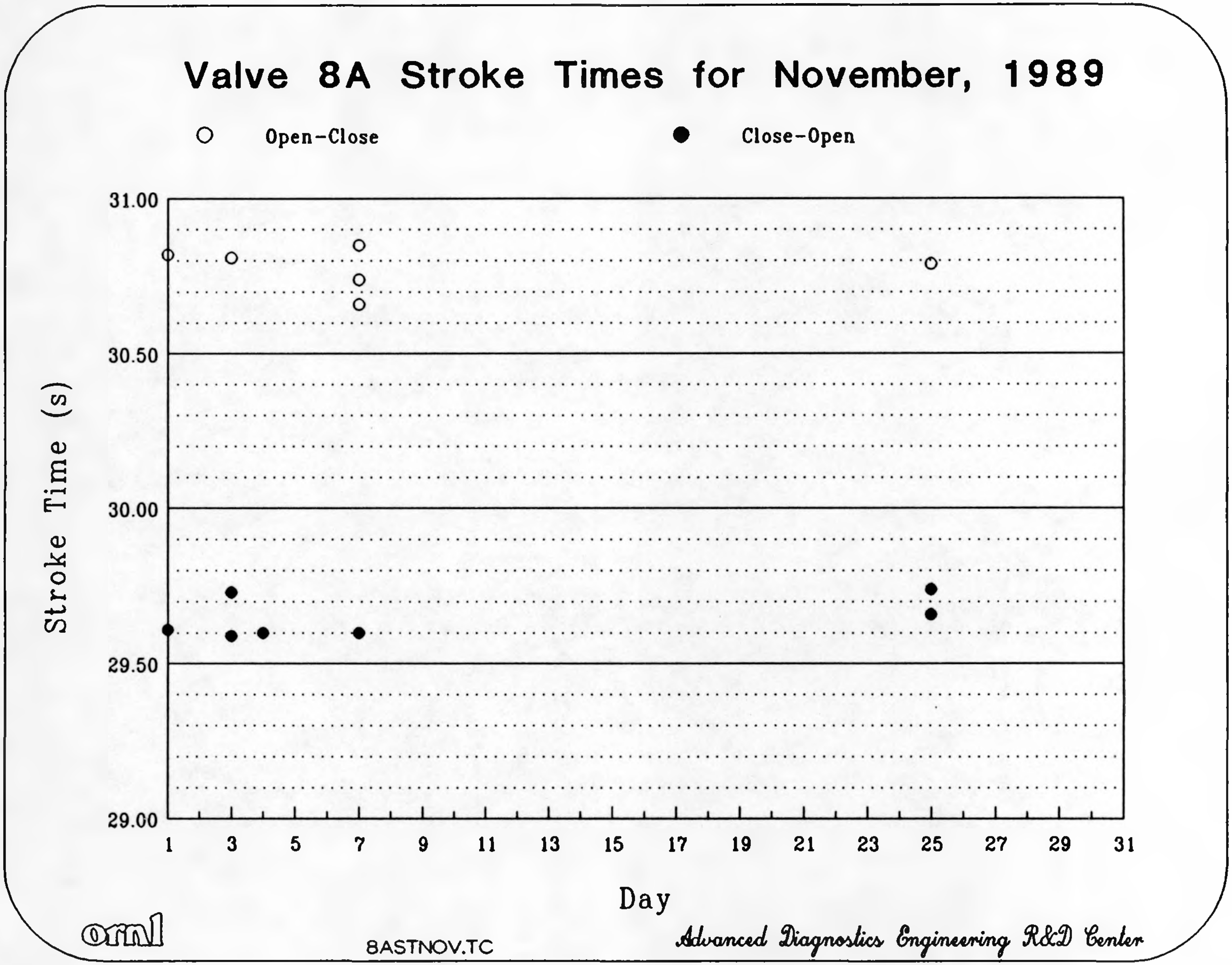
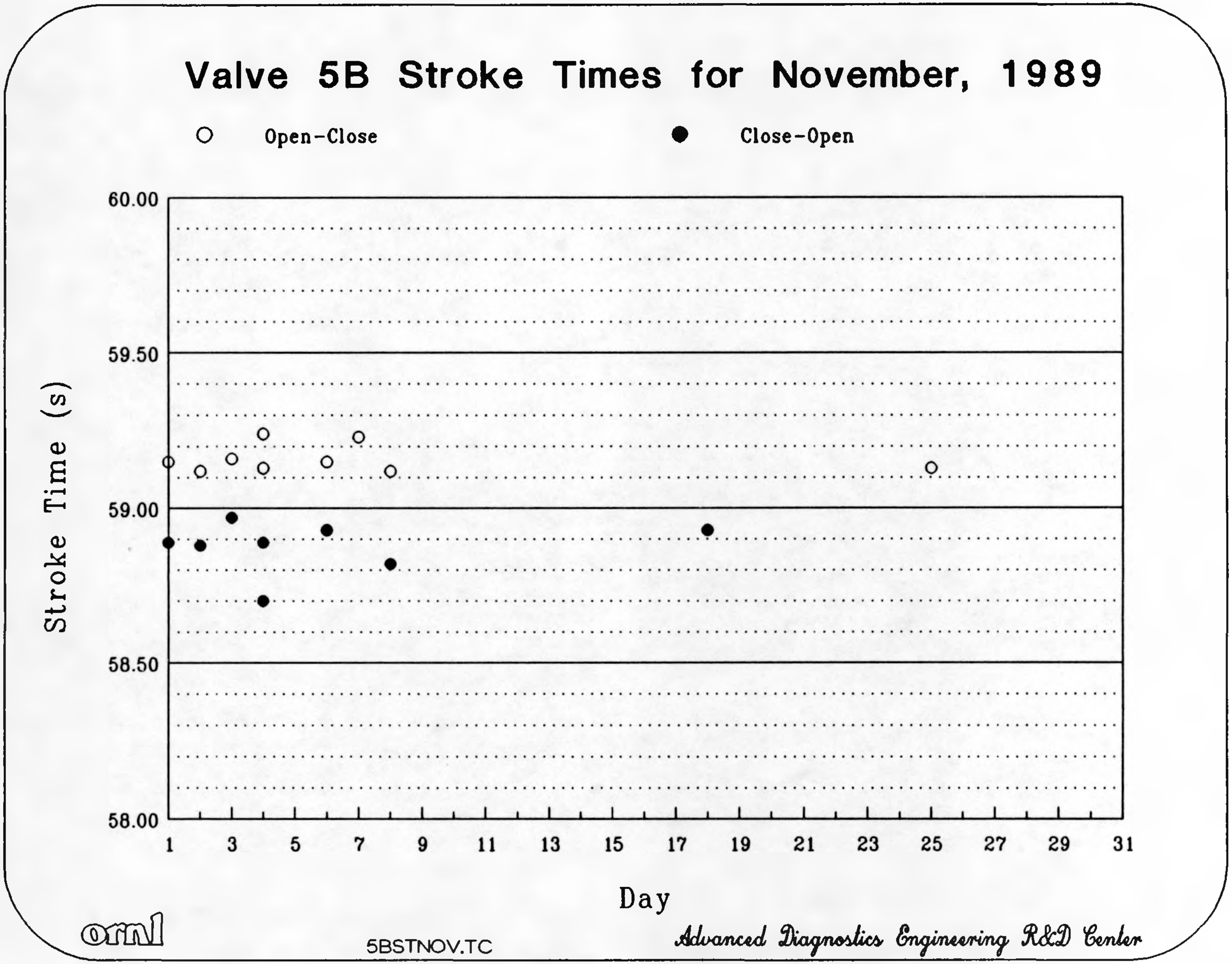

Valve 8A Stroke Times for November, 1989
Open-Close
Close-Open
Stroke Time (s)
31.00
30.50
30.00
29.50
29.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Day
ornl
8ASTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 18



Valve 5B Stroke Times for November, 1989
Open-Close
Close-Open
60.00
59.50
59.00
58.50
58.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BSTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 19

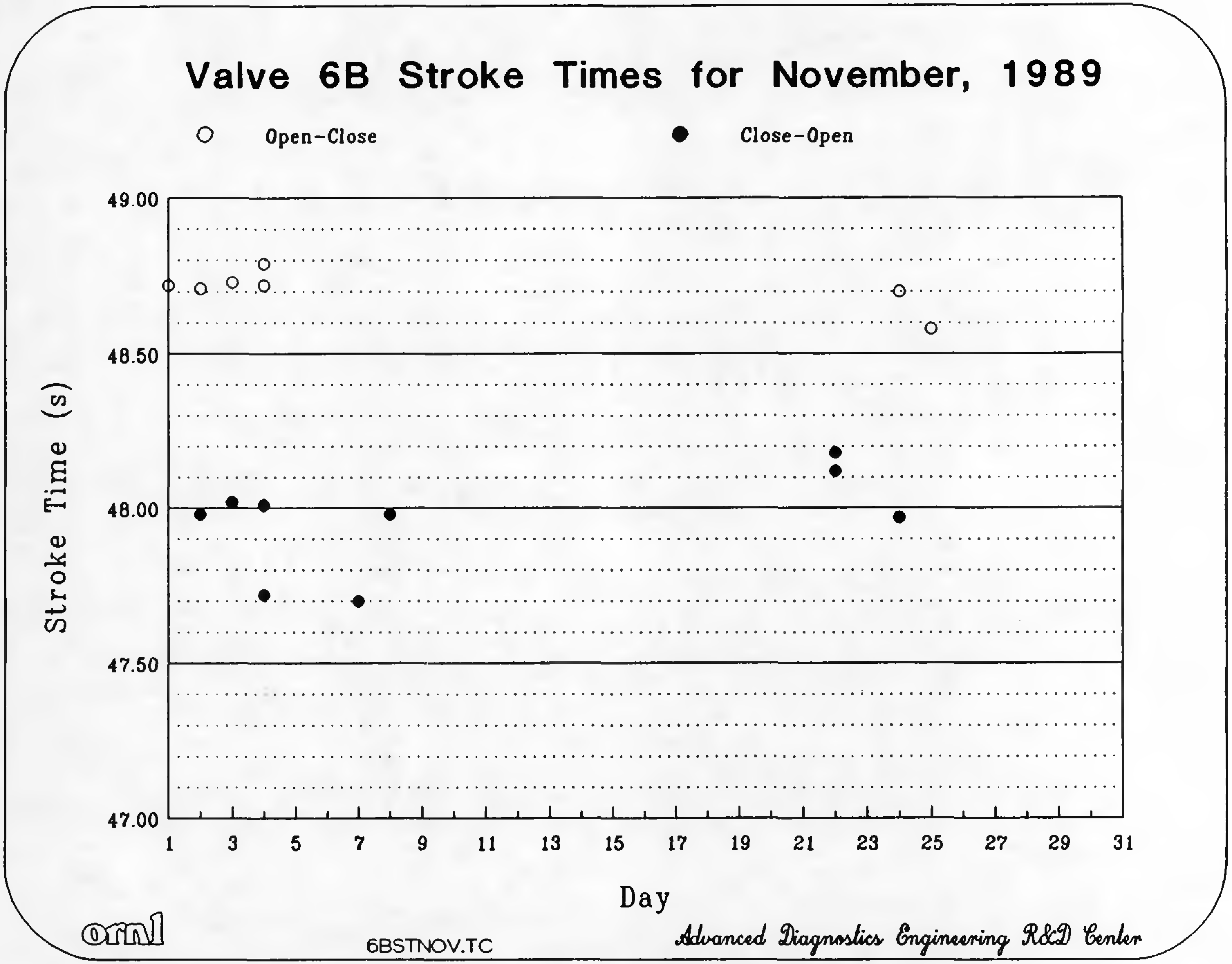

Valve 6B Stroke Times for November, 1989
Open-Close
Close-Open
Stroke Time (s)
49.00
48.50
48.00
47.50
47.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6BSTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 20

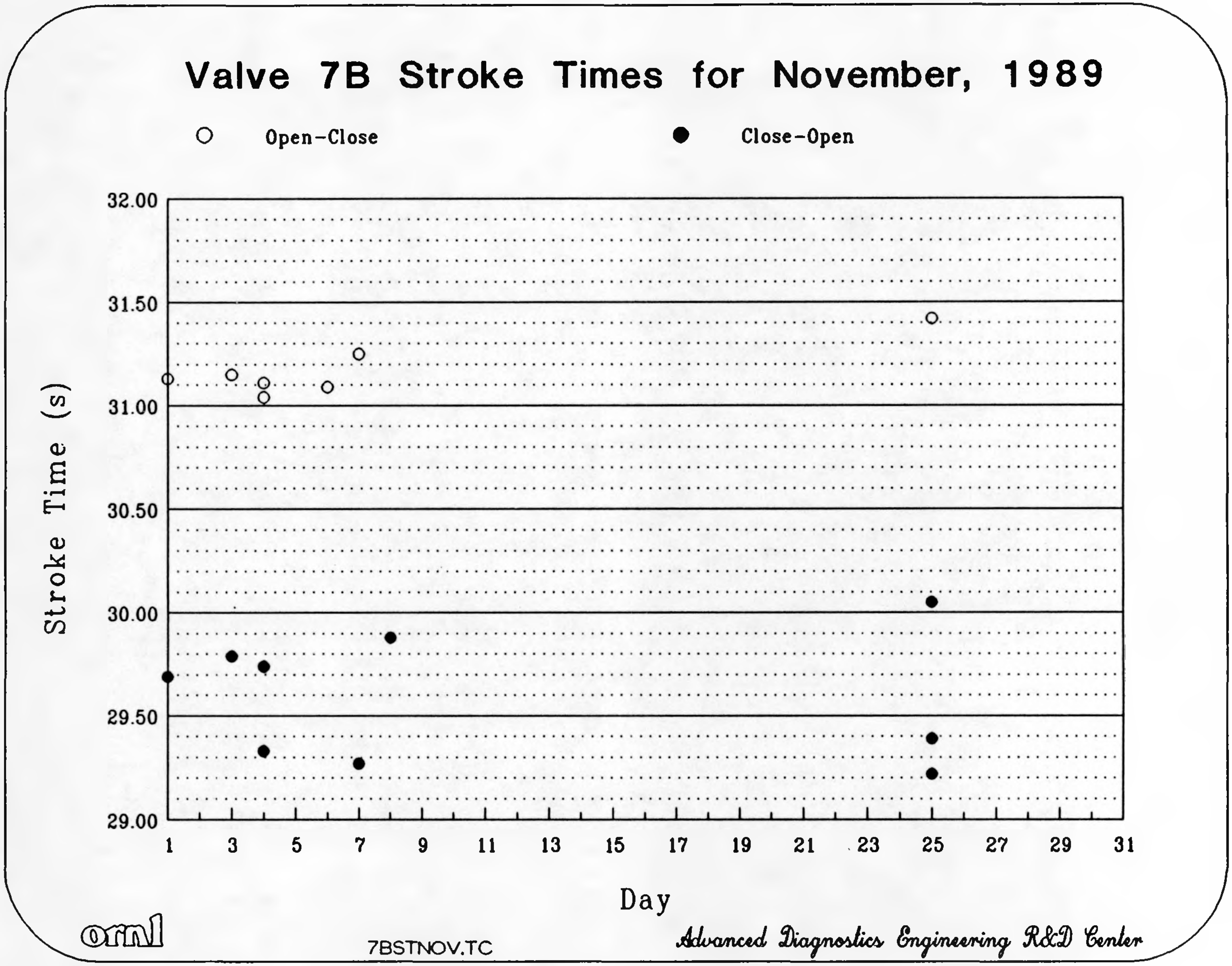
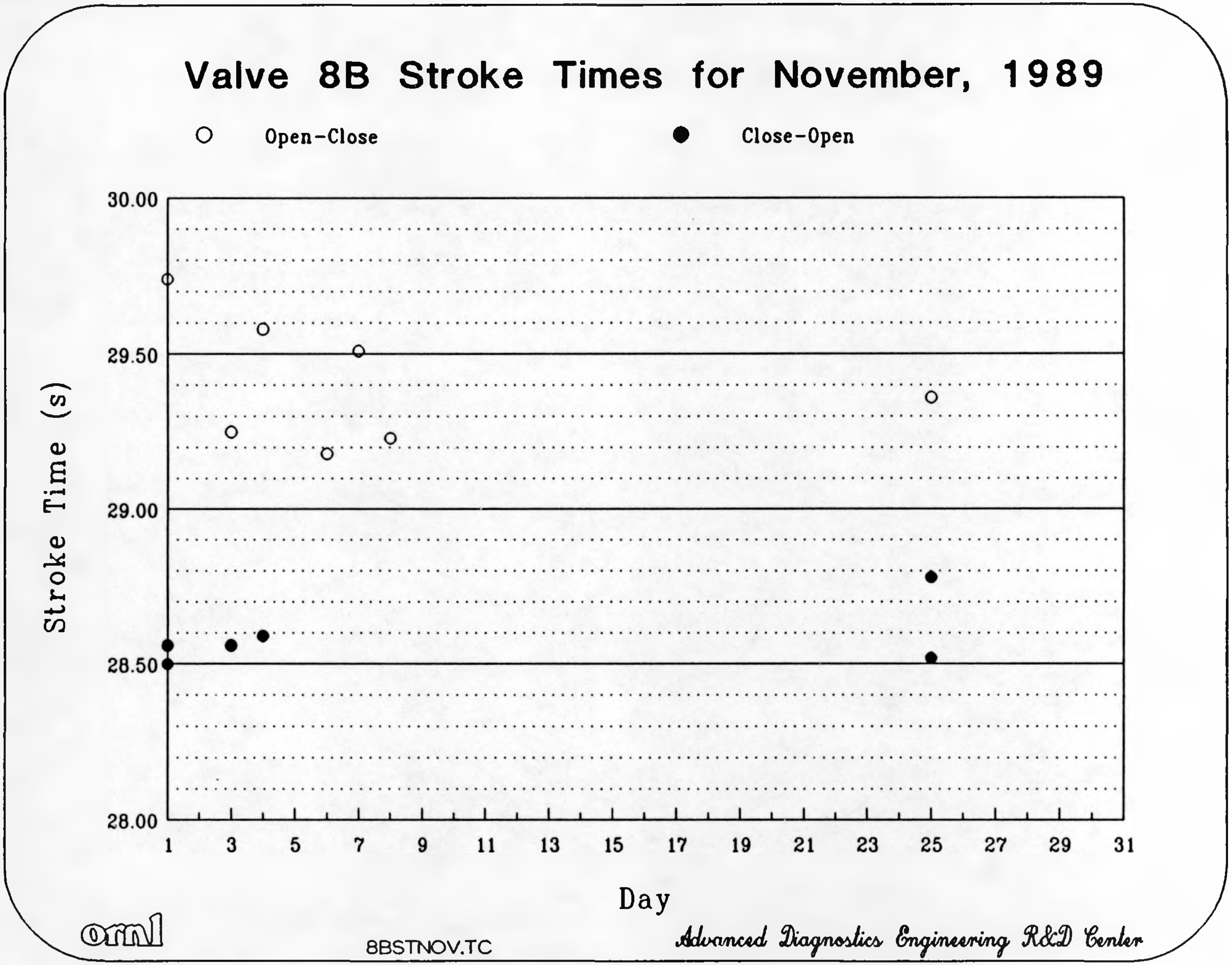

Valve 7B Stroke Times for November, 1989
Open-Close
Close-Open
32.00
31.50
31.00
30.50
30.00
29.50
29.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BSTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 21



Valve 8B Stroke Times for November, 1989
Open-Close
Close-Open
30.00
29.50
29.00
28.50
28.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8BSTNOV.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 22

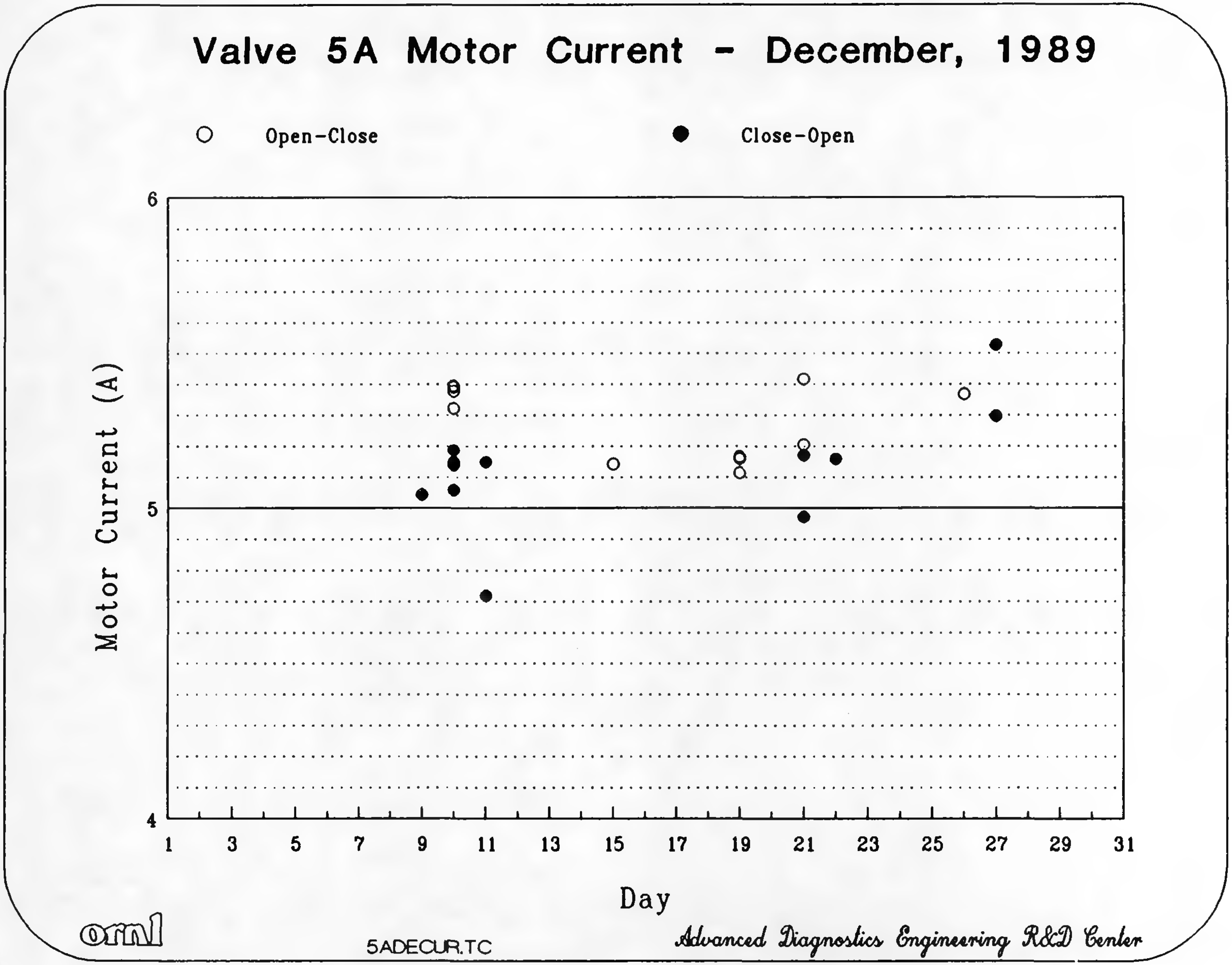

Valve 5A Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
6
5
4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5ADECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 23

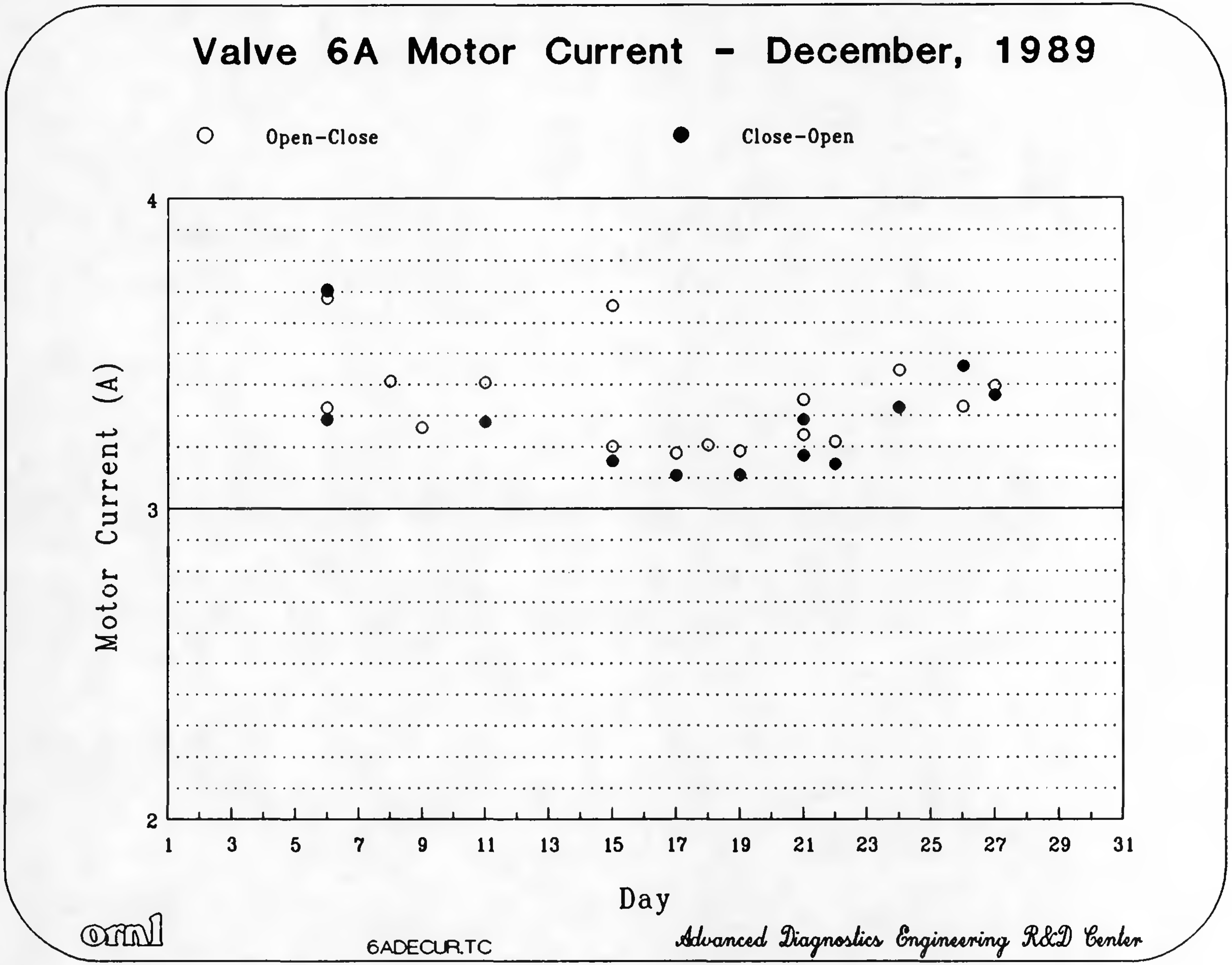
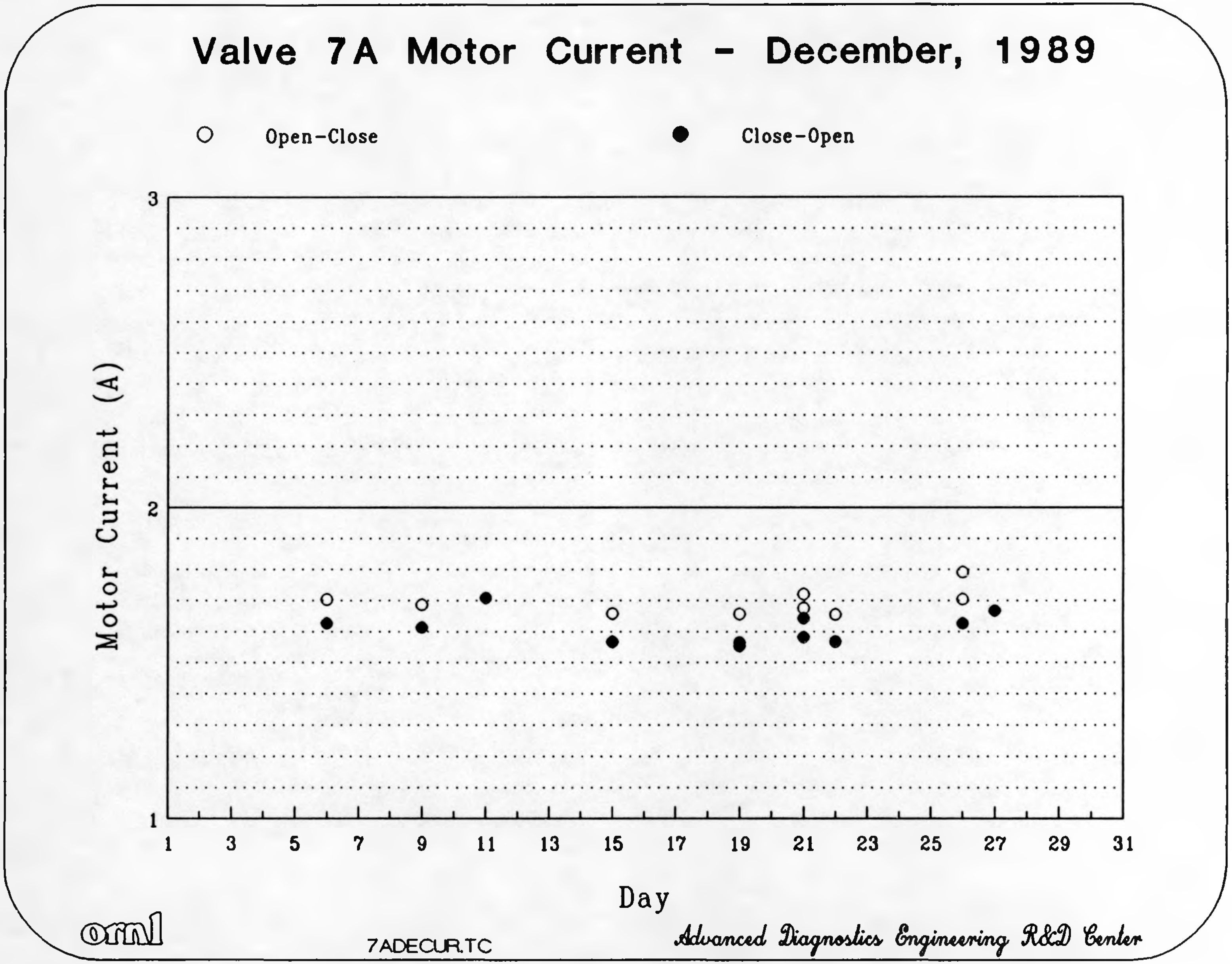

Valve 6A Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6ADECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 24



Valve 7A Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
orml
7ADECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 25

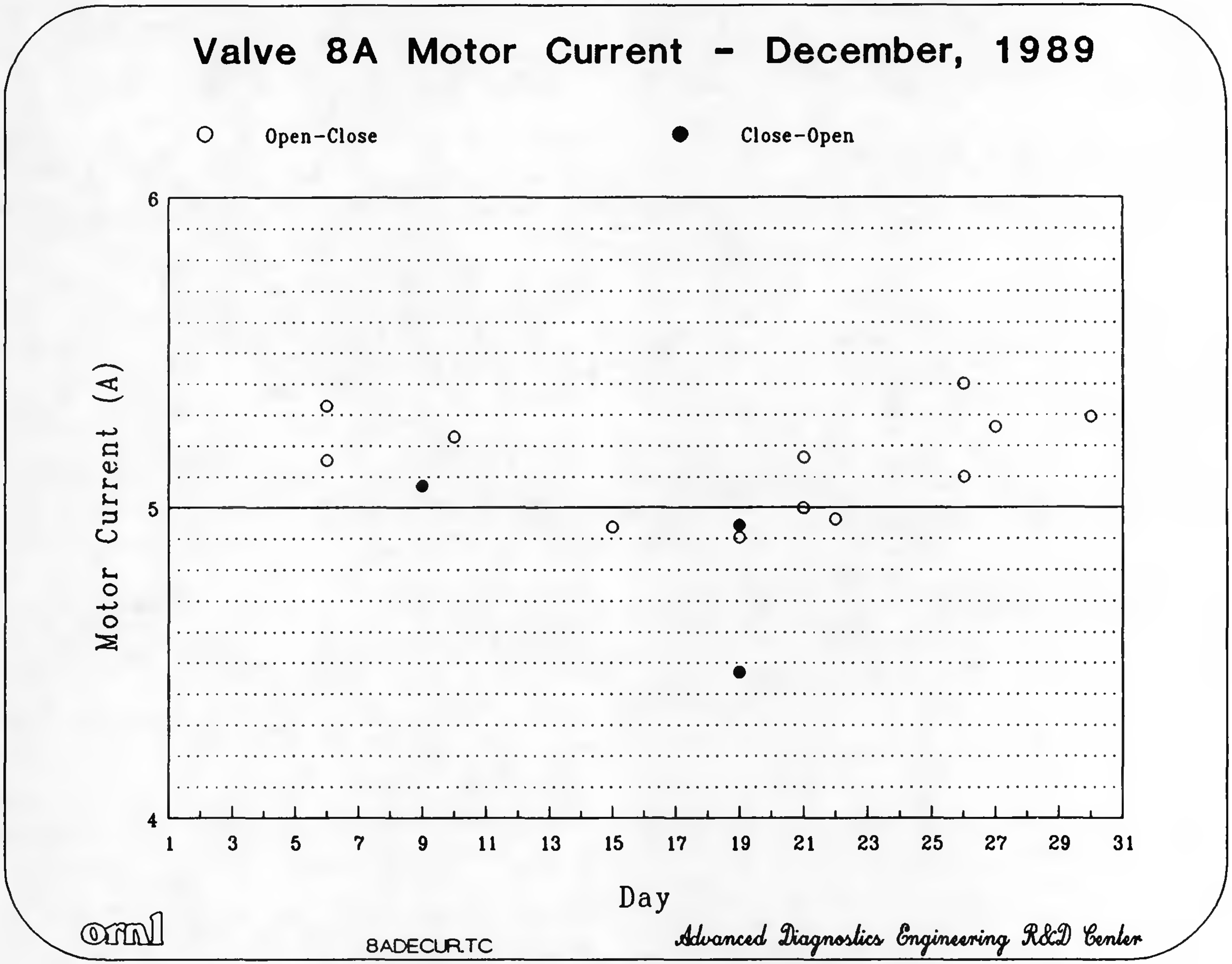
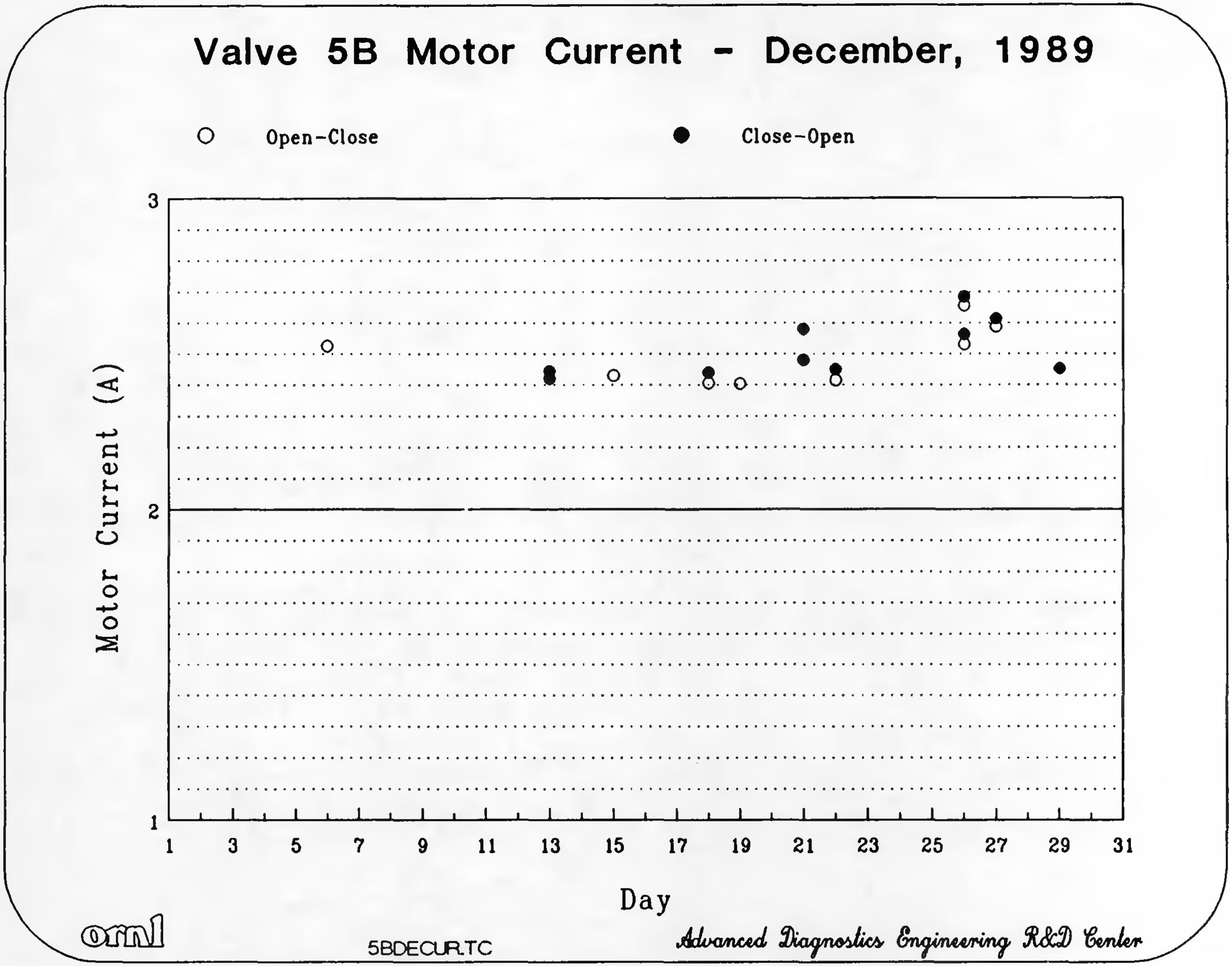
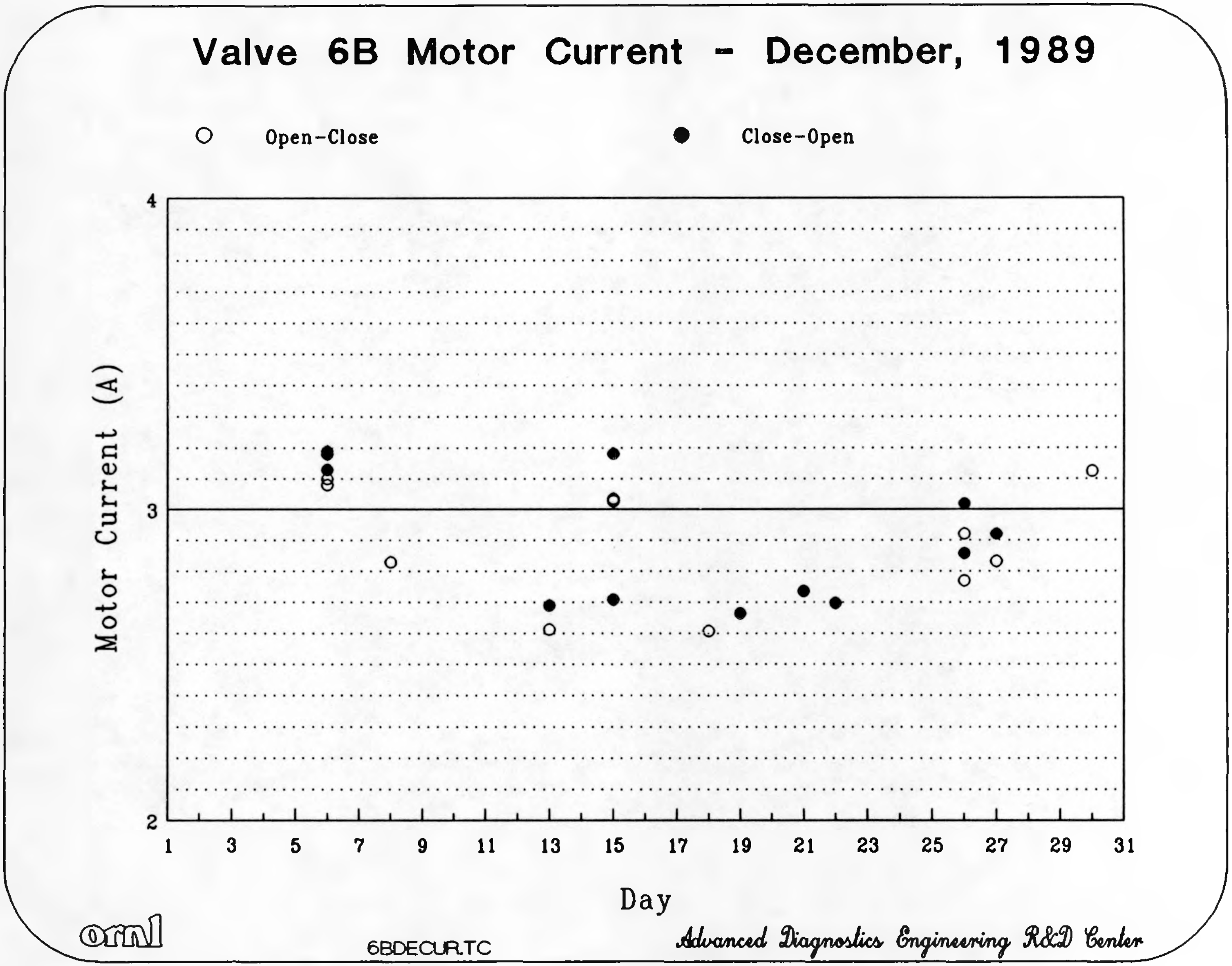

Valve 8A Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
6
5
4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8ADECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 26



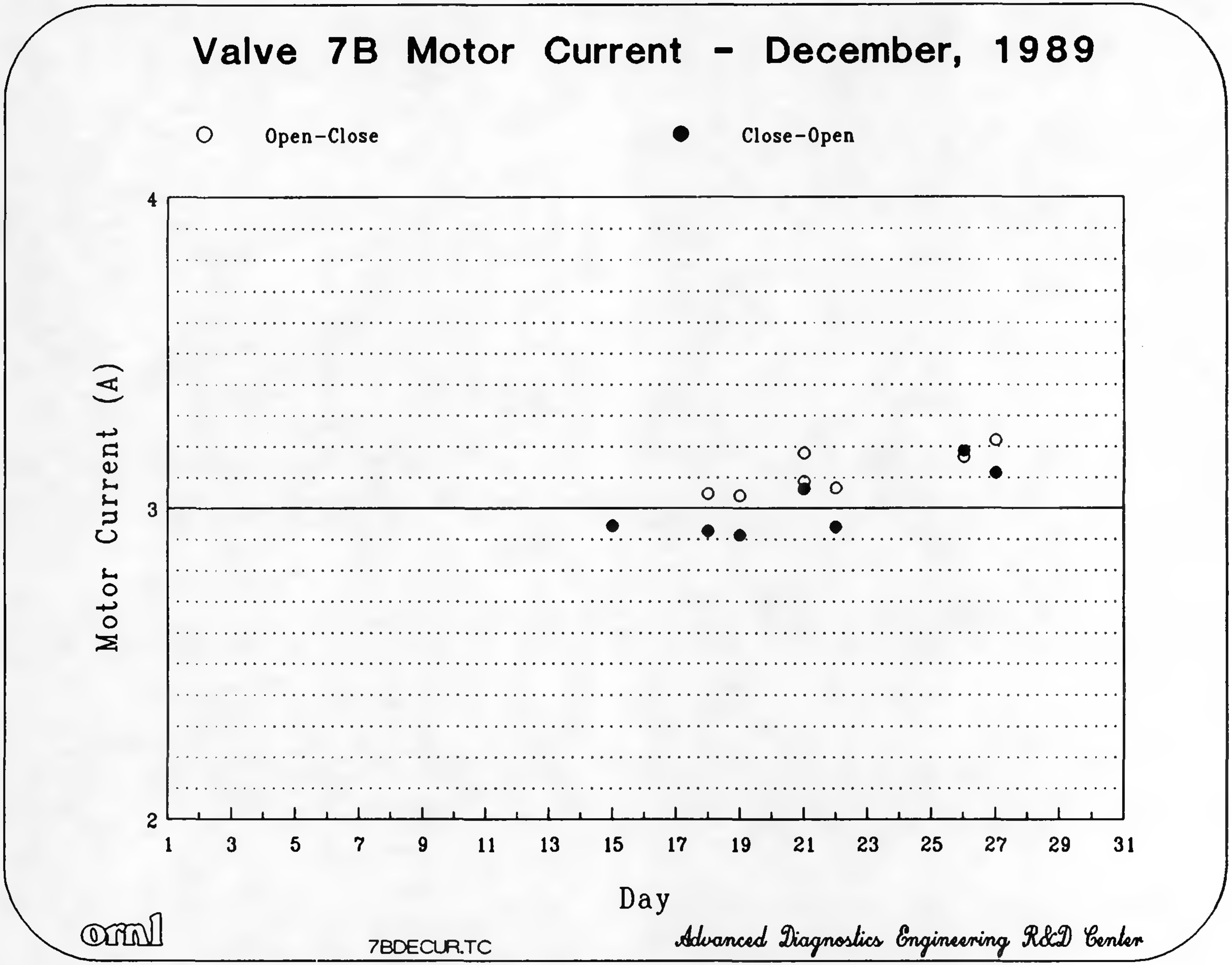
Valve 5B Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BDECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 27



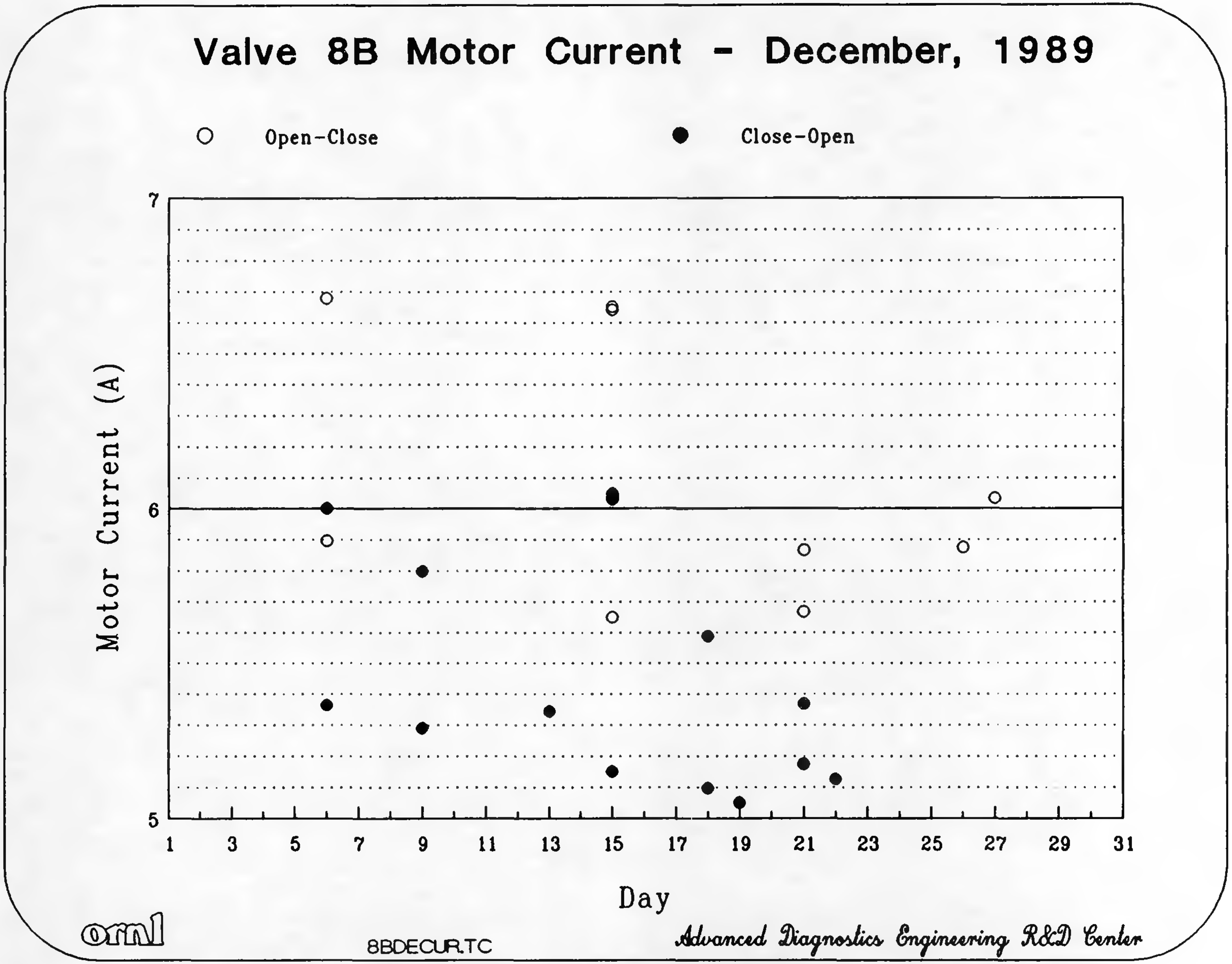
Valve 6B Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6BDECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 28



Valve 7B Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BDECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 29



Valve 8B Motor Current - December, 1989
Open-Close
Close-Open
Motor Current (A)
7
6
5
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8BDECUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 30

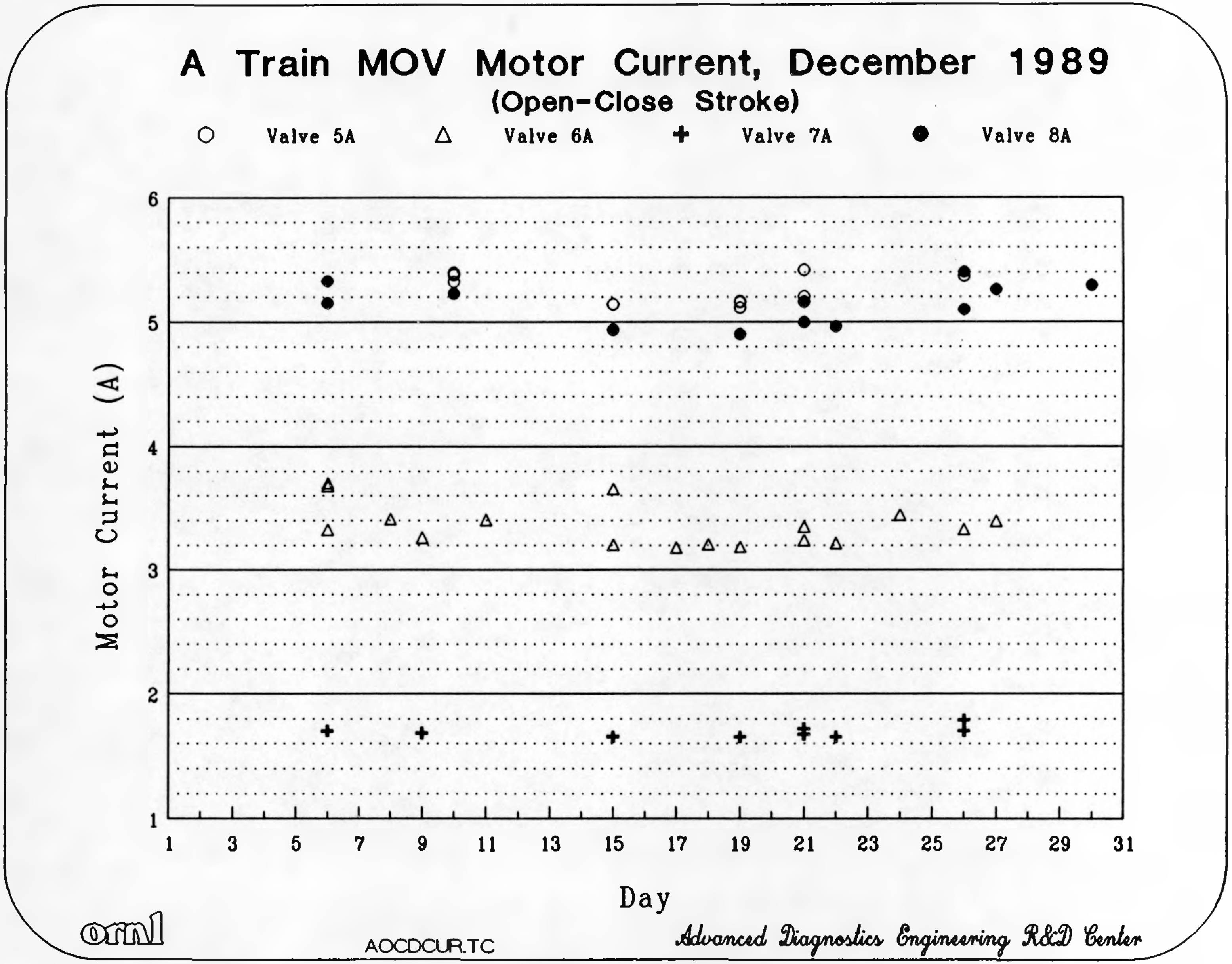
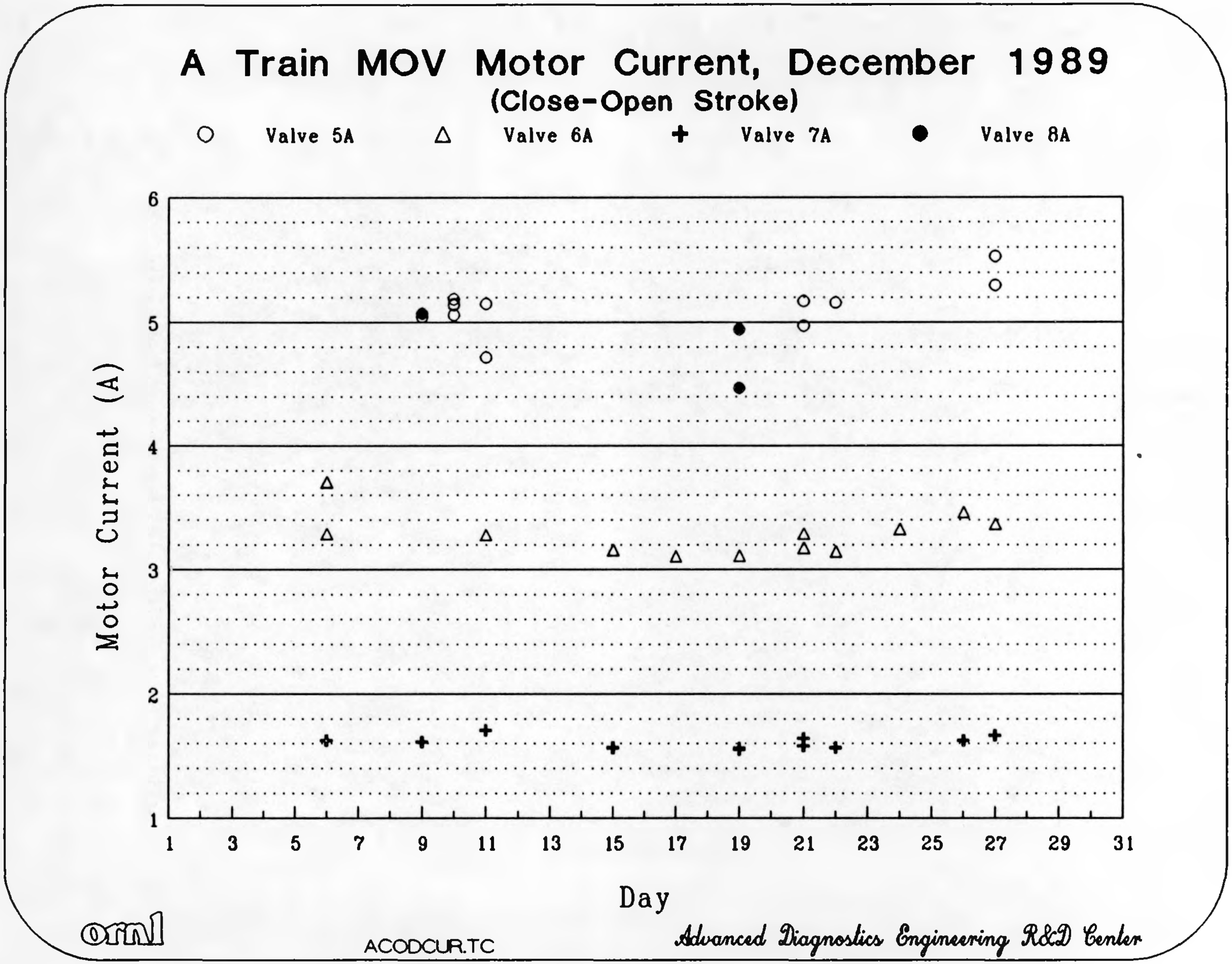
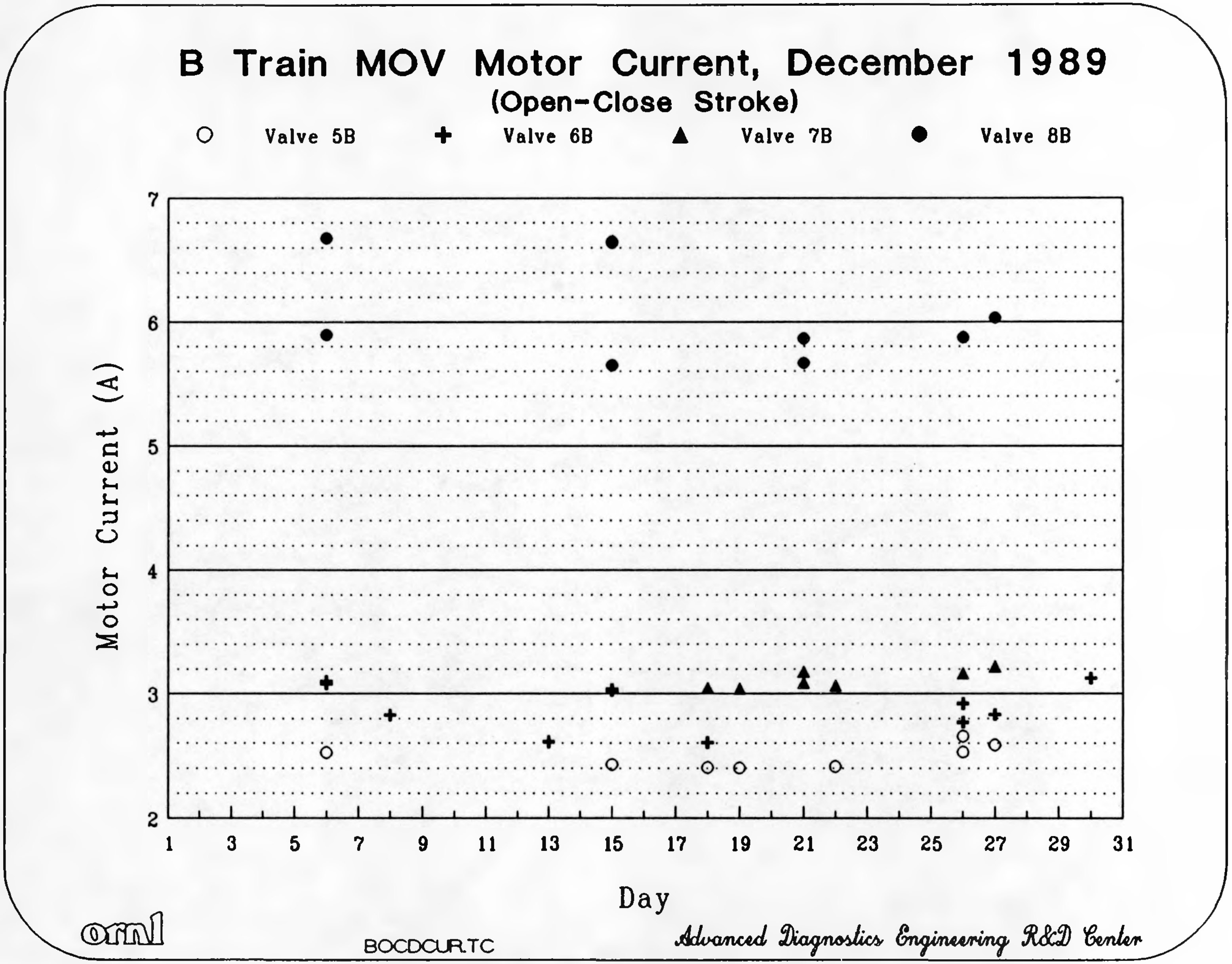

A Train MOV Motor Current, December 1989
(Open-Close Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
AOCDCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 31



A Train MOV Motor Current, December 1989
(Close-Open Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
ACODCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 32



B Train MOV Motor Current, December 1989
(Open-Close Stroke)
Valve 5B
Valve 6B
Valve 7B
Valve 8B
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BOCDCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 33

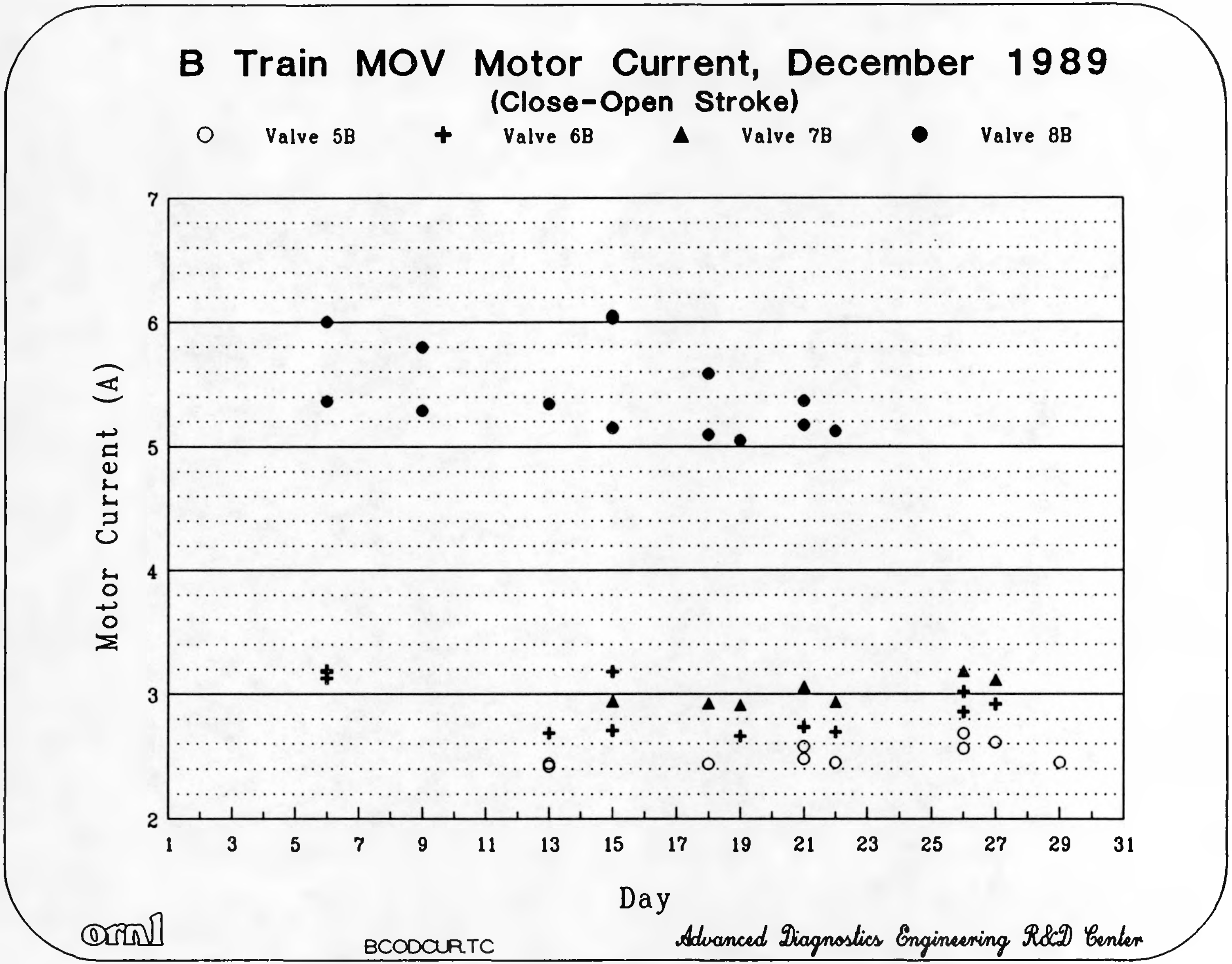

B Train MOV Motor Current, December 1989
(Close-Open Stroke)
Valve 5B
Valve 6B
Valve 7B
Valve 8B
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BCODCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 34

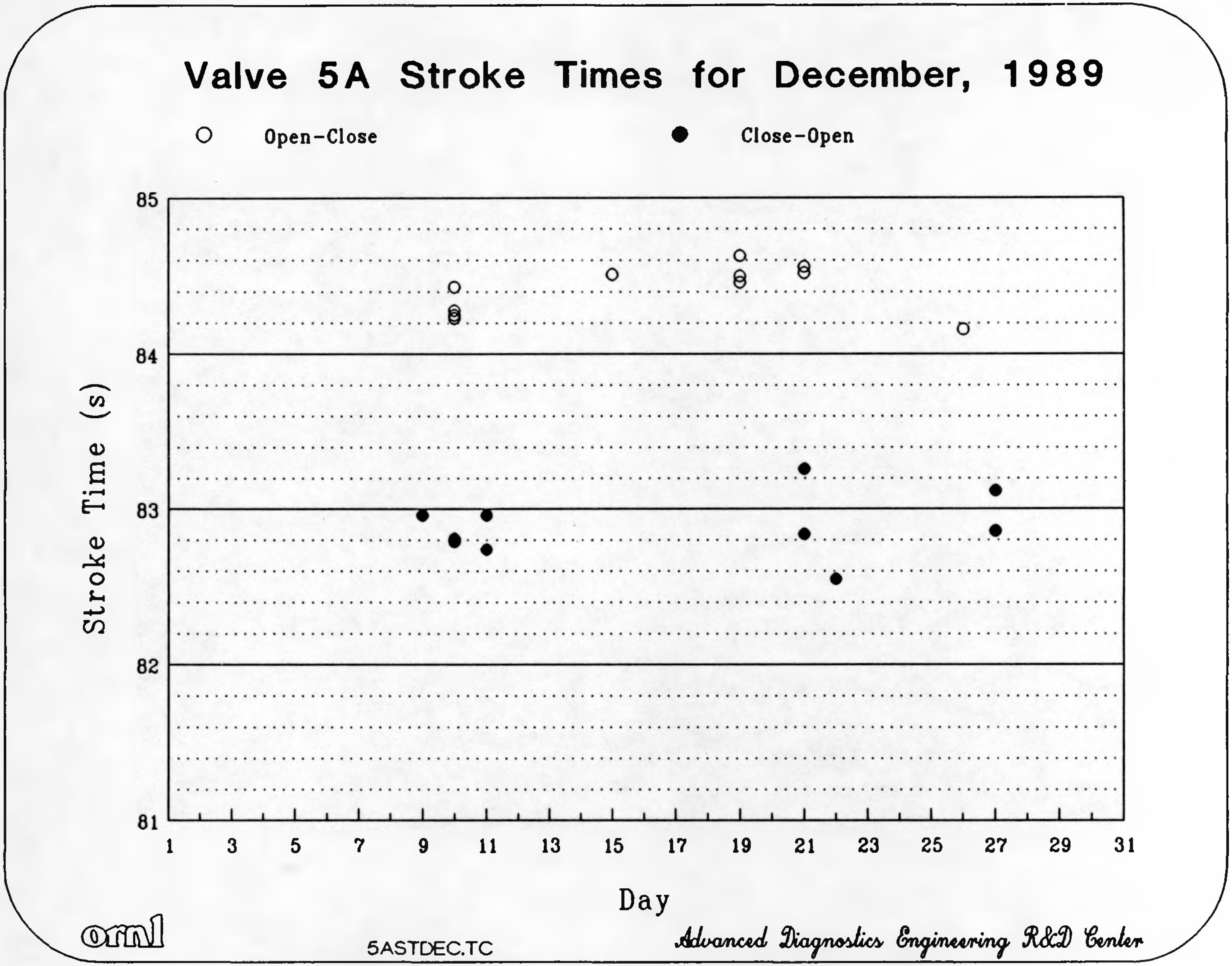

Valve 5A Stroke Times for December, 1989
Open-Close
Close-Open
Stroke Time (s)
85
84
83
82
81
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5ASTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 35

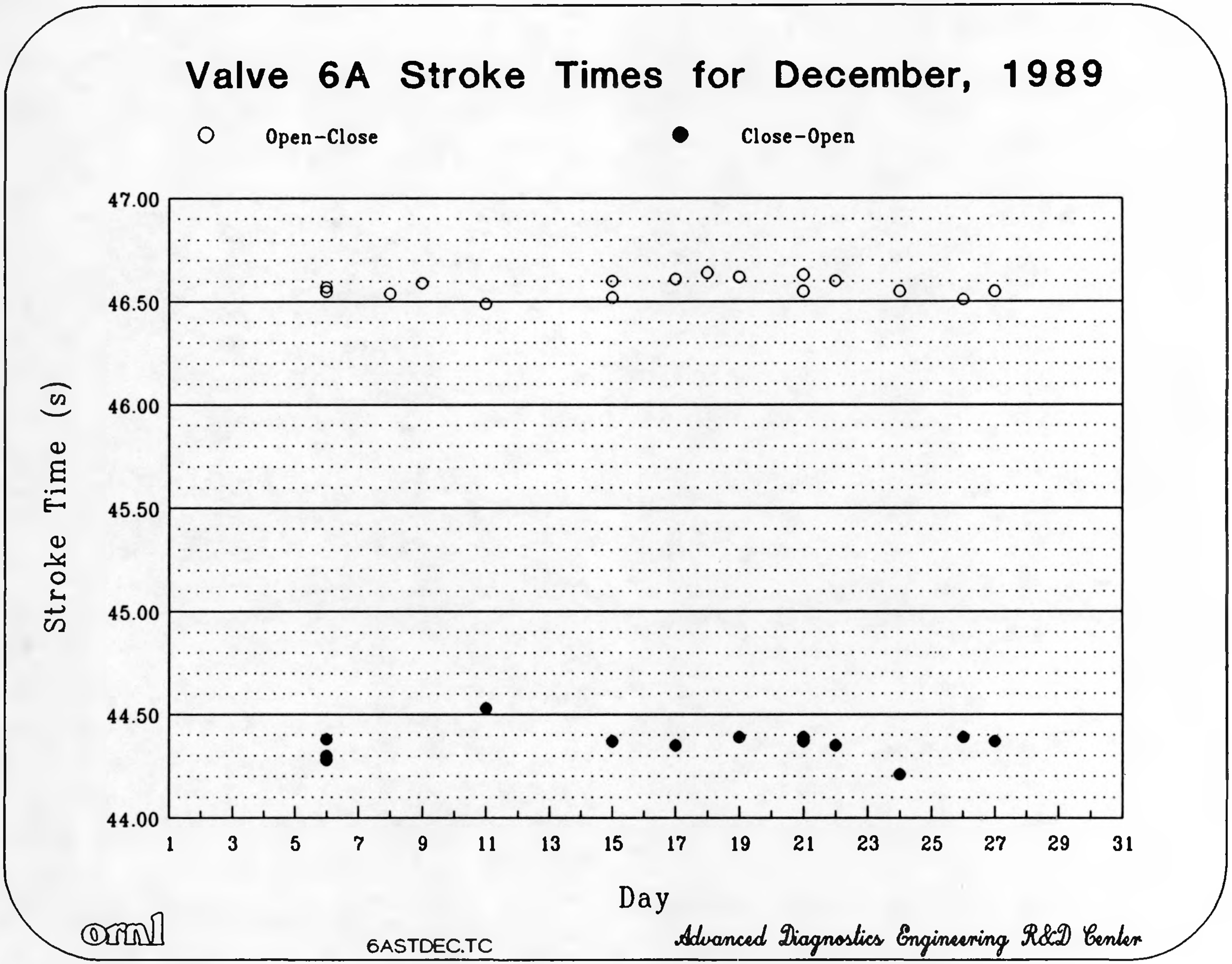
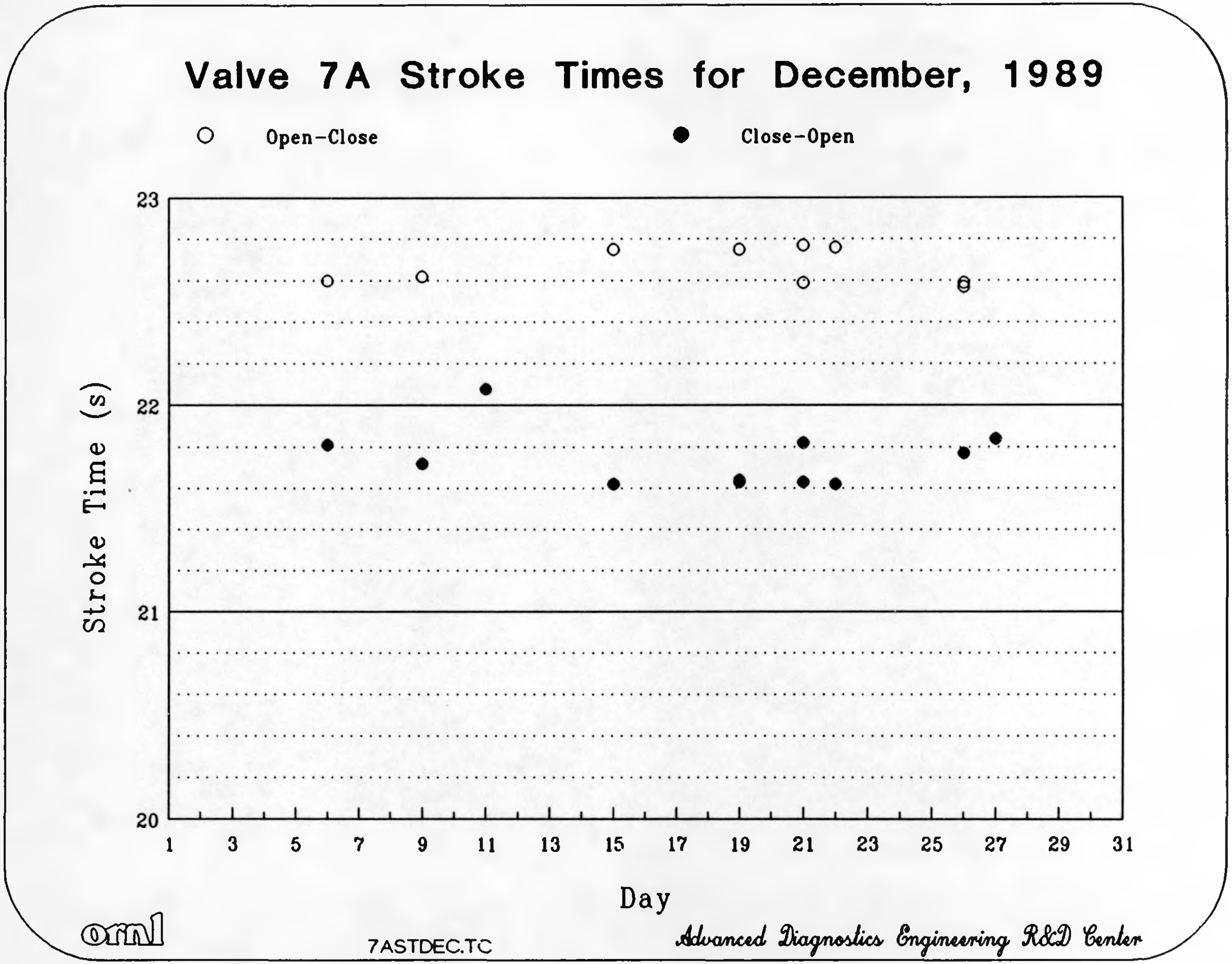
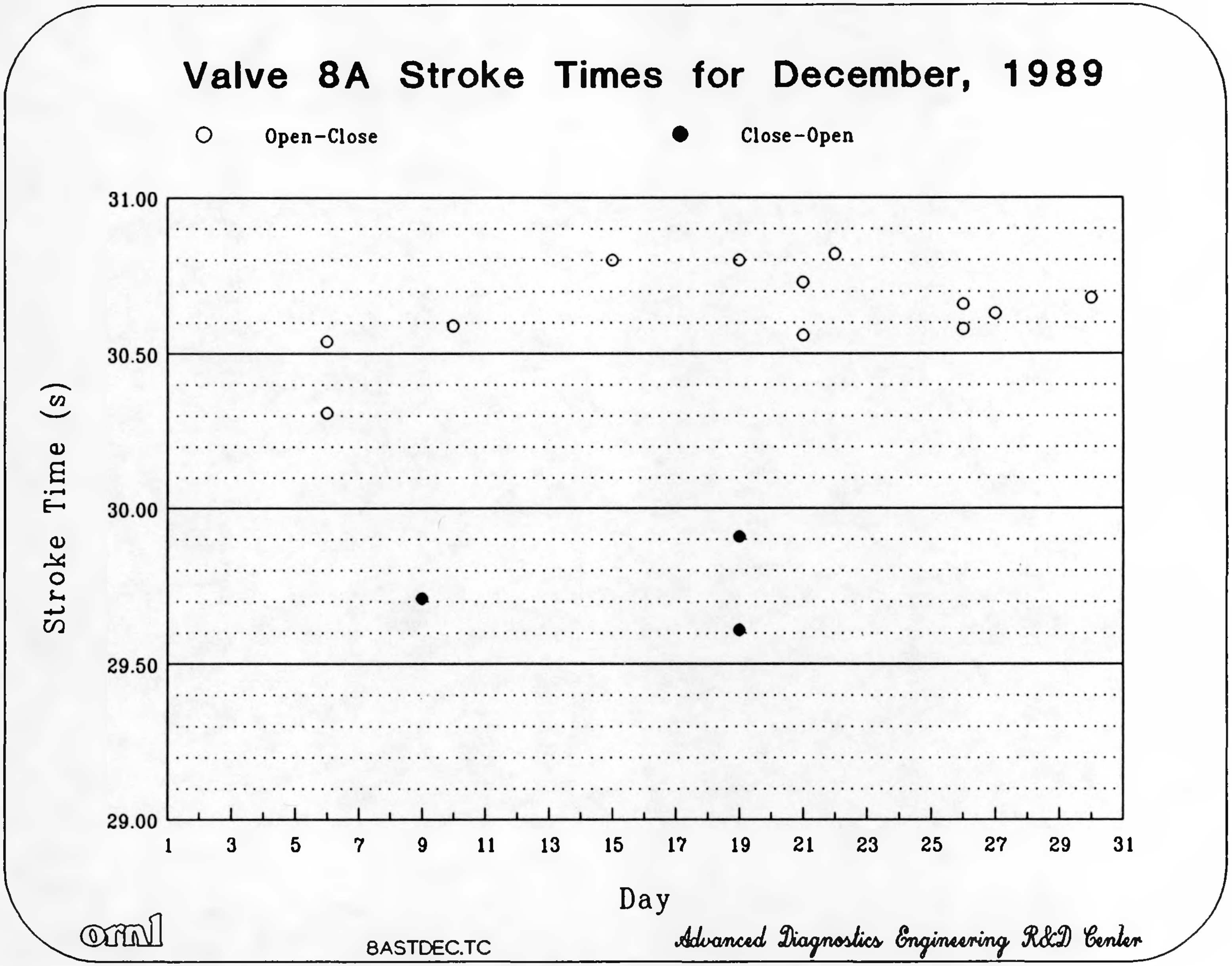

Valve 6A Stroke Times for December, 1989
Open-Close
Close-Open
Stroke Time (s)
47.00
46.50
46.00
45.50
45.00
44.50
44.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Day
ornl
6ASTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 36



Valve 7A Stroke Times for December, 1989
Open-Close
Close-Open
Stroke Time (s)
23
22
21
20
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7ASTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 37



Valve 8A Stroke Times for December, 1989
Open-Close
Close-Open
31.00
30.50
30.00
29.50
29.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8ASTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 38

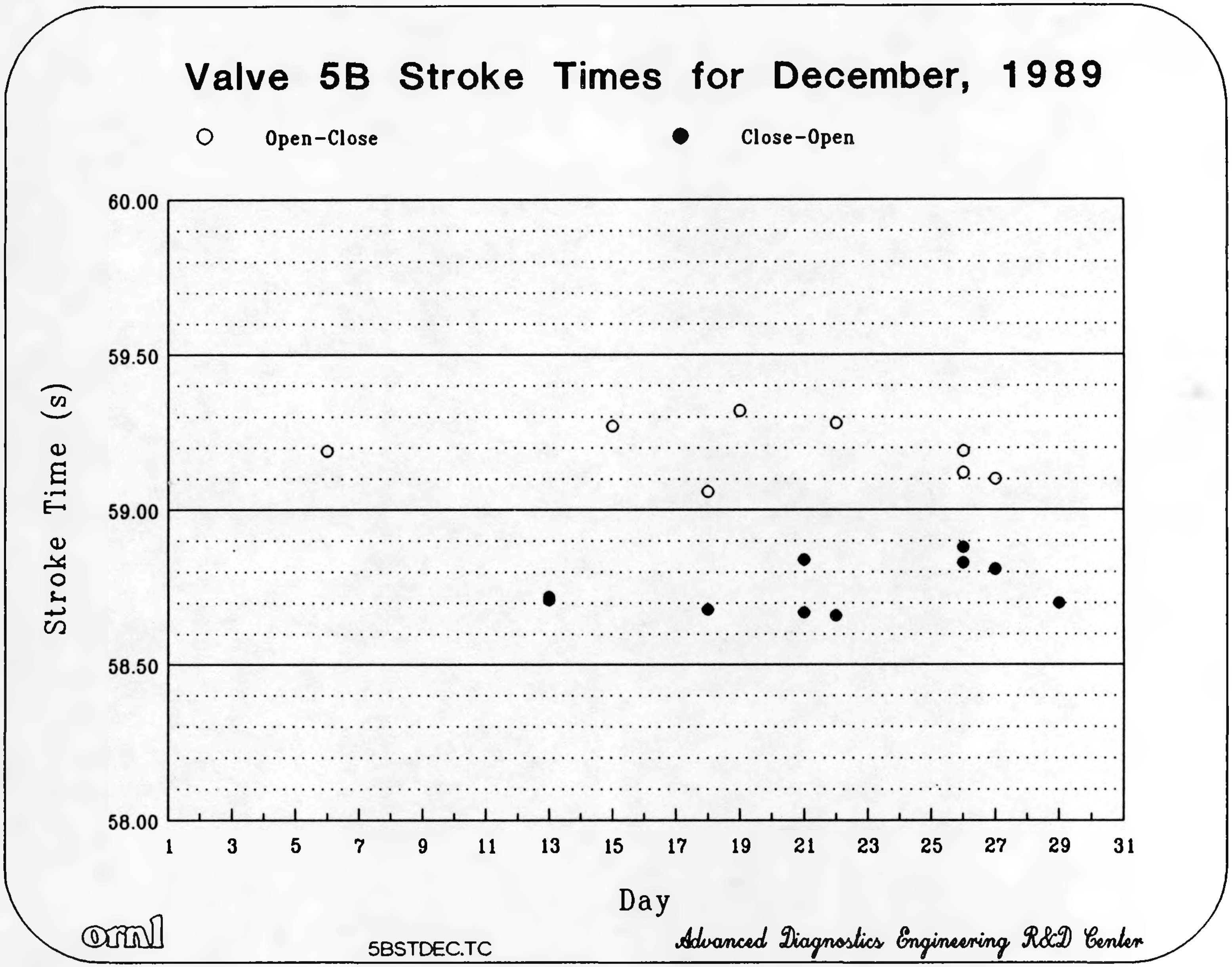

Valve 5B Stroke Times for December, 1989
Open-Close
Close-Open
Stroke Time (s)
60.00
59.50
59.00
58.50
58.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BSTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 39

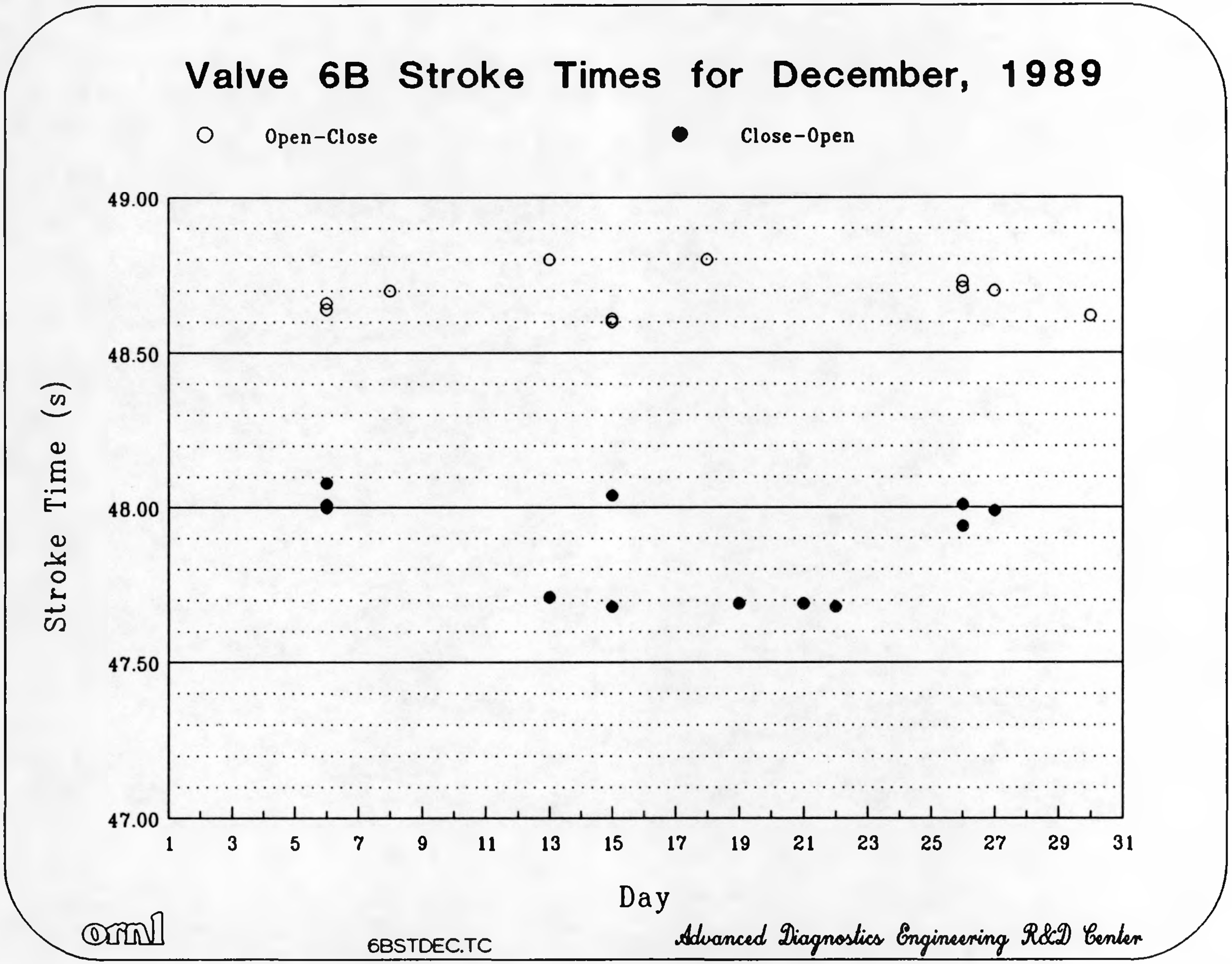

Valve 6B Stroke Times for December, 1989
Open-Close
Close-Open
49.00
48.50
48.00
47.50
47.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
6BSTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 40

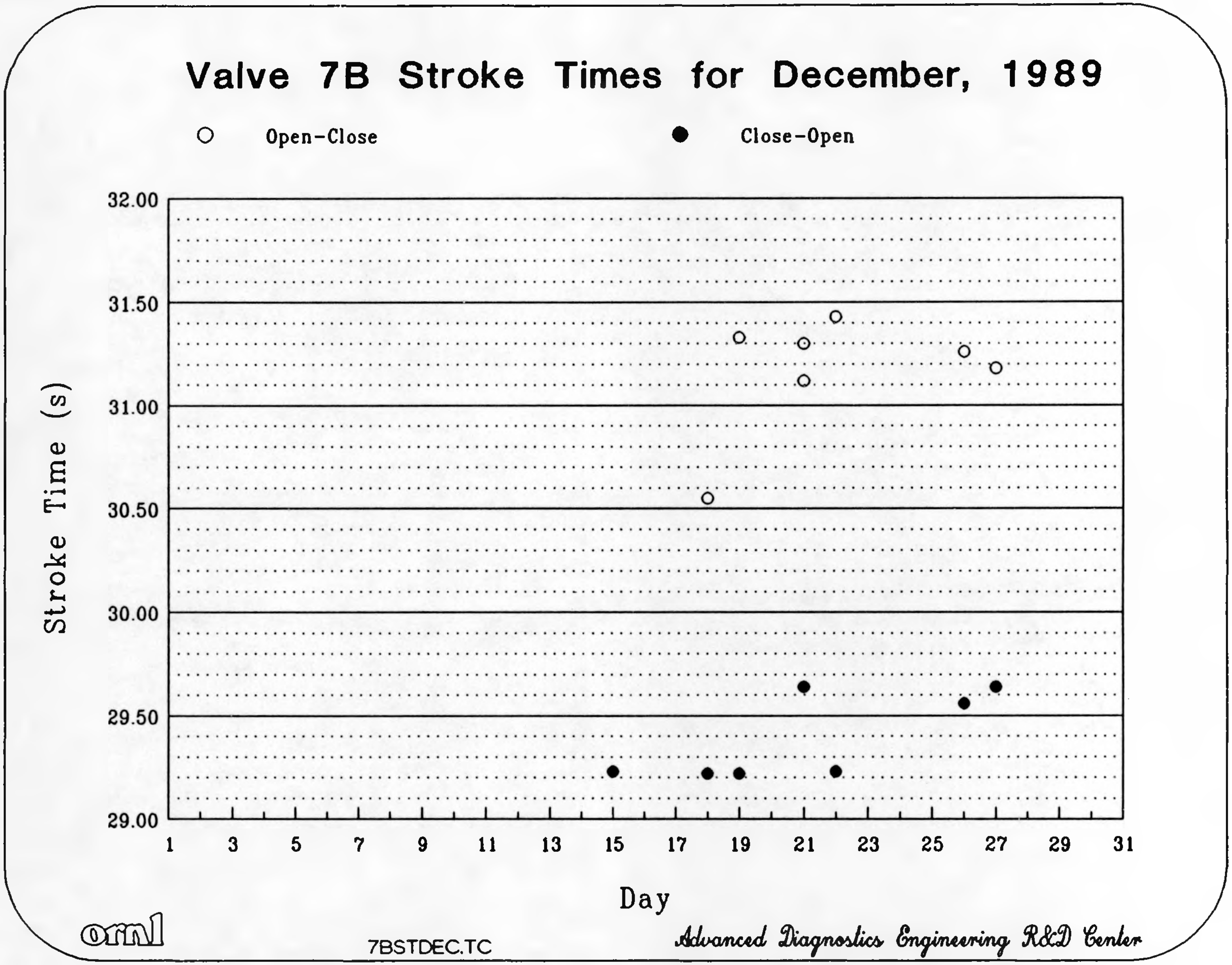

Valve 7B Stroke Times for December, 1989
Open-Close
Close-Open
Stroke Time (s)
32.00
31.50
31.00
30.50
30.00
29.50
29.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BSTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 41

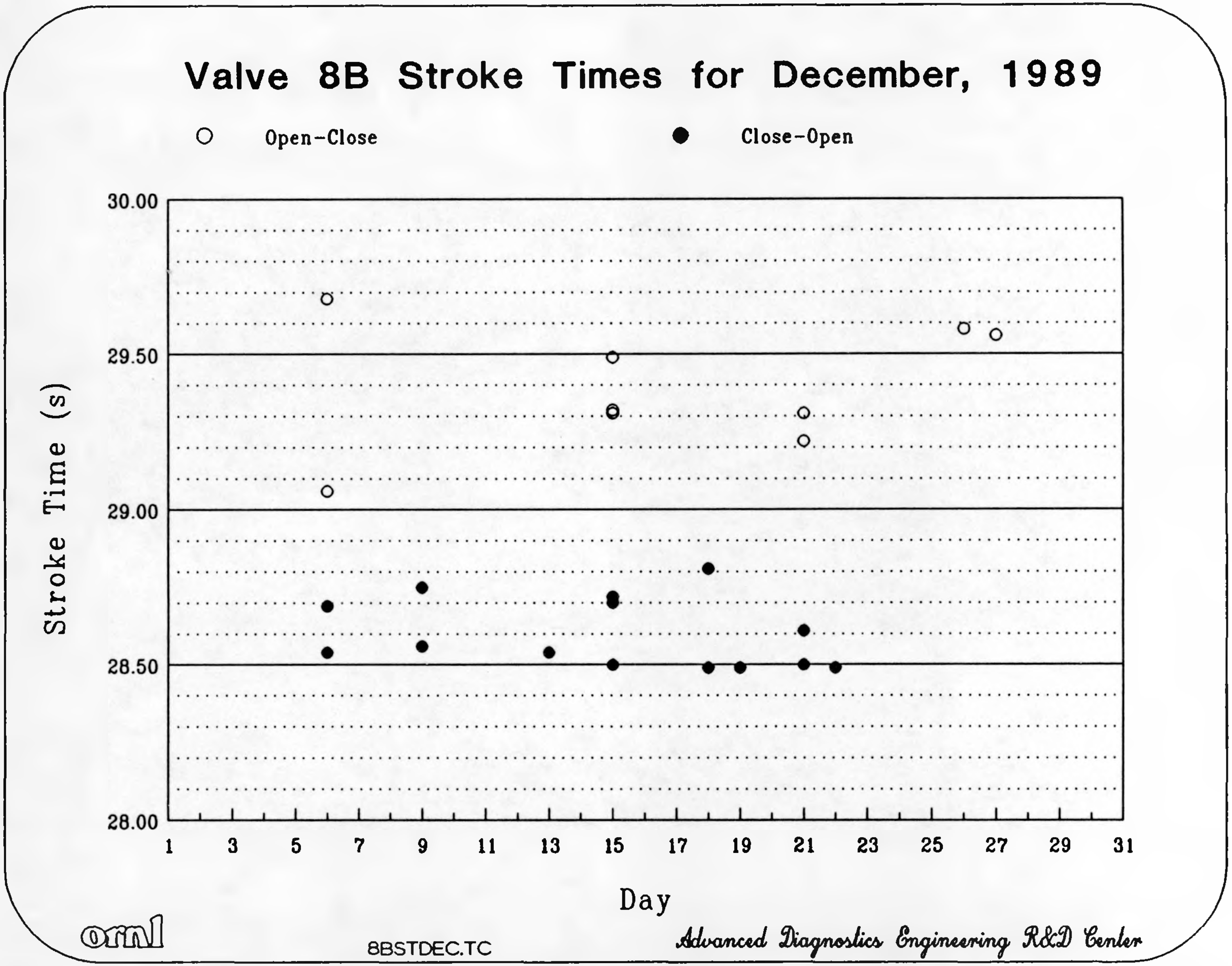

Valve 8B Stroke Times for December, 1989
Open-Close
Close-Open
30.00
29.50
29.00
28.50
28.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
orml
8BSTDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 42

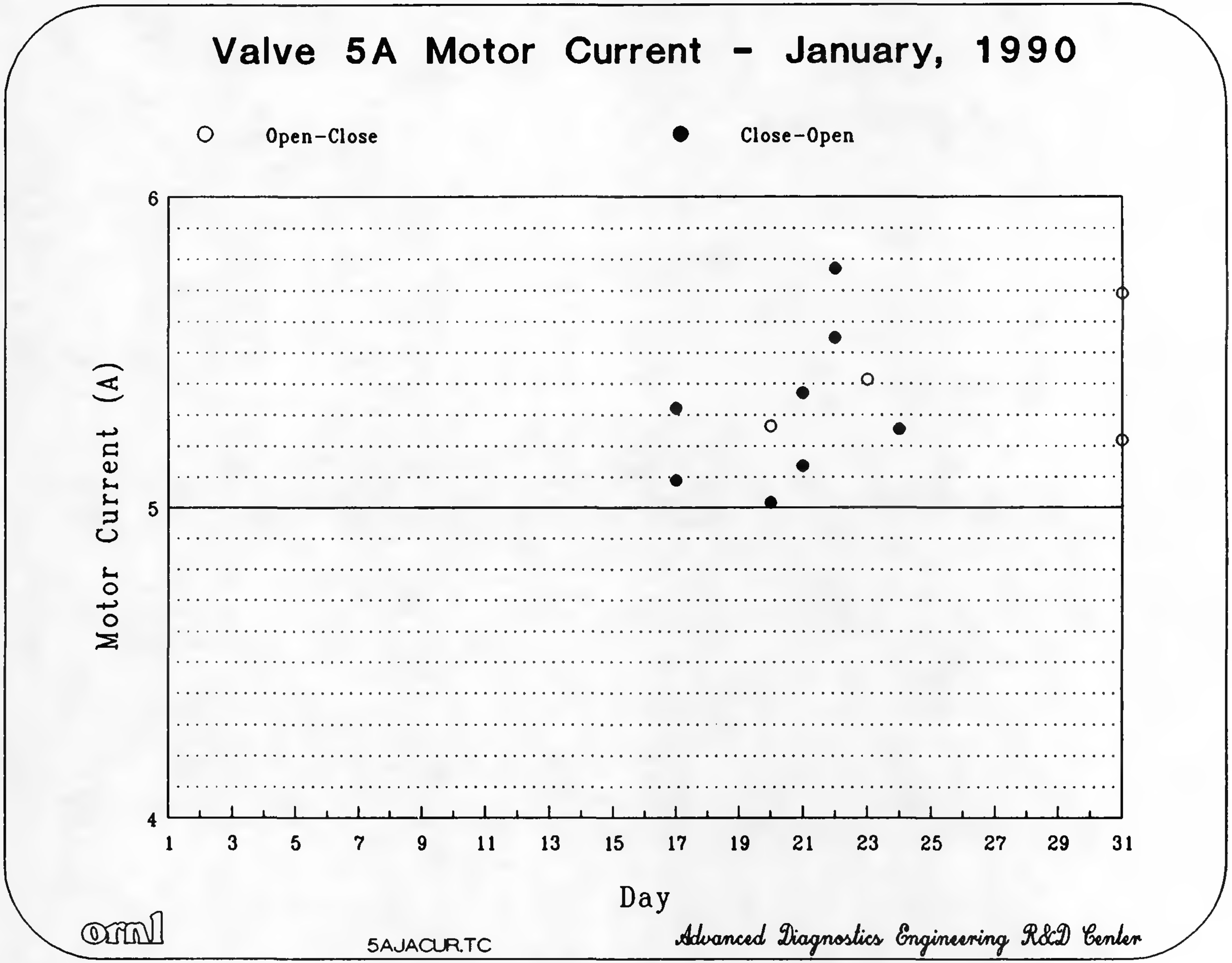

Valve 5A Motor Current - January, 1990
Open-Close
Close-Open
6
5
4
Motor Current (A)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5AJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 43

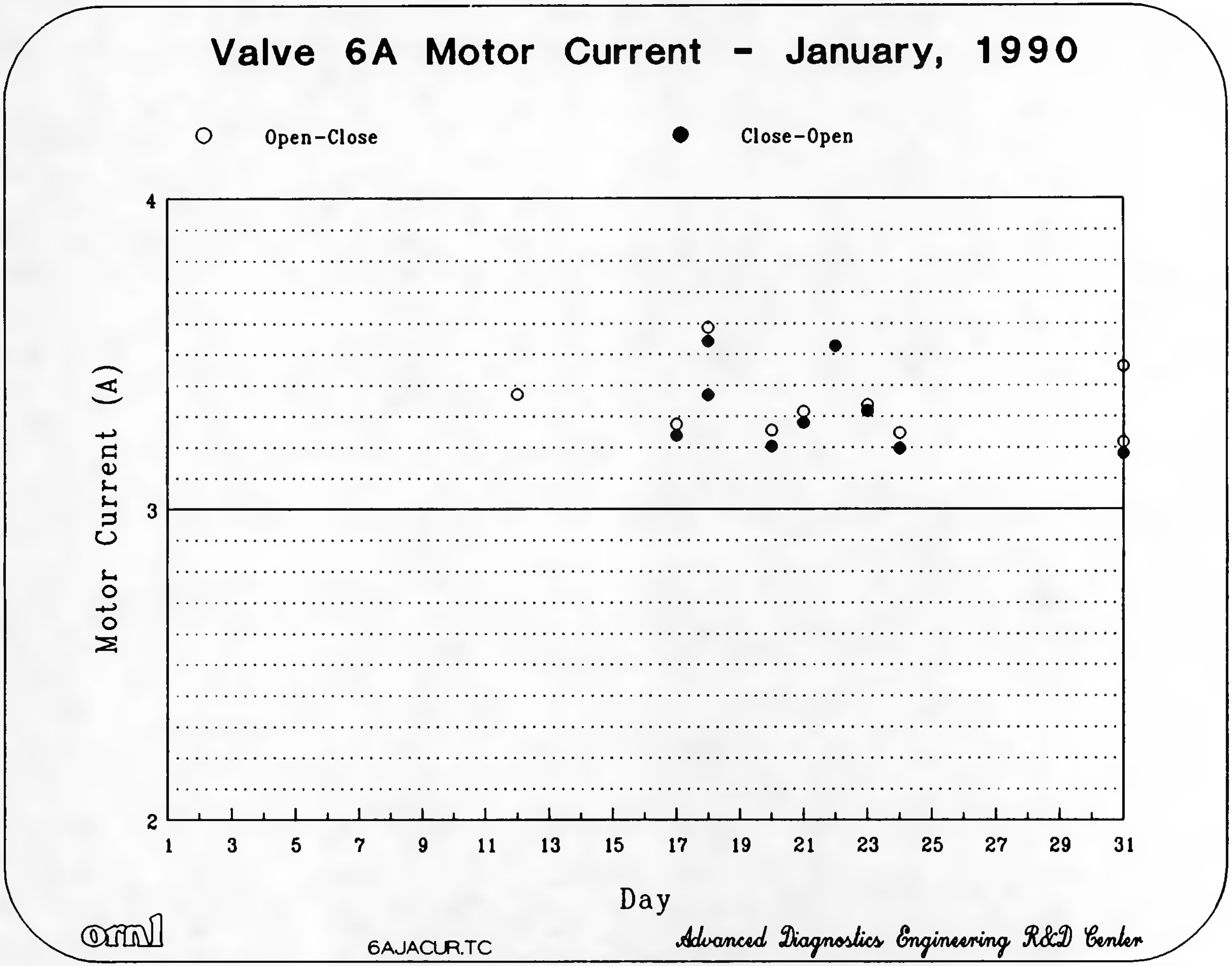
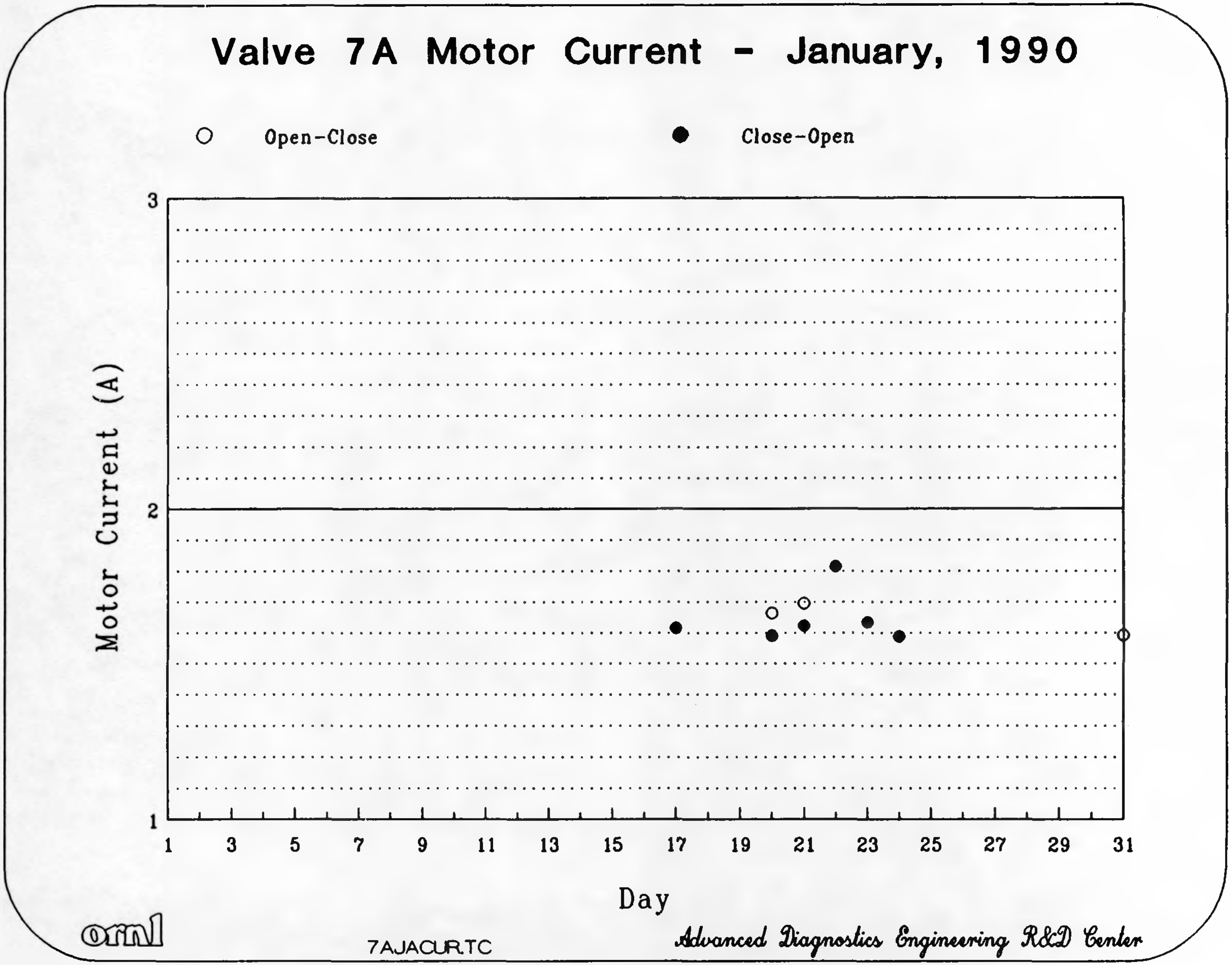

Valve 6A Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6AJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 44



Valve 7A Motor Current - January, 1990
Open-Close
Close-Open
3
2
1
Motor Current (A)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7AJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 45

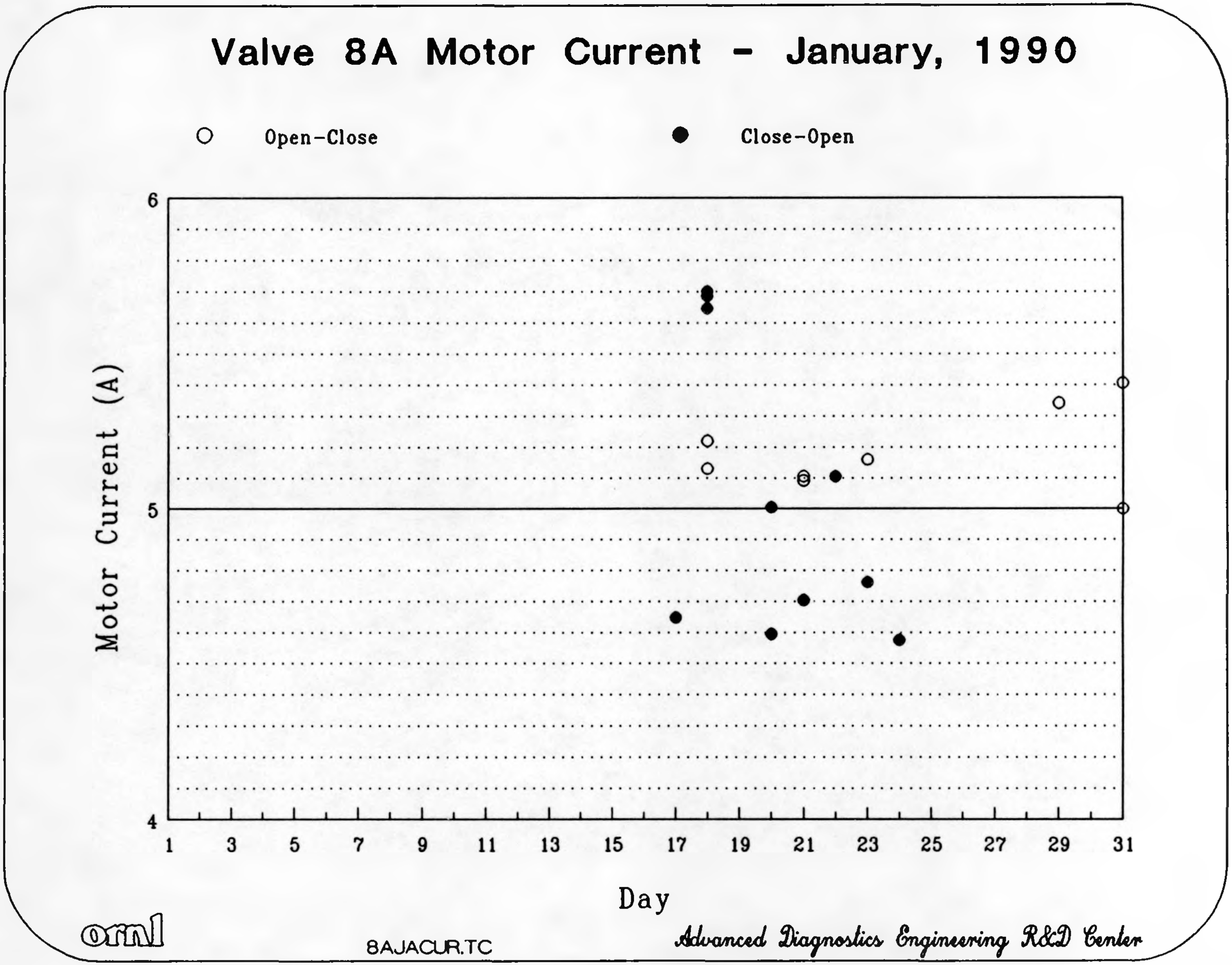
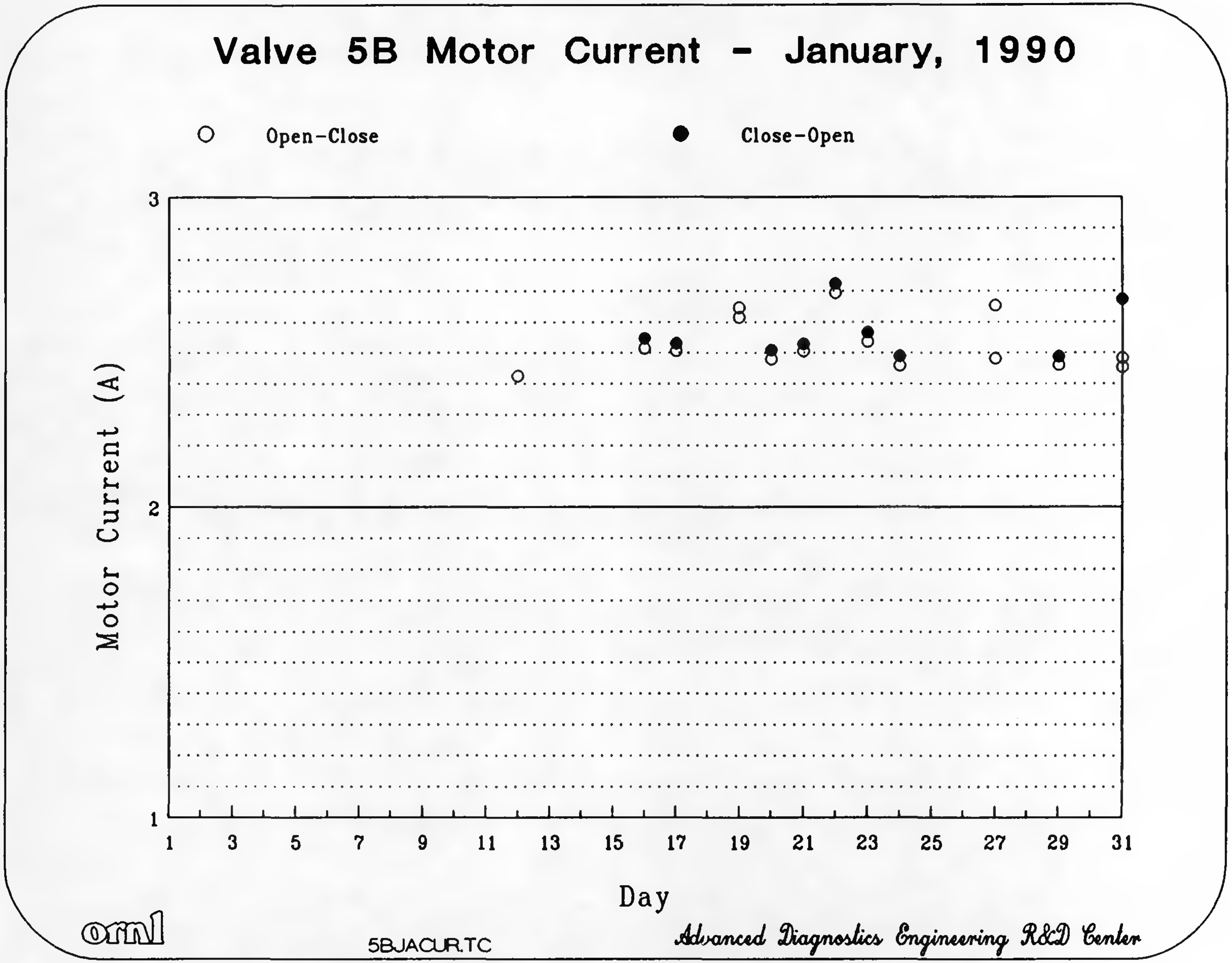

Valve 8A Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
6
5
4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8AJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 46



Valve 5B Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 47

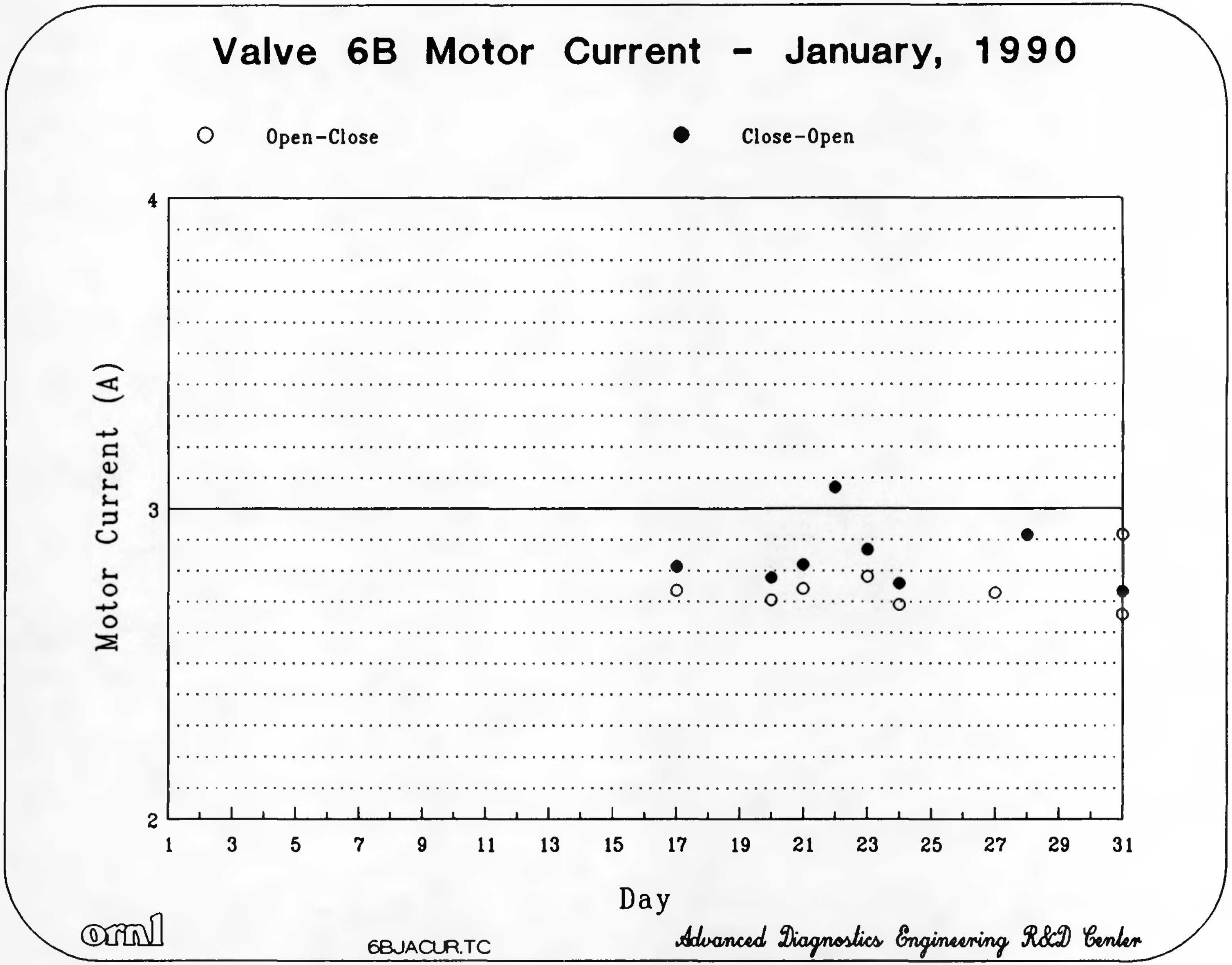
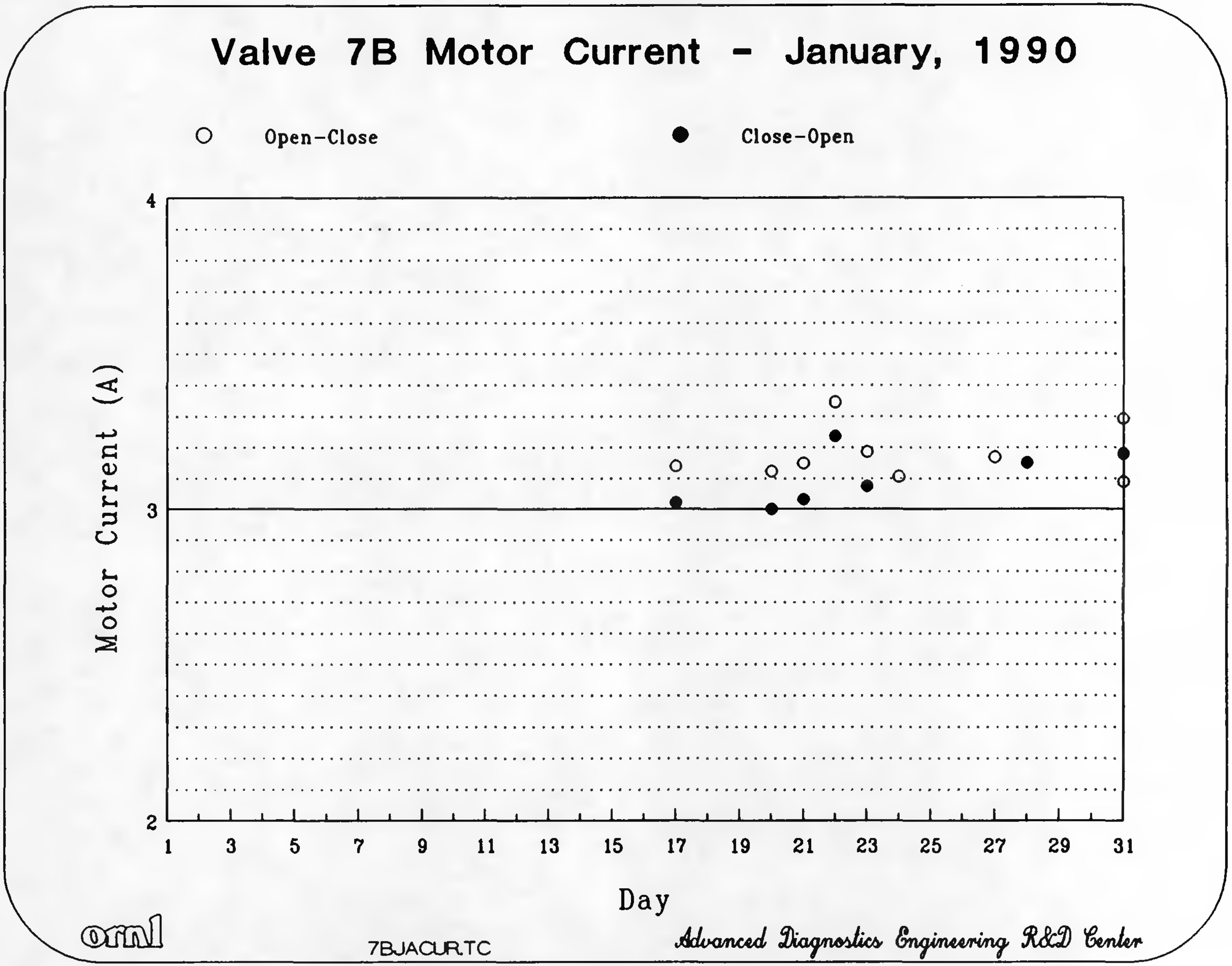

Valve 6B Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6BJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 48



Valve 7B Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 49

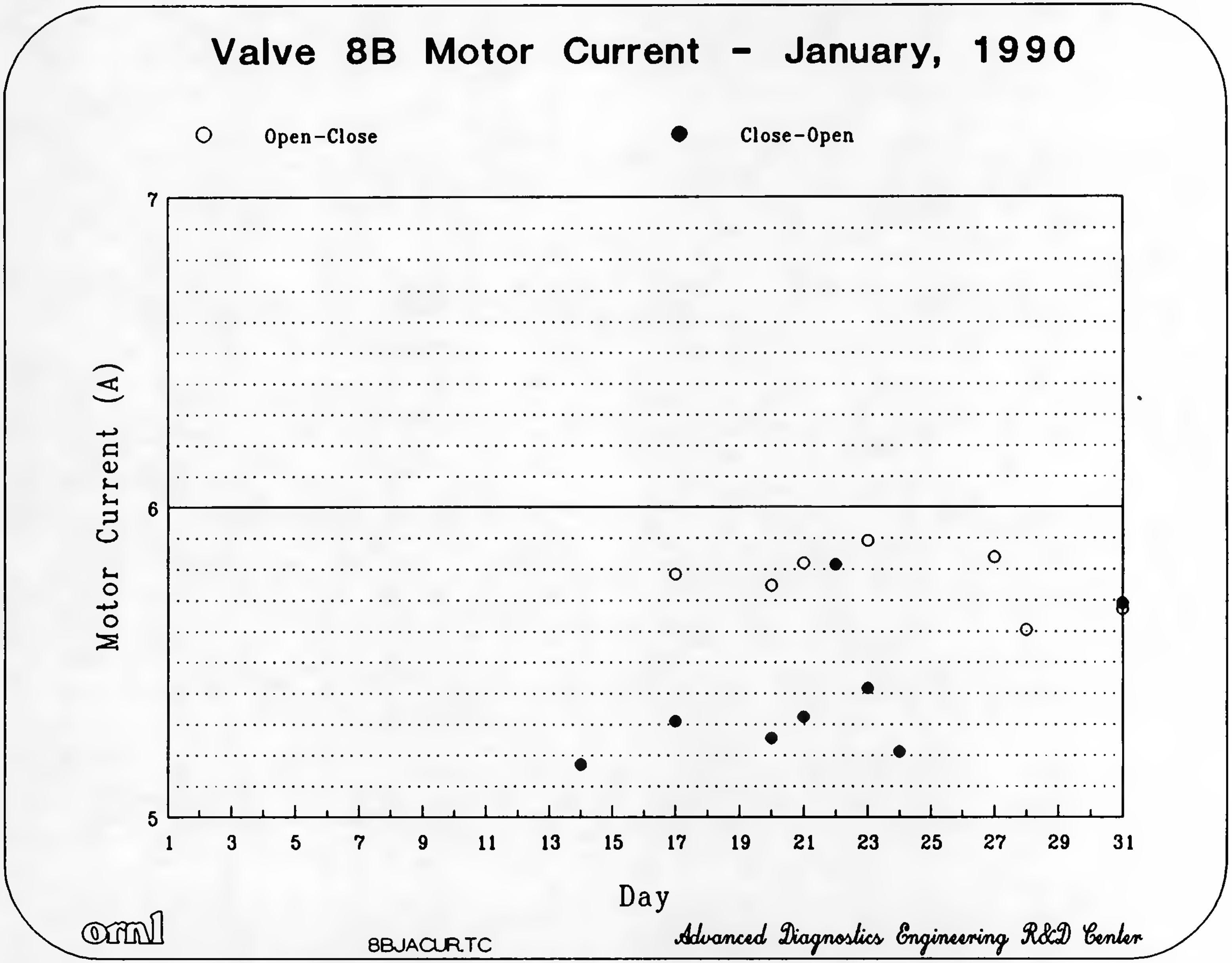
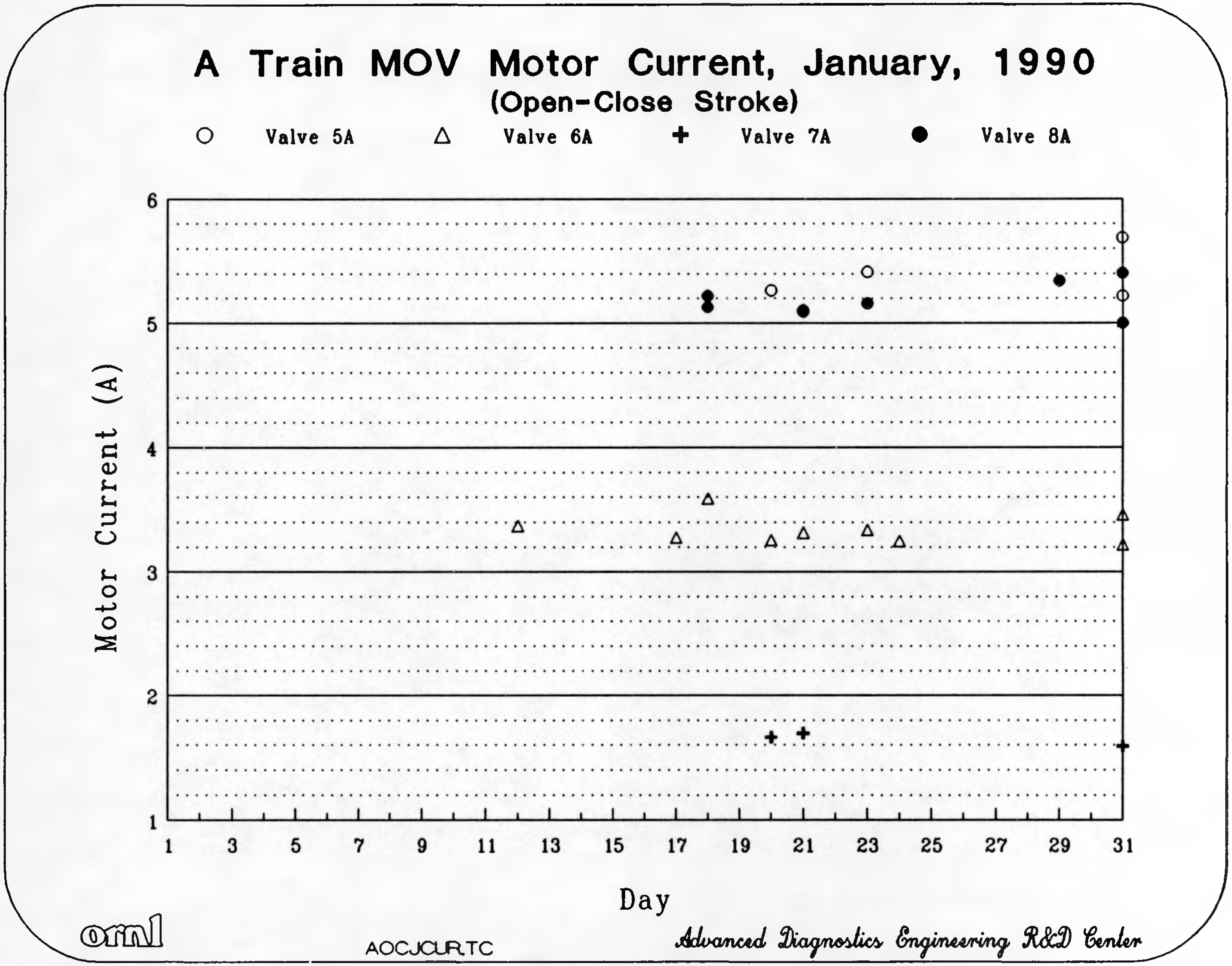

Valve 8B Motor Current - January, 1990
Open-Close
Close-Open
Motor Current (A)
7
6
5
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8BJACUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 50



A Train MOV Motor Current, January, 1990
(Open-Close Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
AOCJCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 51

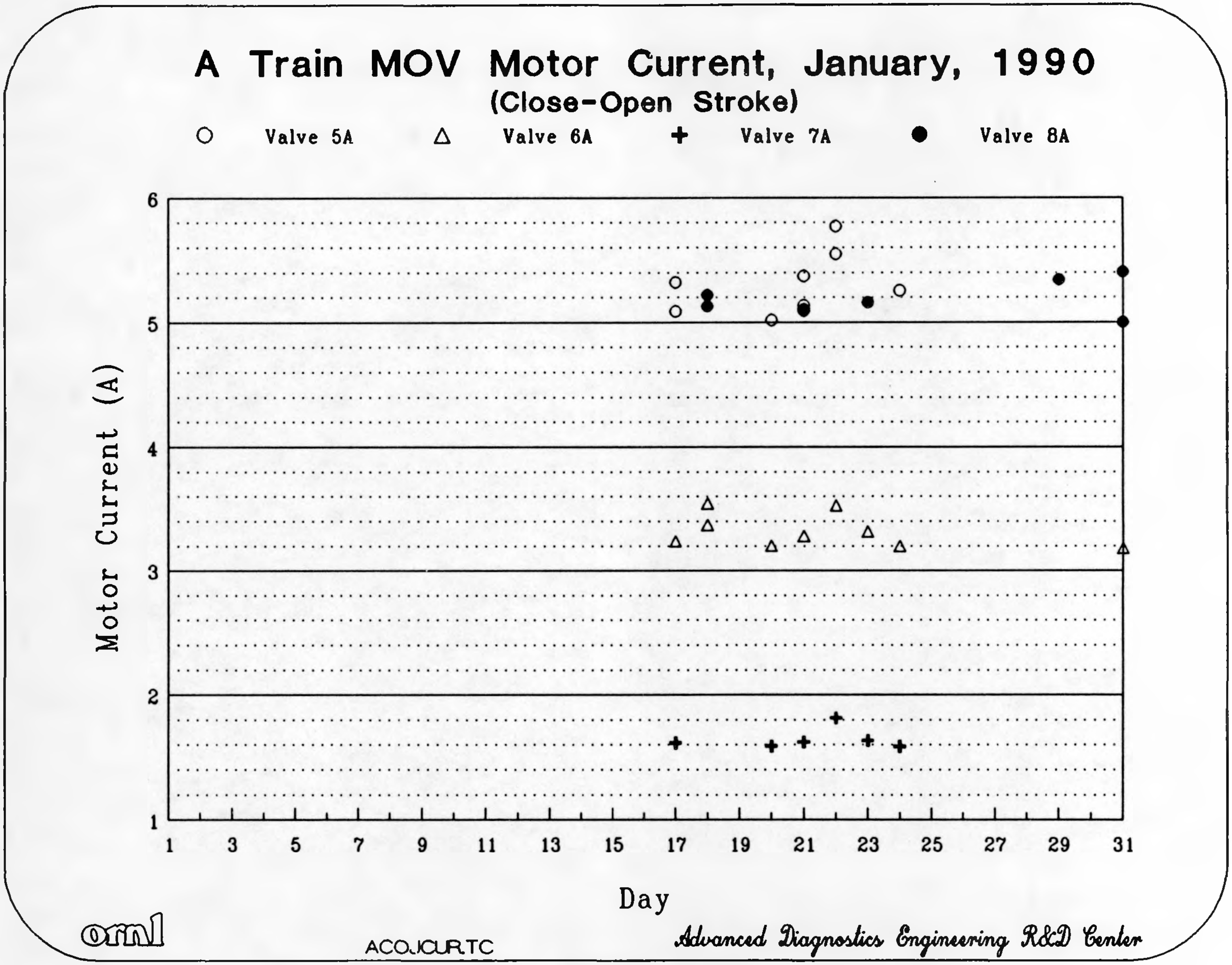

A Train MOV Motor Current, January, 1990
(Close-Open Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
ACOJCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 52

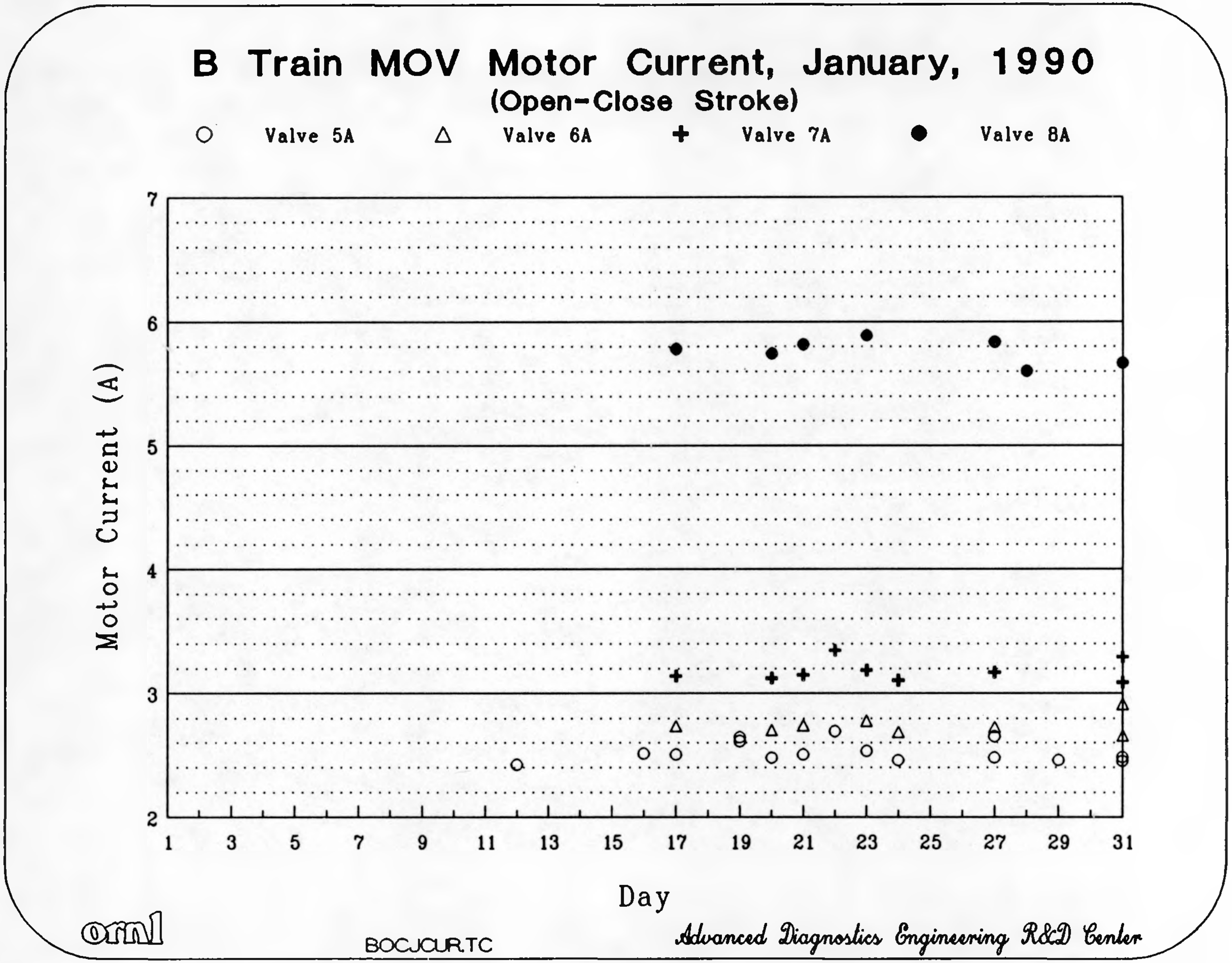

B Train MOV Motor Current, January, 1990
(Open-Close Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BOCJCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 53

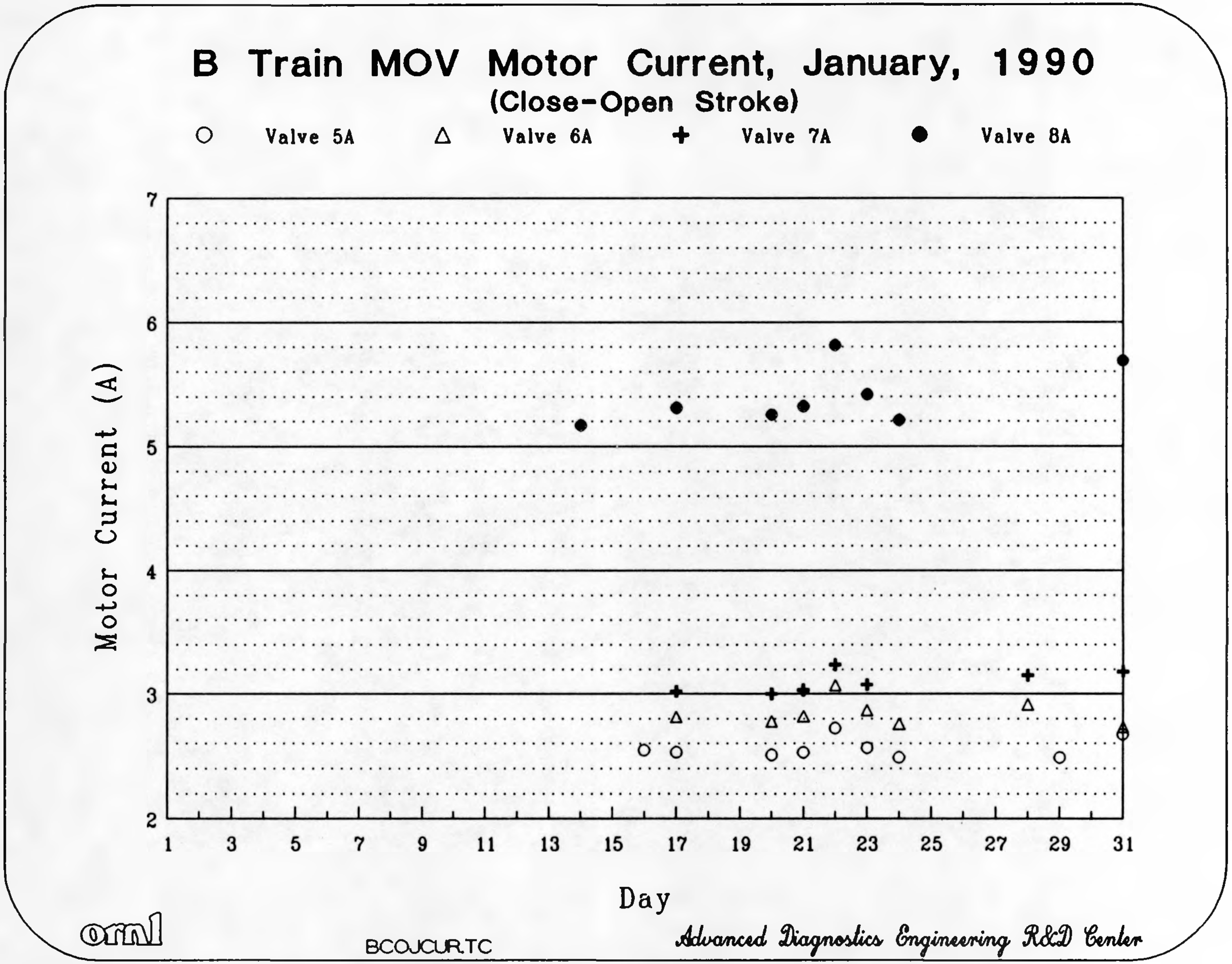
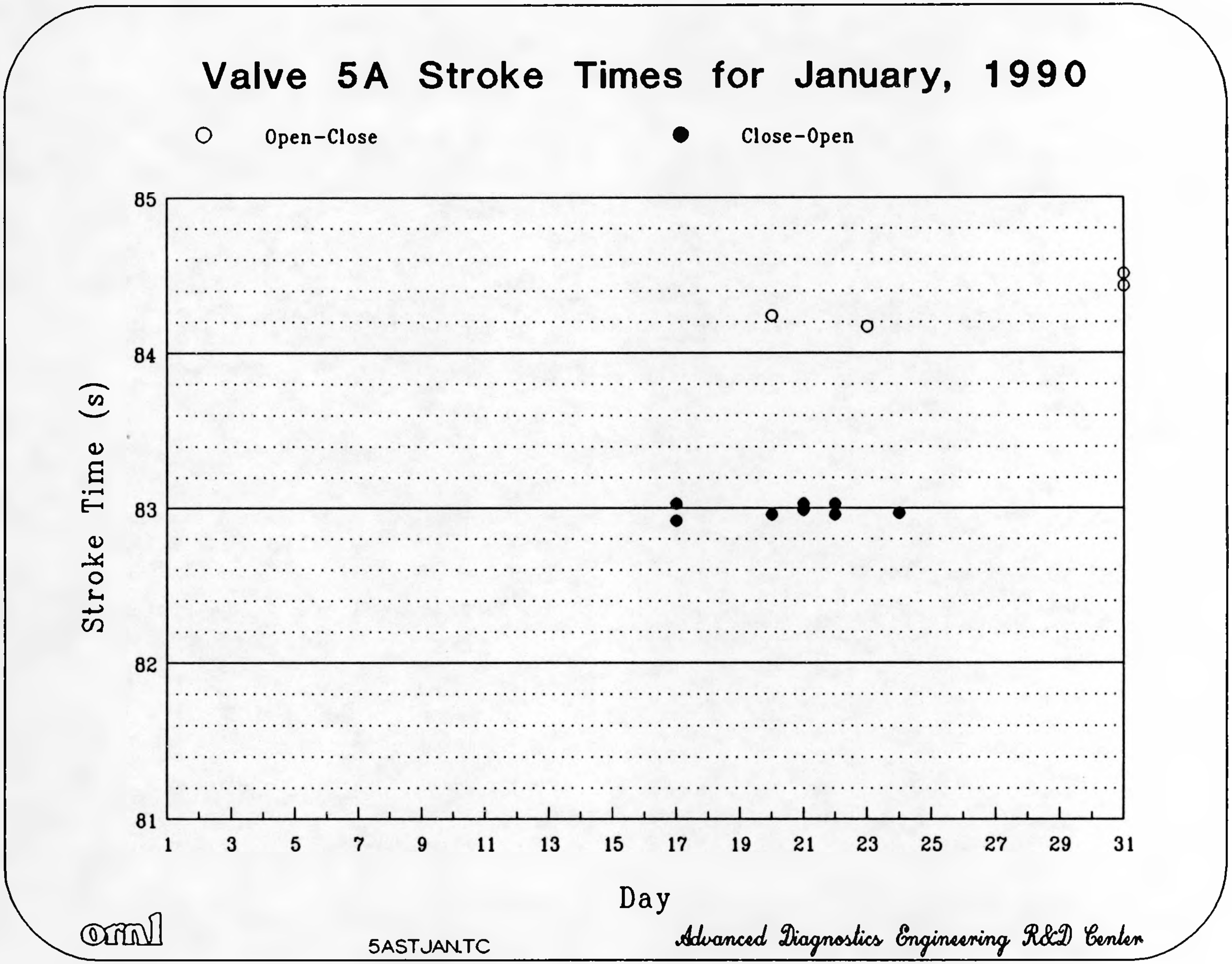

B Train MOV Motor Current, January, 1990
(Close-Open Stroke)
Valve 5A
Valve 6A
Valve 7A
Valve 8A
Motor Current (A)
7
6
5
4
3
2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
BCOJCUR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 54



Valve 5A Stroke Times for January, 1990
Open-Close
Close-Open
Stroke Time (s)
85
84
83
82
81
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5ASTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 55

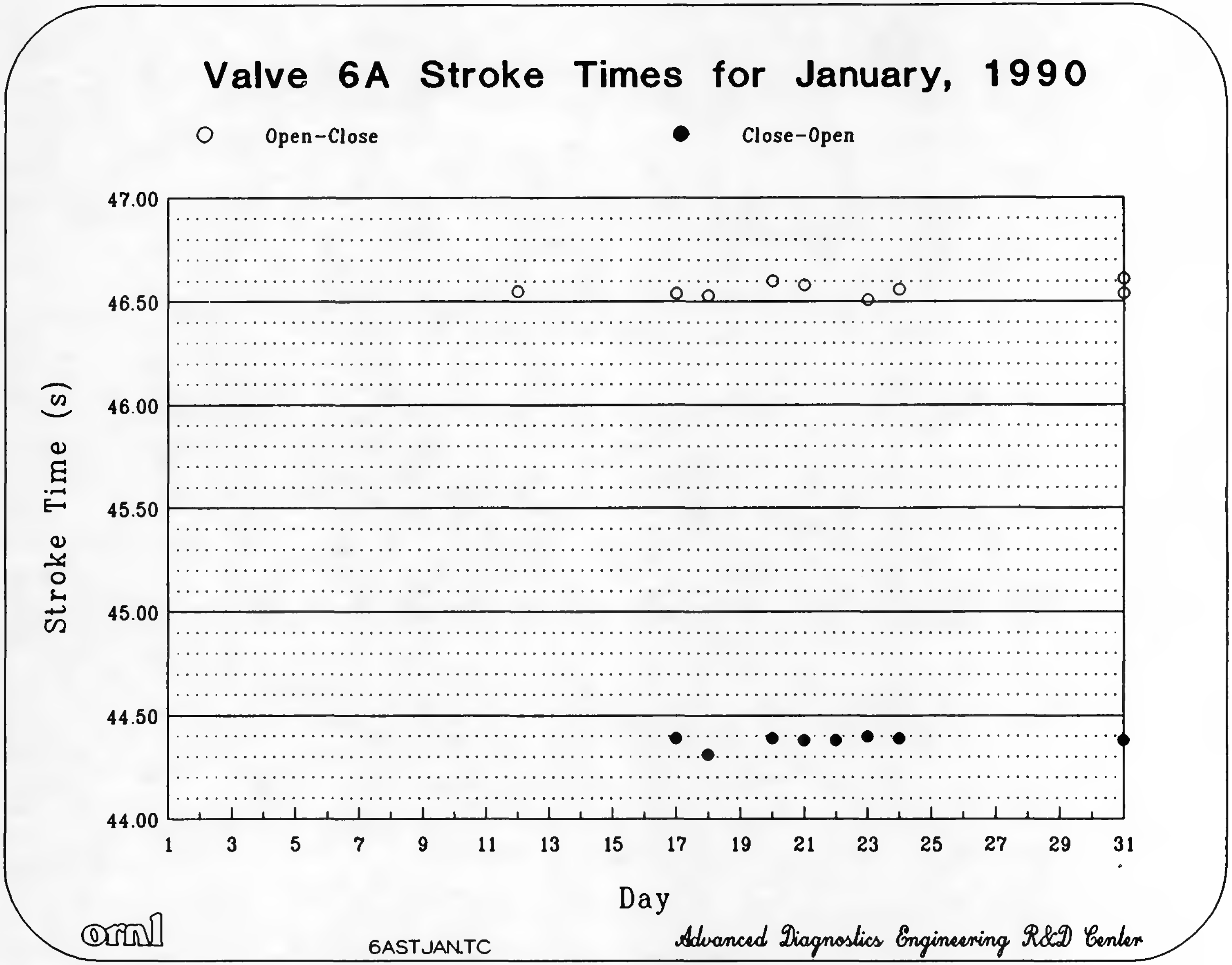

Valve 6A Stroke Times for January, 1990
Open-Close
Close-Open
Stroke Time (s)
47.00
46.50
46.00
45.50
45.00
44.50
44.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
6ASTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 56

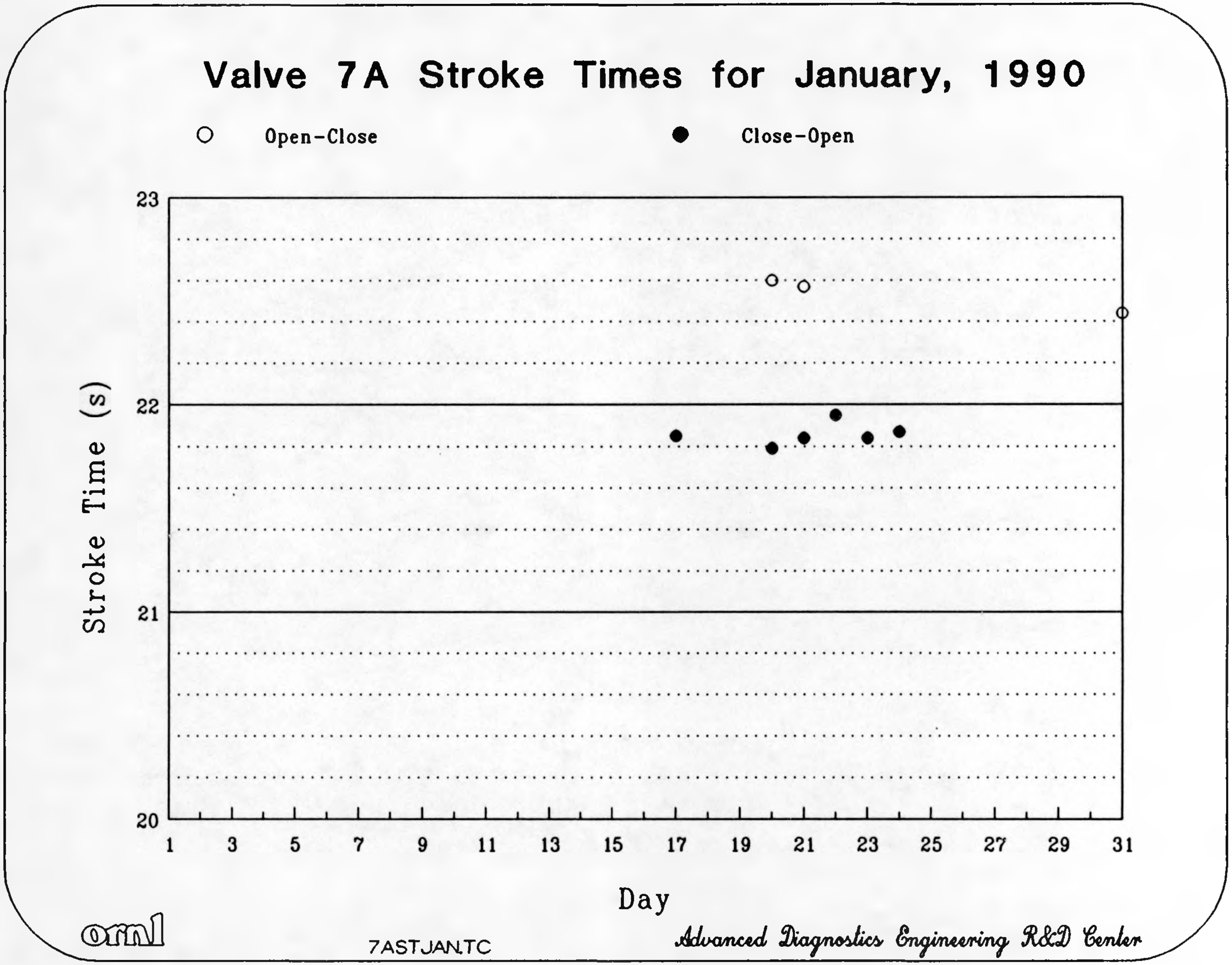

Valve 7A Stroke Times for January, 1990
Open-Close
Close-Open
Stroke Time (s)
23
22
21
20
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7ASTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 57

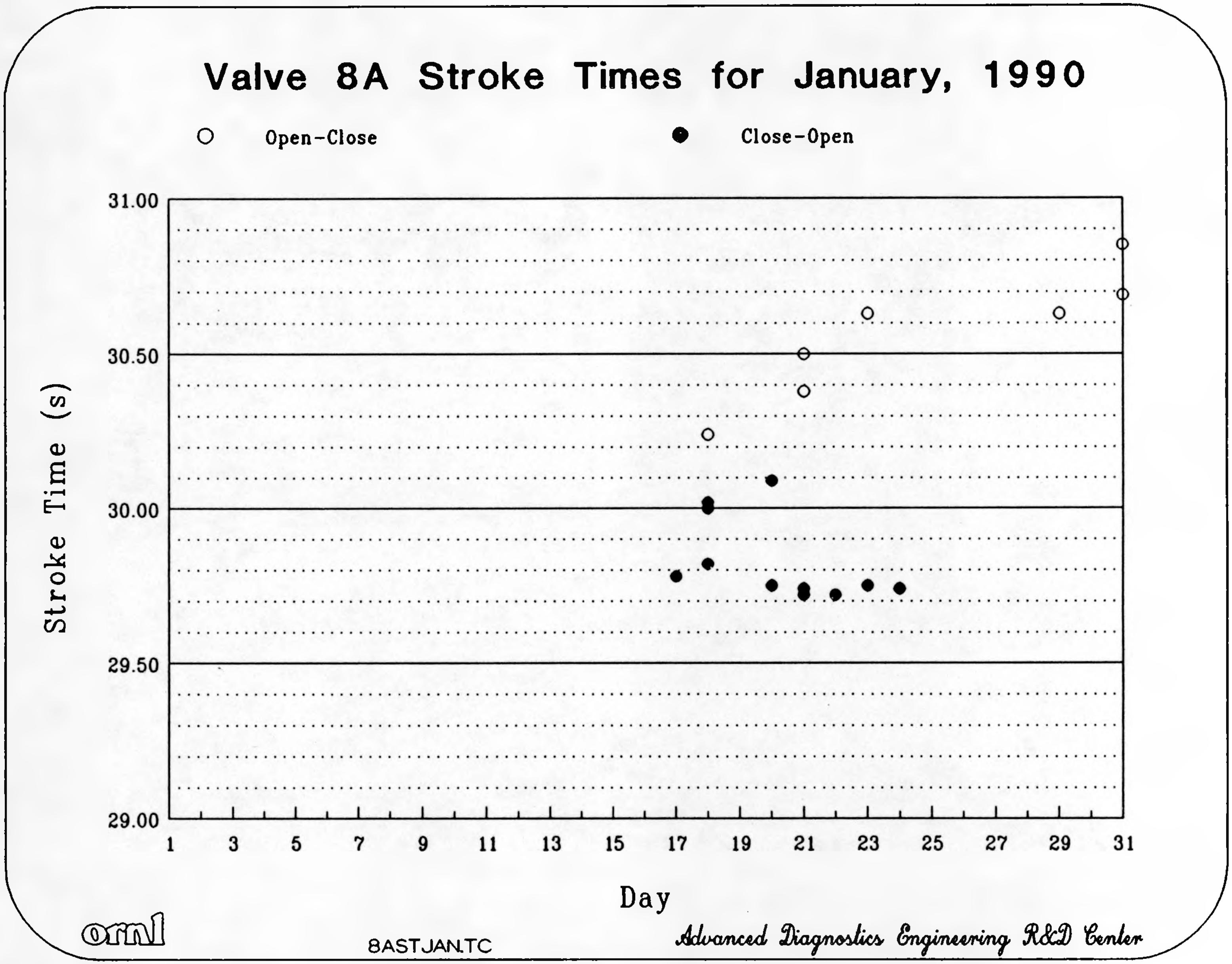
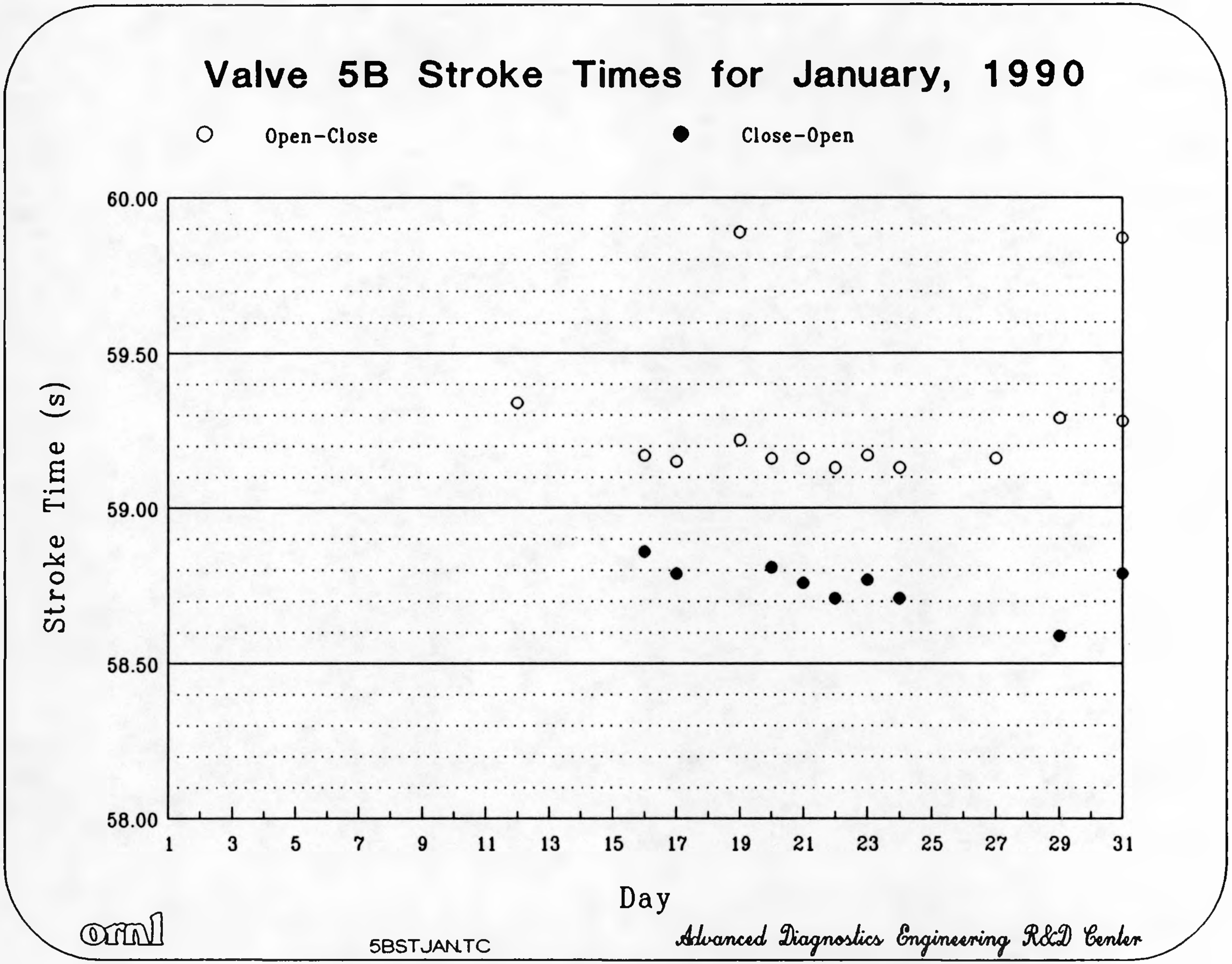
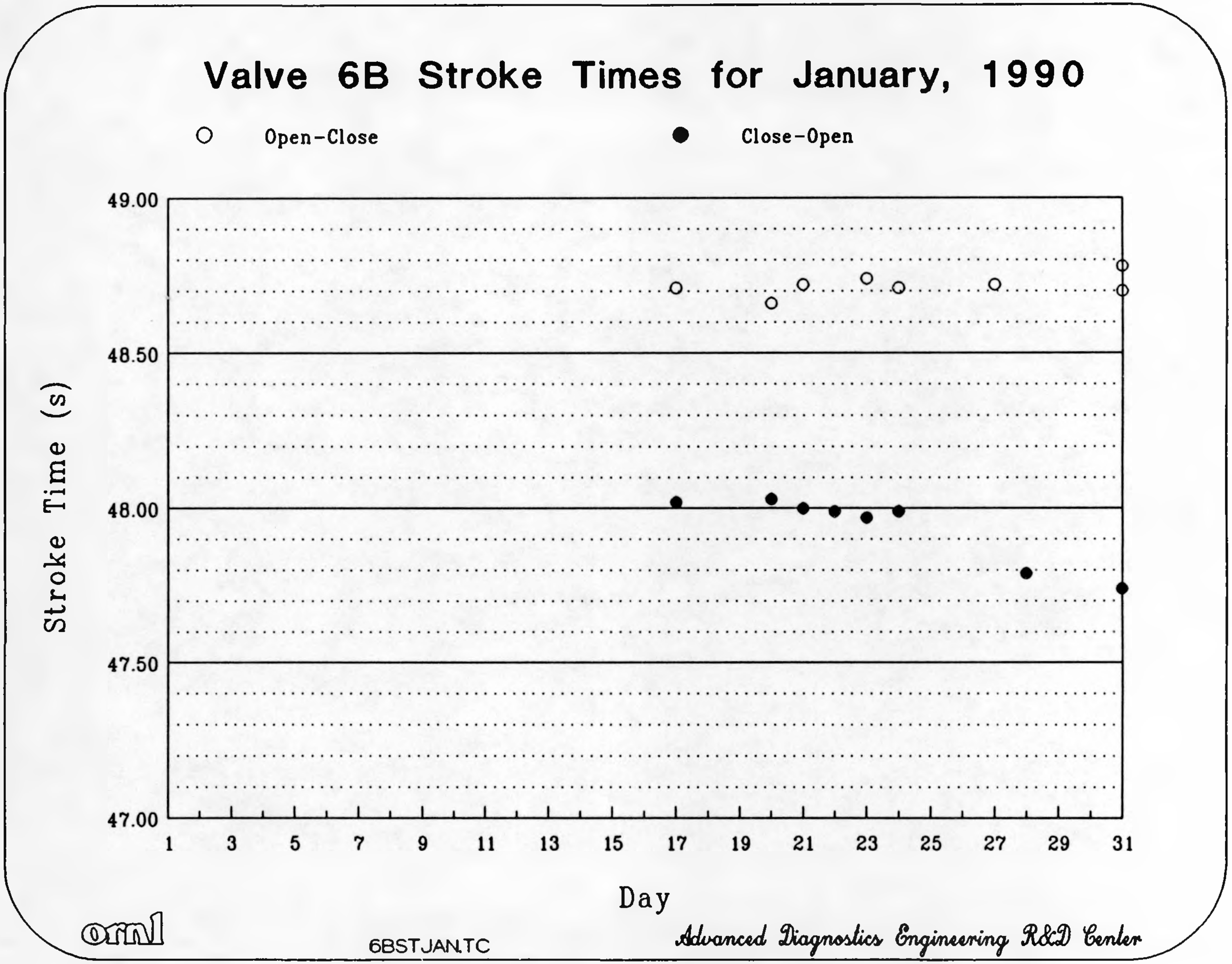

Valve 8A Stroke Times for January, 1990
Open-Close
Close-Open
31.00
30.50
30.00
29.50
29.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8ASTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 58



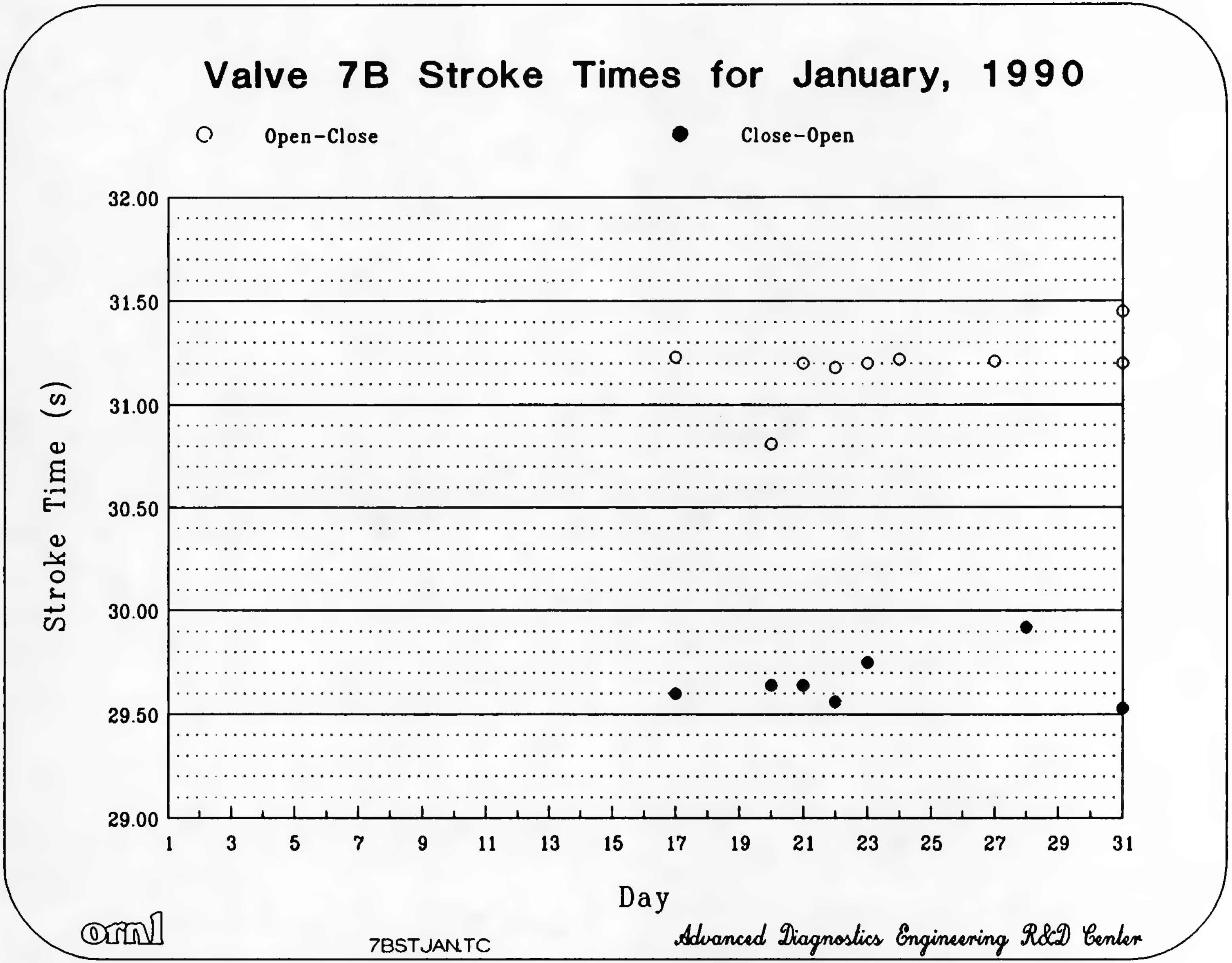
Valve 5B Stroke Times for January, 1990
Open-Close
Close-Open
60.00
59.50
59.00
58.50
58.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
5BSTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 59



Valve 6B Stroke Times for January, 1990
Open-Close
Close-Open
Stroke Time (s)
49.00
48.50
48.00
47.50
47.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
6BSTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 60



Valve 7B Stroke Times for January, 1990
Open-Close
Close-Open
Stroke Time (s)
32.00
31.50
31.00
30.50
30.00
29.50
29.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
7BSTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 61

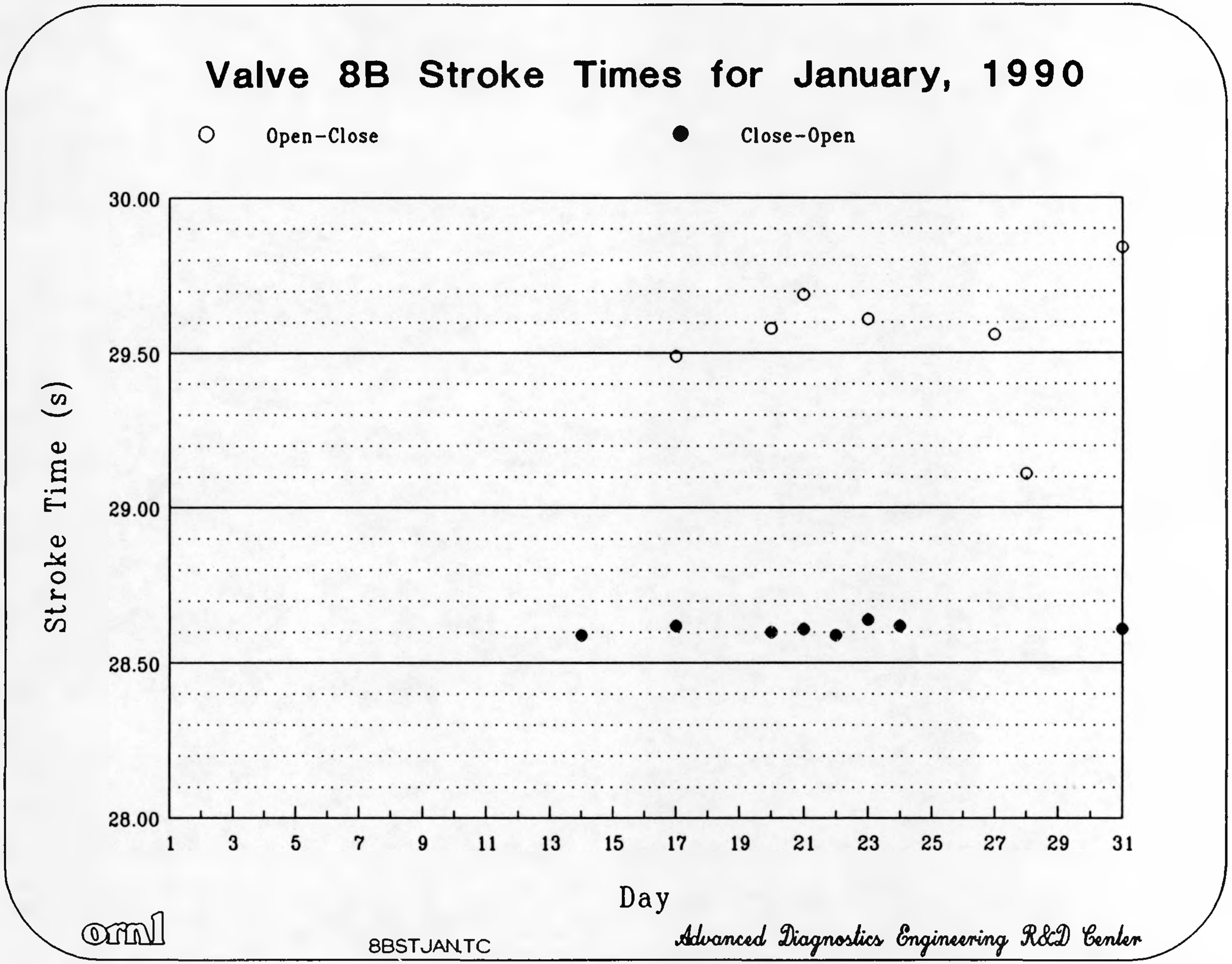
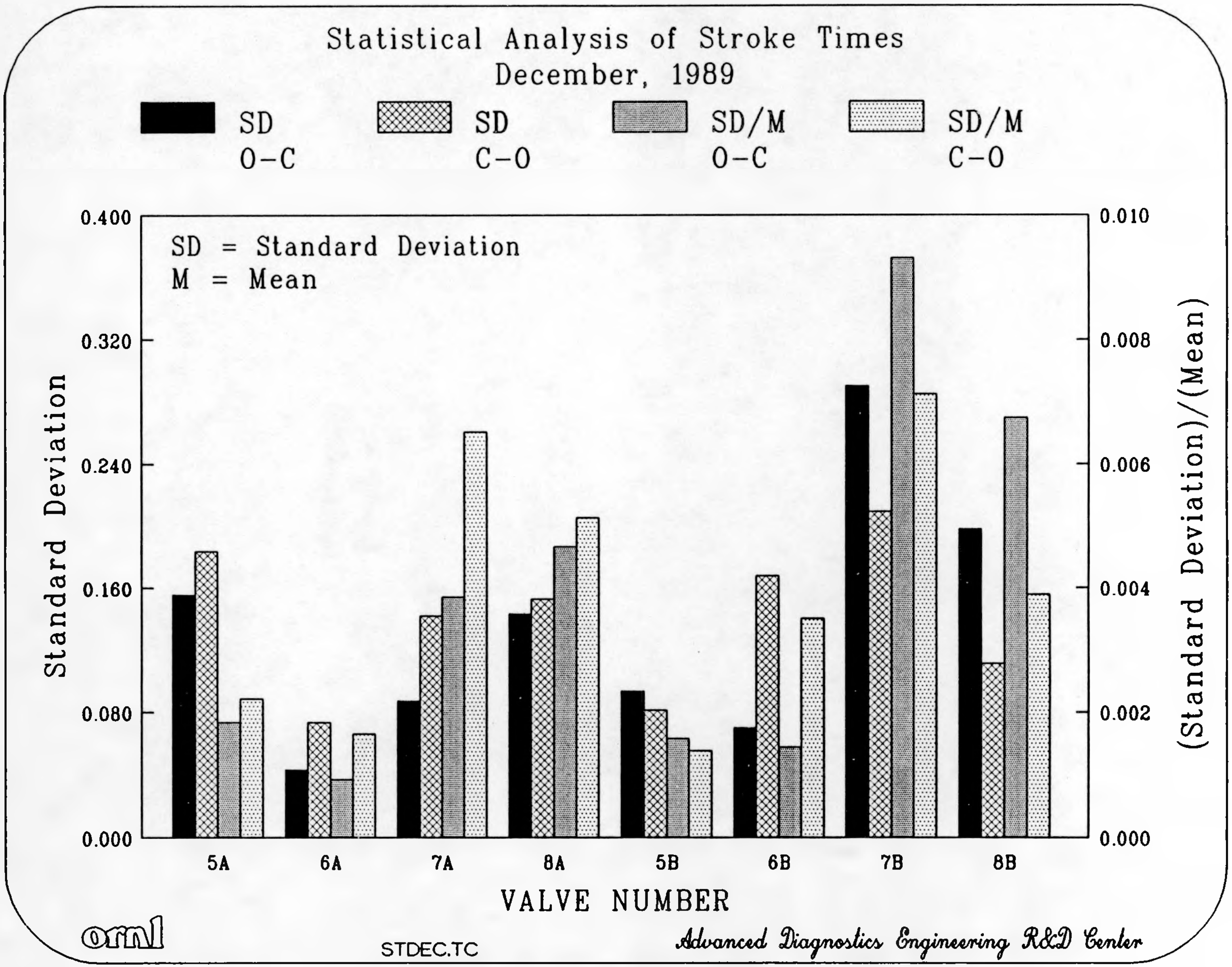
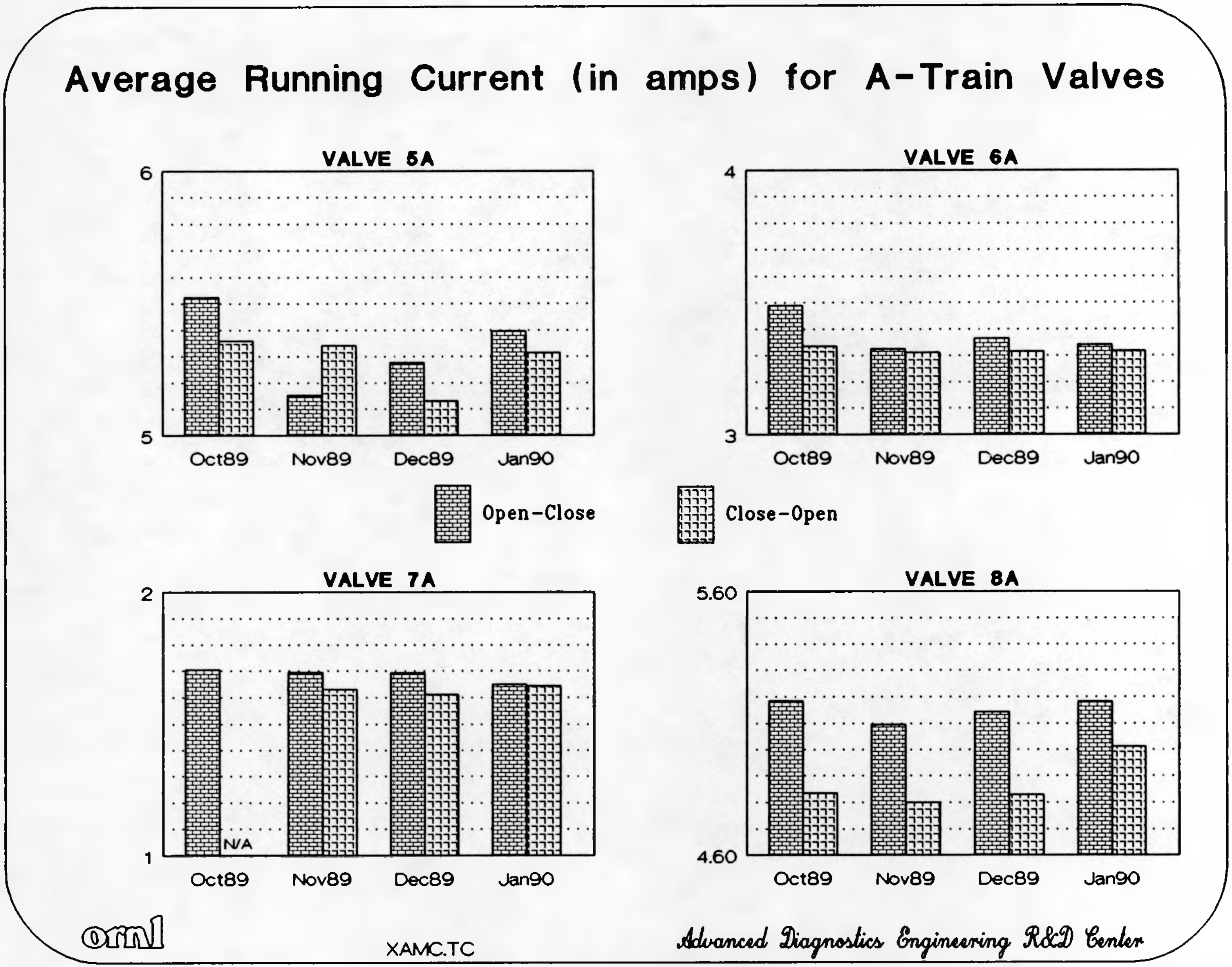

Valve 8B Stroke Times for January, 1990
Open-Close
Close-Open
30.00
29.50
29.00
28.50
28.00
Stroke Time (s)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
ornl
8BSTJAN.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 62



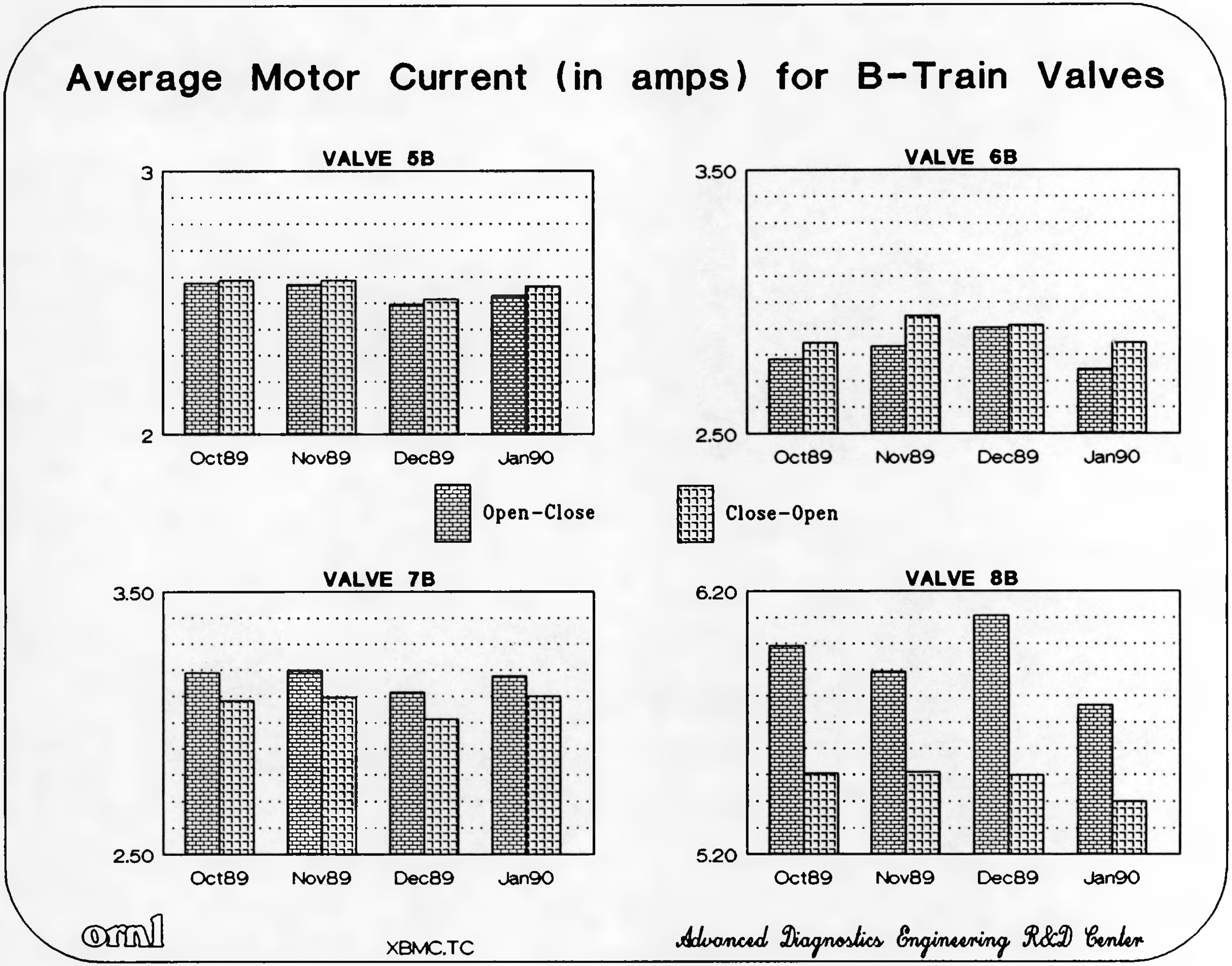
Statistical Analysis of Stroke Times
December, 1989
SD O-C
SD C-O
SD/M O-C
SD/M C-O
SD = Standard Deviation
M = Mean
Standard Deviation
(Standard Deviation)/(Mean)
0.400
0.320
0.240
0.160
0.080
0.000
0.010
0.008
0.006
0.004
0.002
0.000
5A
6A
7A
8A
5B
6B
7B
8B
VALVE NUMBER
ornl
STDEC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 63



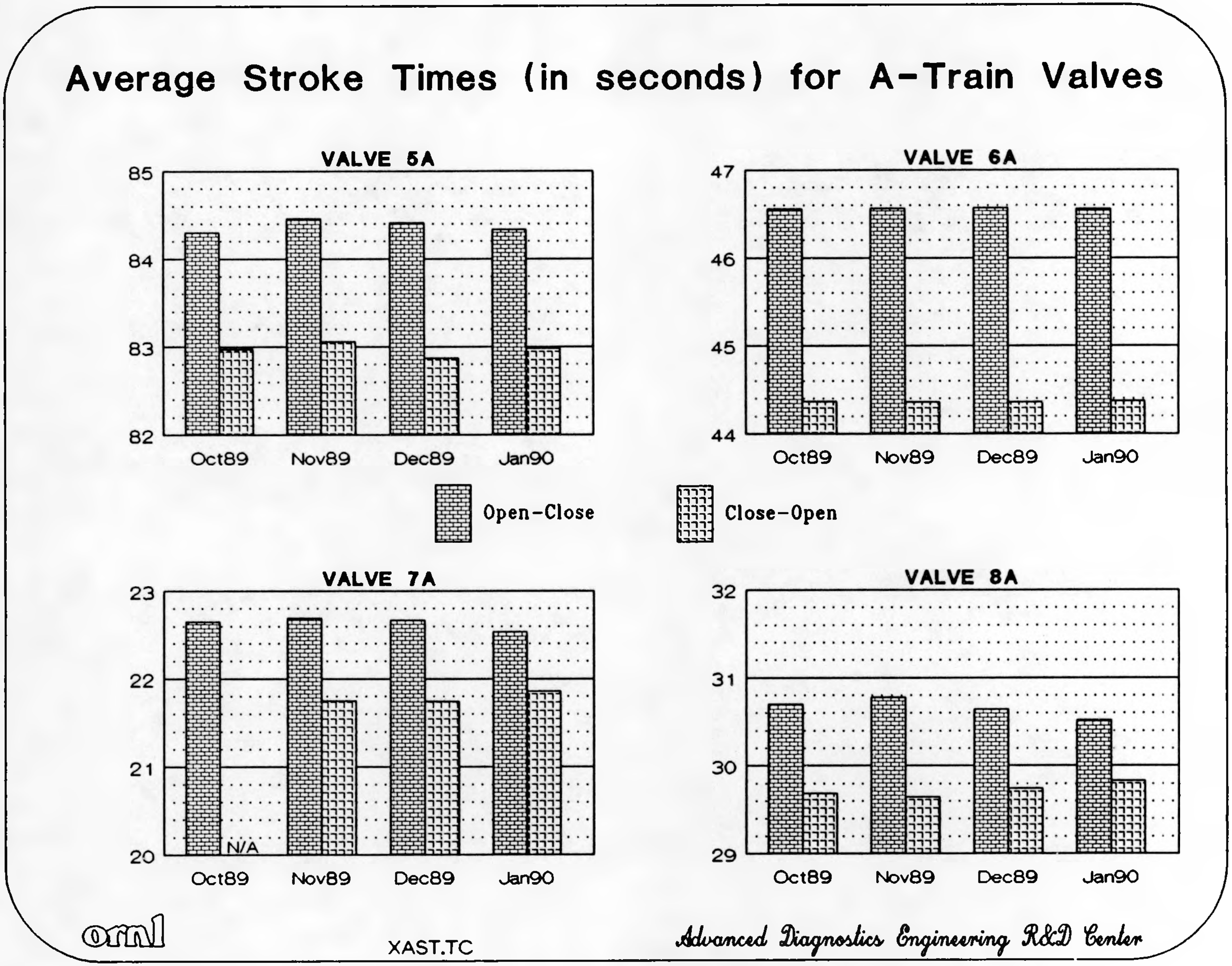
Average Running Current (in amps) for A-Train Valves
VALVE 5A
6
5
Oct89
Nov89
Dec89
Jan90
VALVE 6A
4
3
Oct89
Nov89
Dec89
Jan90
Open-Close
Close-Open
VALVE 7A
2
1
N/A
Oct89
Nov89
Dec89
Jan90
VALVE 8A
5.60
4.60
Oct89
Nov89
Dec89
Jan90
ornl
XAMC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 64



Average Motor Current (in amps) for B-Train Valves
VALVE 5B
3
2
Oct89 Nov89 Dec89 Jan90
VALVE 6B
3.50
2.50
Oct89 Nov89 Dec89 Jan90
Open-Close
Close-Open
VALVE 7B
3.50
2.50
Oct89 Nov89 Dec89 Jan90
VALVE 8B
6.20
5.20
Oct89 Nov89 Dec89 Jan90
ornl
XBMC.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 65



Average Stroke Times (in seconds) for A-Train Valves
VALVE 5A
85
84
83
82
Oct89
Nov89
Dec89
Jan90
VALVE 6A
47
46
45
44
Oct89
Nov89
Dec89
Jan90
Open-Close
Close-Open
VALVE 7A
23
22
21
20
N/A
Oct89
Nov89
Dec89
Jan90
VALVE 8A
32
31
30
29
Oct89
Nov89
Dec89
Jan90
ornl
XAST.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 66

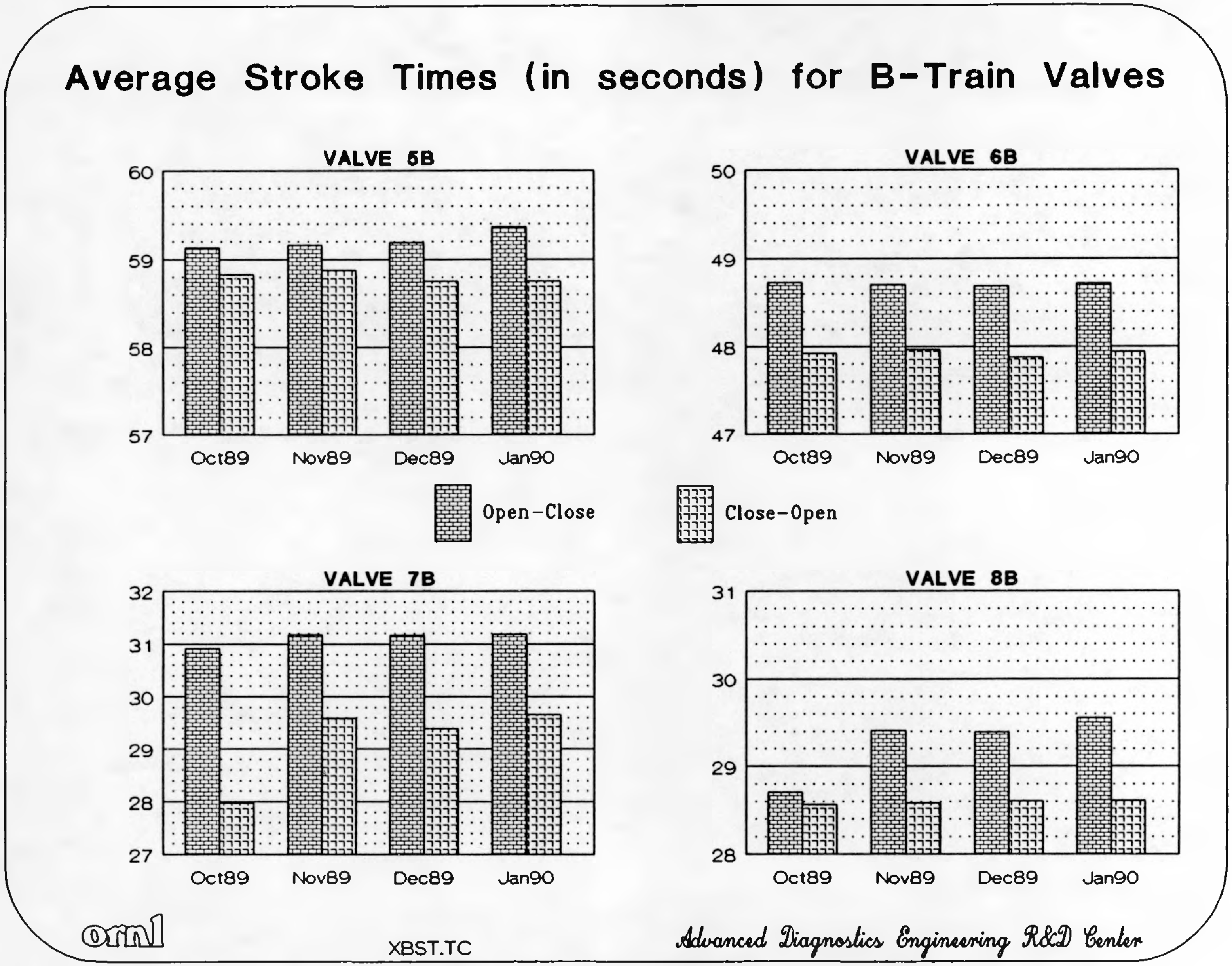

Average Stroke Times (in seconds) for B-Train Valves
VALVE 5B
60
59
58
57
Oct89
Nov89
Dec89
Jan90
VALVE 6B
50
49
48
47
Oct89
Nov89
Dec89
Jan90
Open-Close
Close-Open
VALVE 7B
32
31
30
29
28
27
Oct89
Nov89
Dec89
Jan90
VALVE 8B
31
30
29
28
Oct89
Nov89
Dec89
Jan90
ornl
XBST.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 67

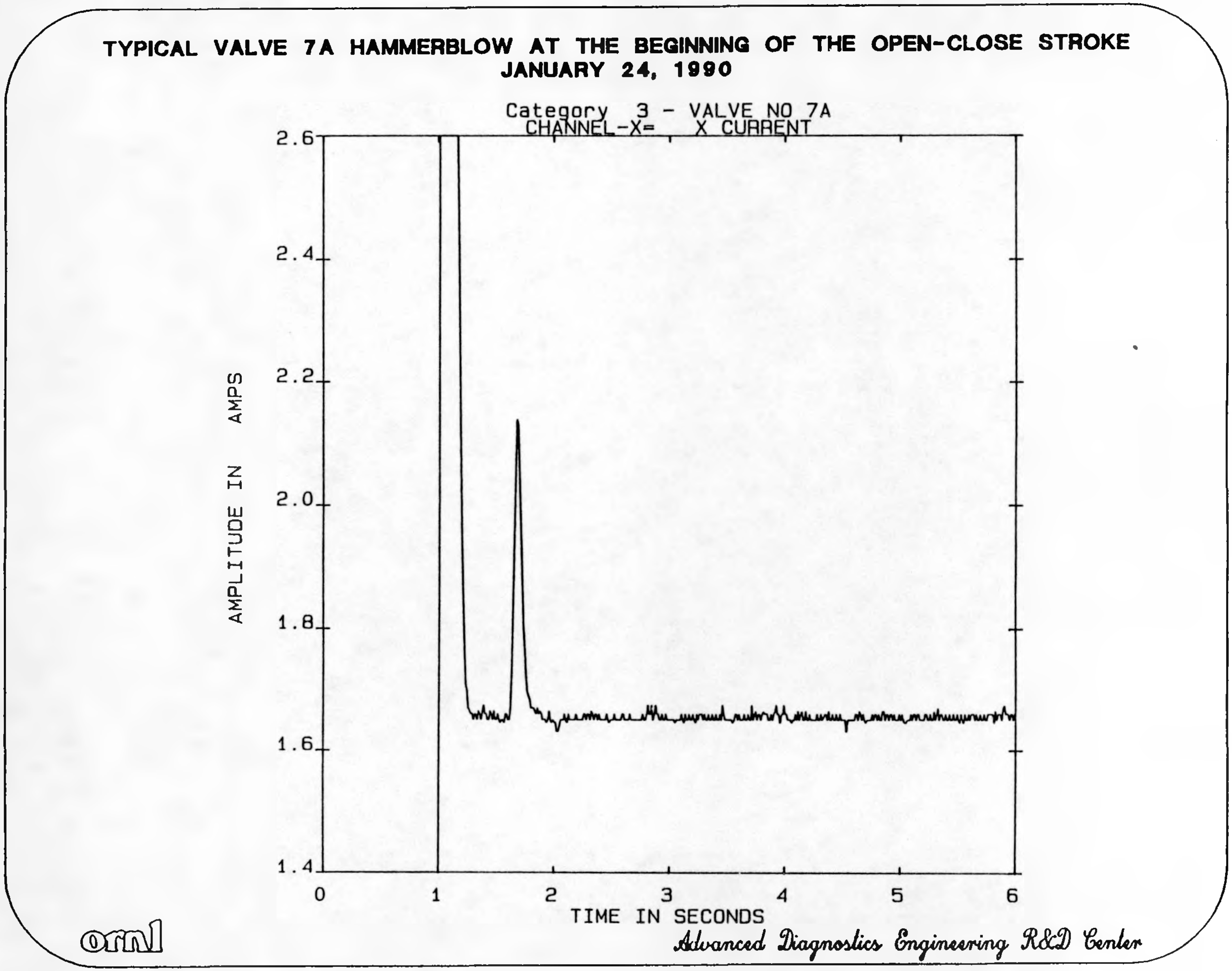
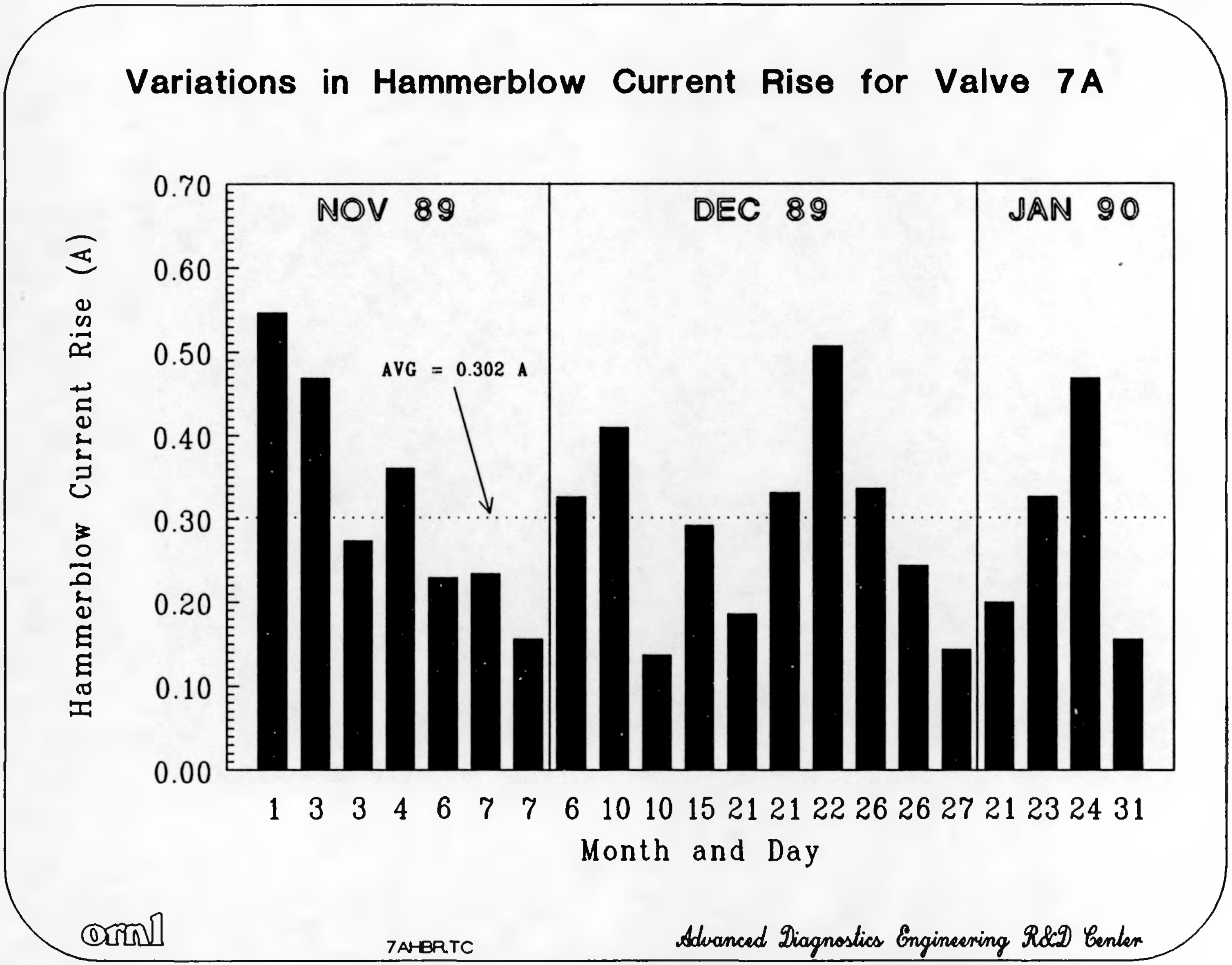

TYPICAL VALVE 7A HAMMERBLOW AT THE BEGINNING OF THE OPEN-CLOSE STROKE
JANUARY 24, 1990
Category 3 - VALVE NO 7A
CHANNEL-X= X CURRENT
2.6
2.4
2.2
2.0
1.8
1.6
1.4
AMPLITUDE IN AMPS
0
1
2
3
4
5
6
TIME IN SECONDS
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 68



Variations in Hammerblow Current Rise for Valve 7A
Hammerblow Current Rise (A)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NOV 89
DEC 89
JAN 90
AVG = 0.302 A
1 3 3 4 6 7 7 6 10 10 15 21 21 22 26 26 27 21 23 24 31
Month and Day
ornl
7AHBR.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 69

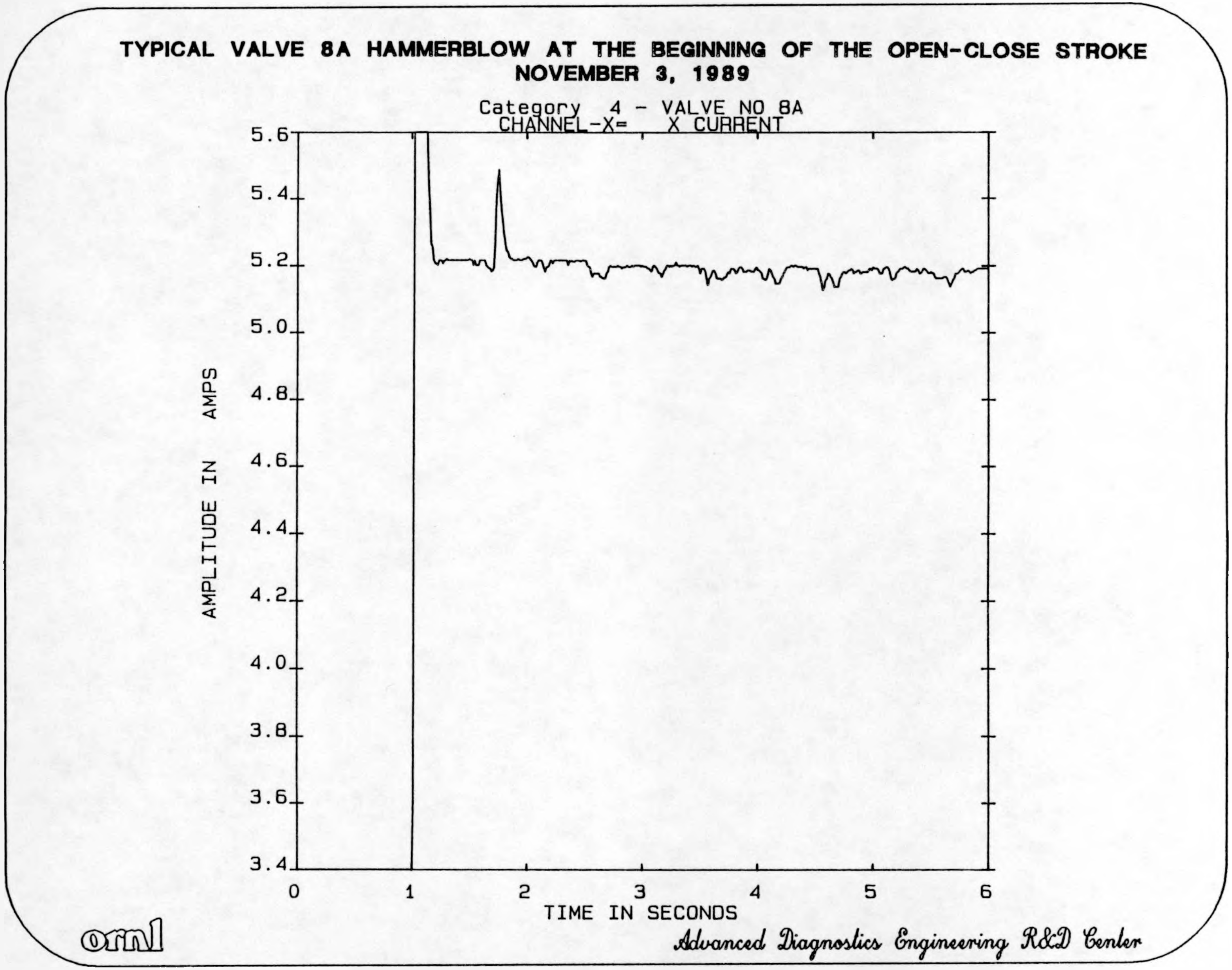
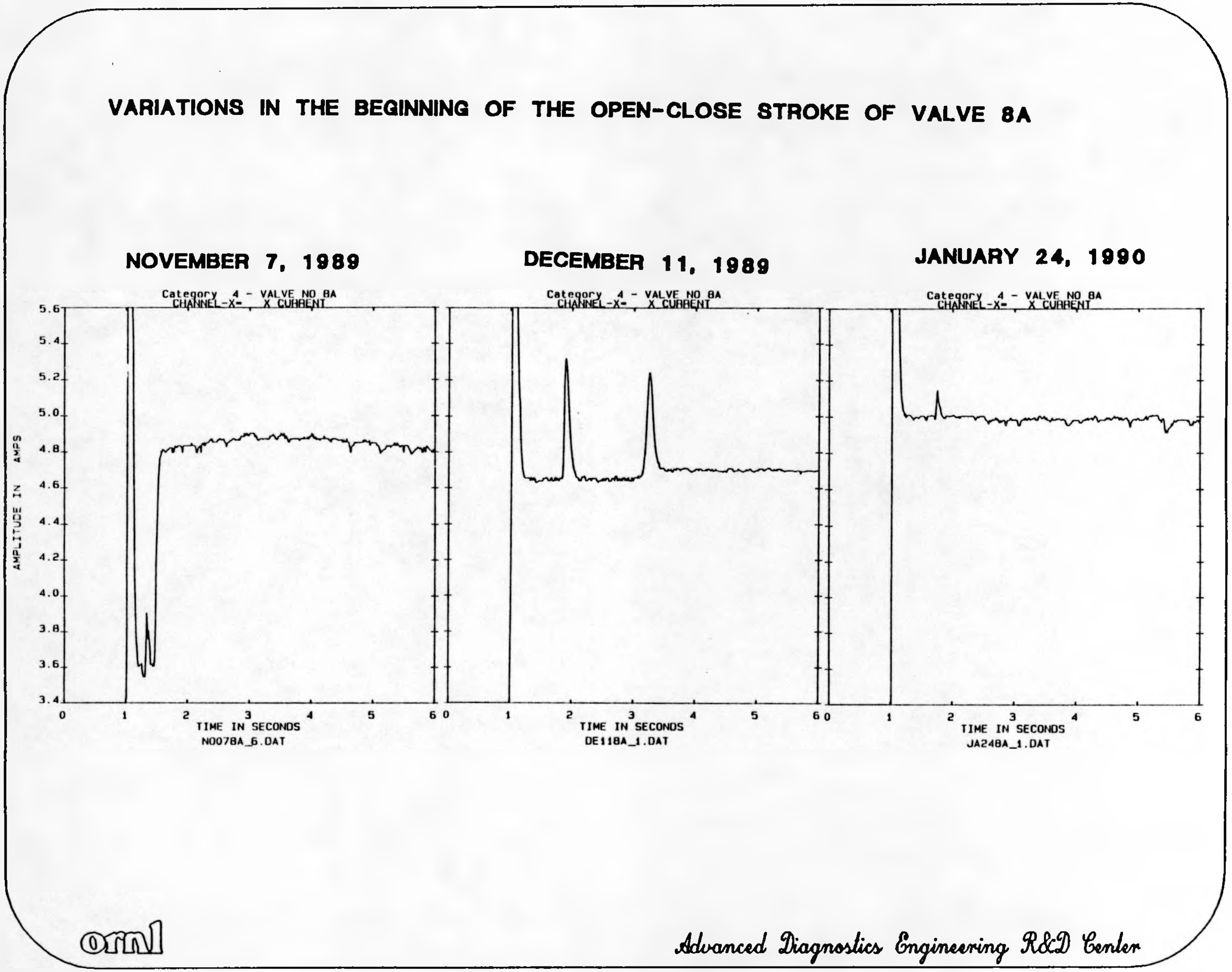

TYPICAL VALVE 8A HAMMERBLOW AT THE BEGINNING OF THE OPEN-CLOSE STROKE
NOVEMBER 3, 1989
Category 4 - VALVE NO 8A
CHANNEL-X= X CURRENT
AMPLITUDE IN AMPS
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
0
1
2
3
4
5
6
TIME IN SECONDS
ornl
Advanced Diagnostics Engineering R&D Center

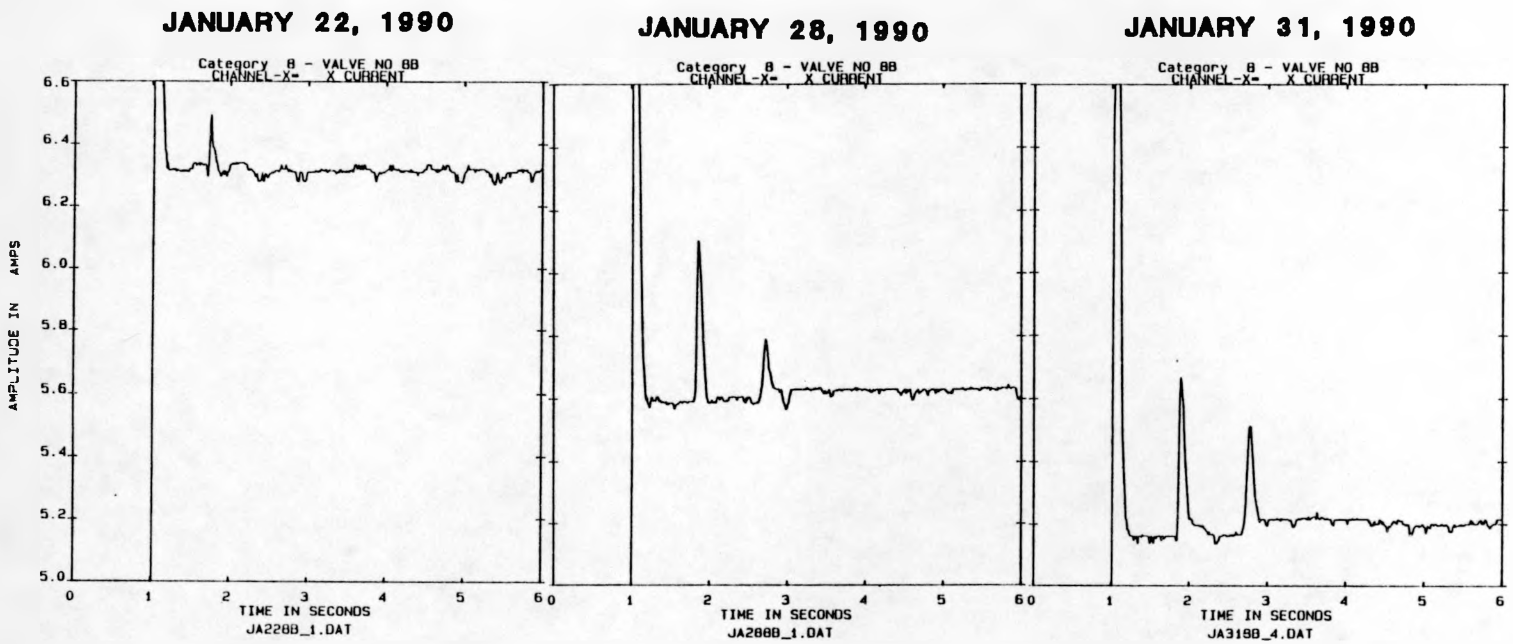
FIGURE 70



VARIATIONS IN THE BEGINNING OF THE OPEN-CLOSE STROKE OF VALVE 8A
NOVEMBER 7, 1989
DECEMBER 11, 1989
JANUARY 24, 1990
Category 4 - VALVE NO 8A
CHANNEL-X= X CURRENT
AMPLITUDE IN AMPS
TIME IN SECONDS
N0078A_6.DAT
DE118A_1.DAT
JA248A_1.DAT
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 71

VARIATIONS IN THE BEGINNING OF THE OPEN-CLOSE STROKE OF VALVE 8B



ornl

Advanced Diagnostics Engineering R&D Center

FIGURE 72

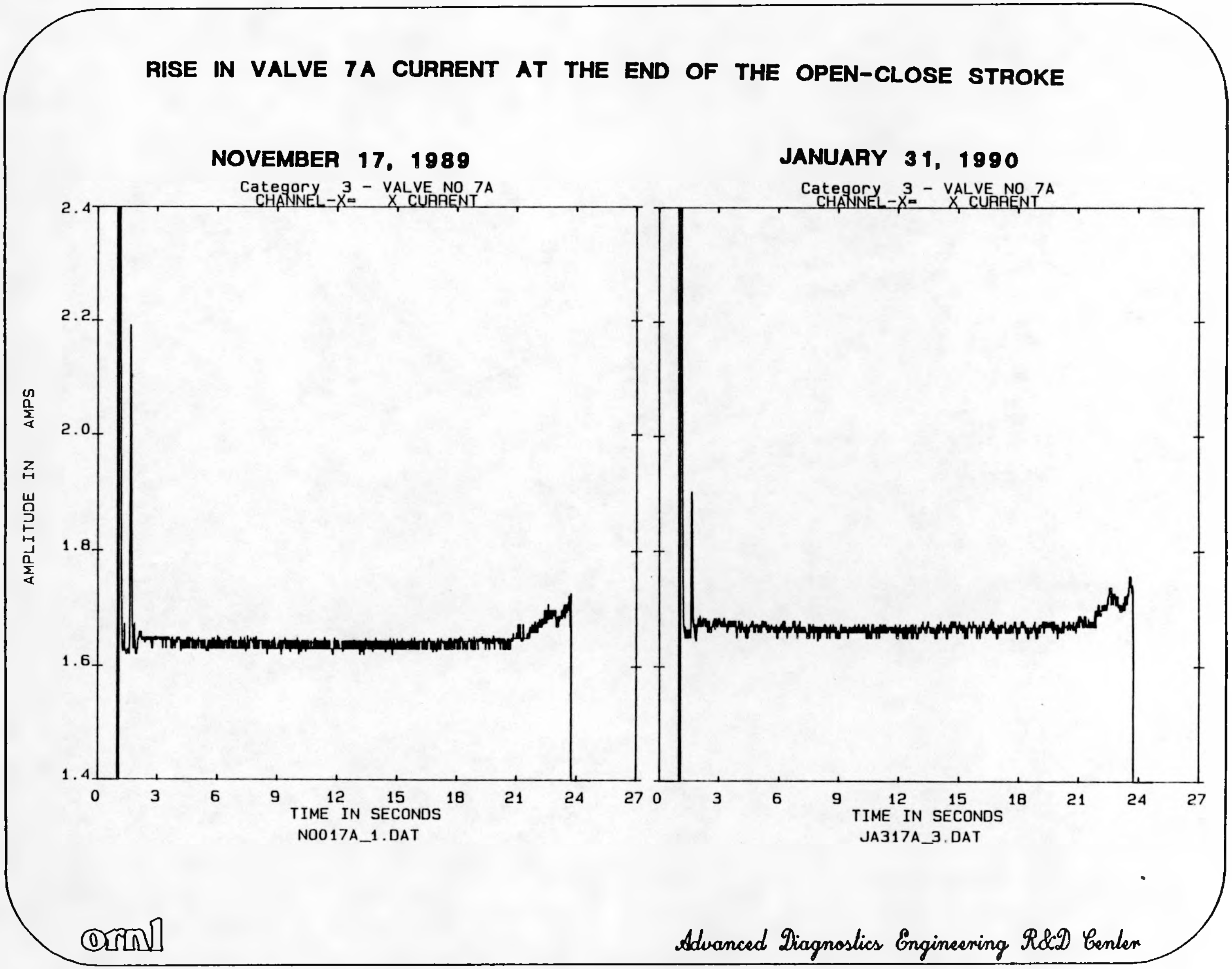
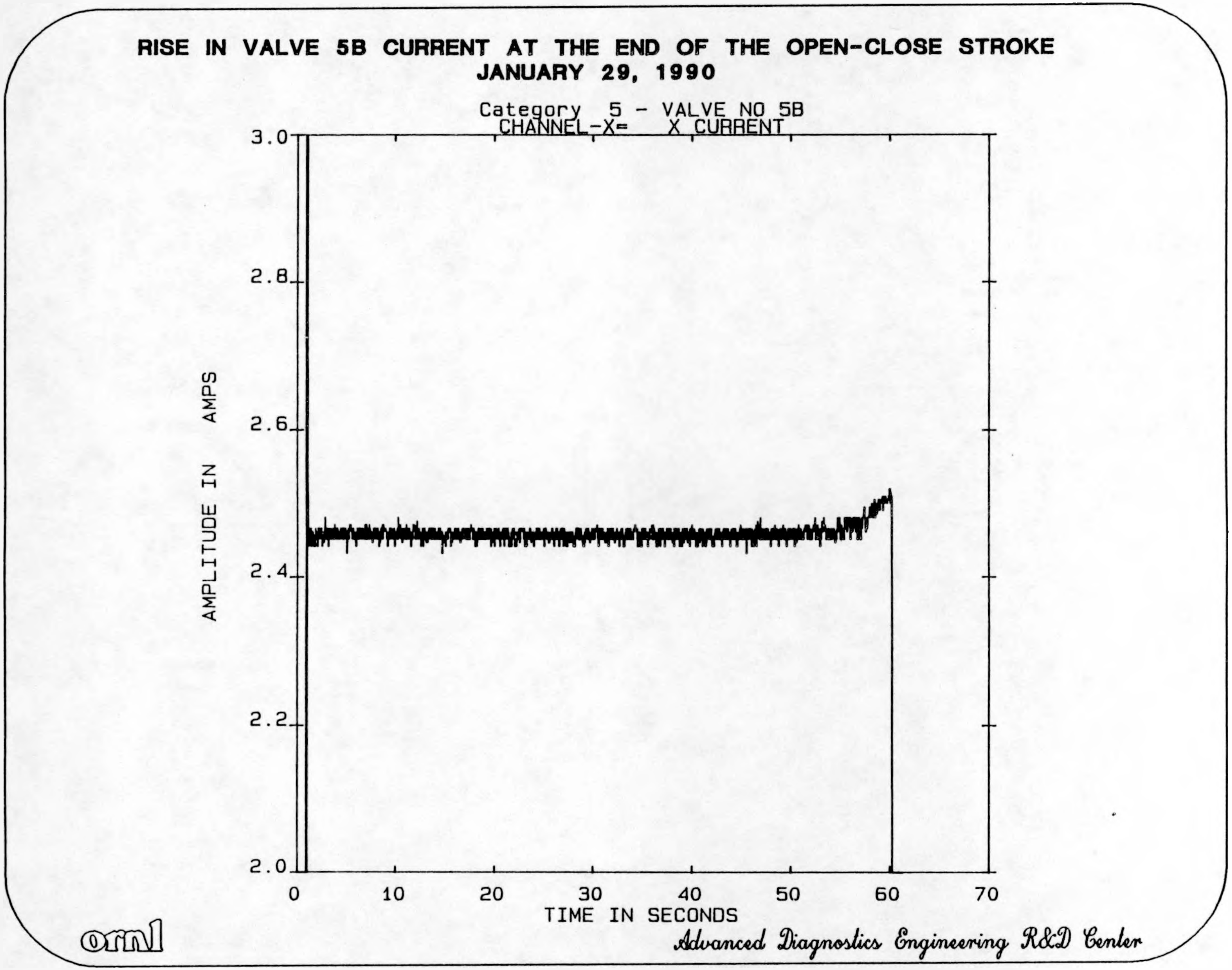
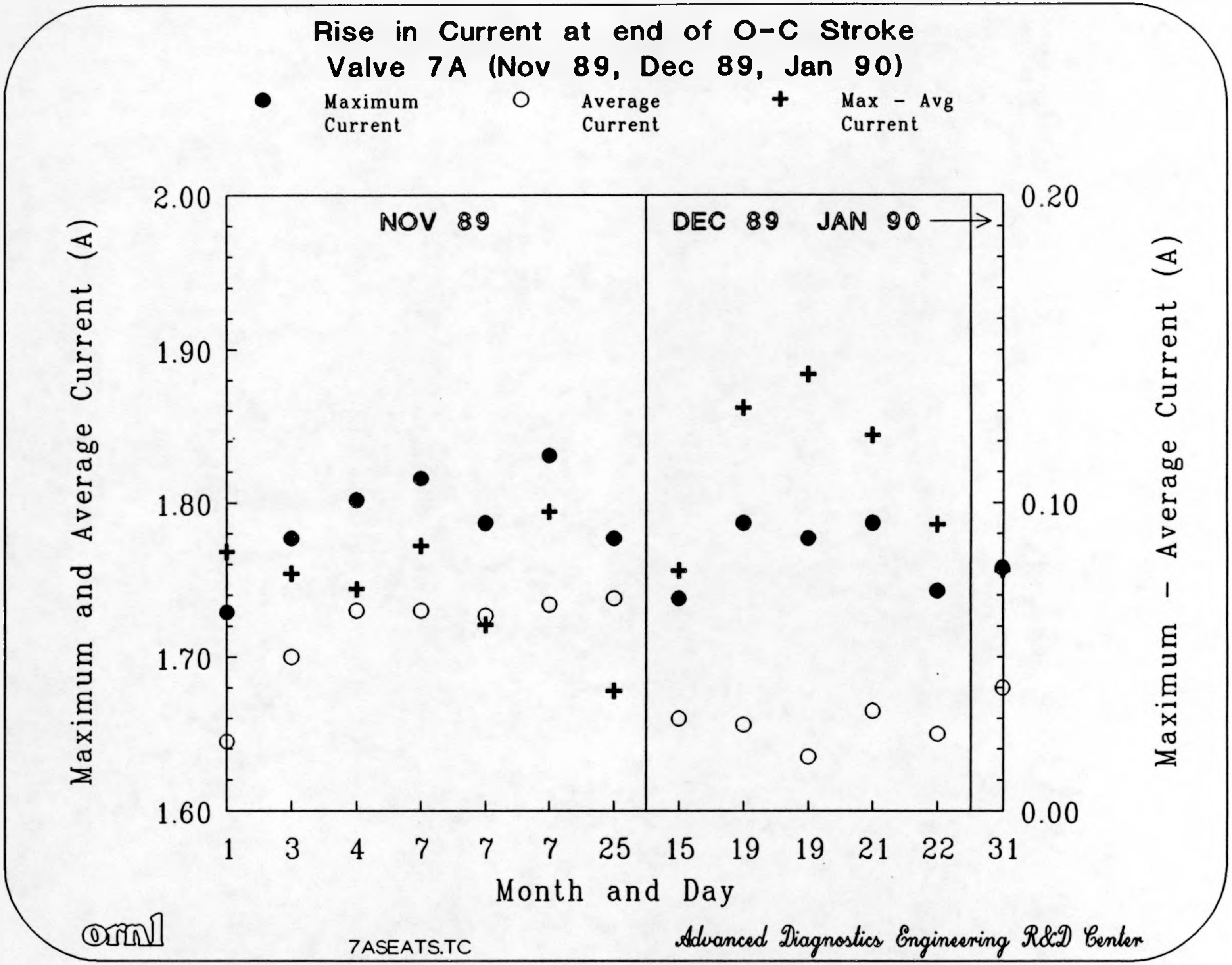

RISE IN VALVE 7A CURRENT AT THE END OF THE OPEN-CLOSE STROKE
NOVEMBER 17, 1989
Category 3 - VALVE NO 7A
CHANNEL-X= X CURRENT
AMPLITUDE IN AMPS
TIME IN SECONDS
NO017A_1.DAT
JANUARY 31, 1990
Category 3 - VALVE NO 7A
CHANNEL-X= X CURRENT
TIME IN SECONDS
JA317A_3.DAT
Advanced Diagnostics Engineering R&D Center

FIGURE 73



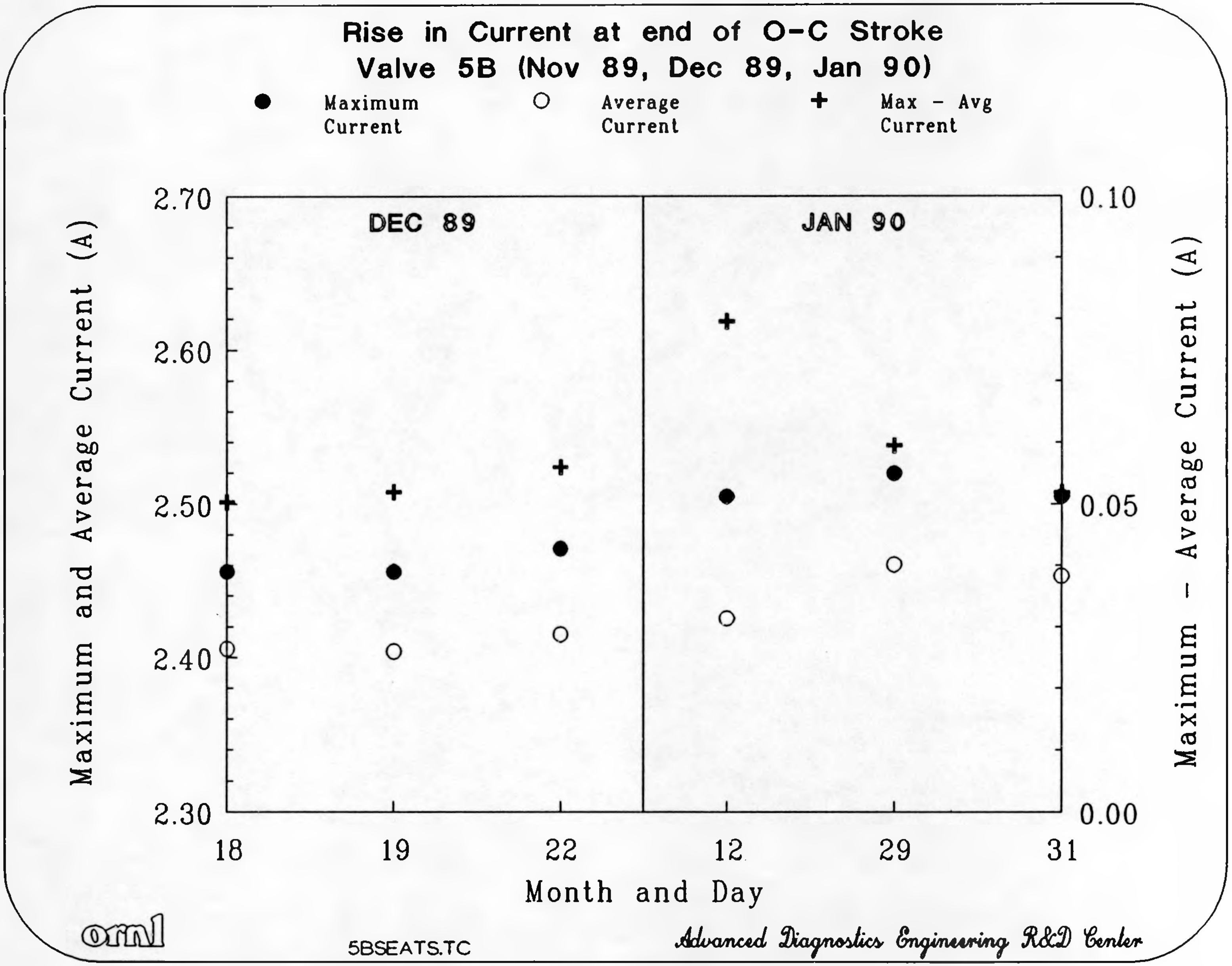
RISE IN VALVE 5B CURRENT AT THE END OF THE OPEN-CLOSE STROKE
JANUARY 29, 1990
Category 5 - VALVE NO 5B
CHANNEL-X= X CURRENT
3.0
2.8
2.6
2.4
2.2
2.0
AMPLITUDE IN AMPS
0
10
20
30
40
50
60
70
TIME IN SECONDS
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 74



Rise in Current at end of O-C Stroke
Valve 7A (Nov 89, Dec 89, Jan 90)
Maximum Current
Average Current
Max - Avg Current
Maximum and Average Current (A)
2.00
1.90
1.80
1.70
1.60
NOV 89
DEC 89
JAN 90
0.20
0.10
0.00
Maximum - Average Current (A)
1
3
4
7
7
7
25
15
19
19
21
22
31
Month and Day
ornl
7ASEATS.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 75



Rise in Current at end of O-C Stroke
Valve 5B (Nov 89, Dec 89, Jan 90)
Maximum Current
Average Current
Max - Avg Current
DEC 89
JAN 90
2.70
2.60
2.50
2.40
2.30
0.10
0.05
0.00
18
19
22
12
29
31
Maximum and Average Current (A)
Maximum - Average Current (A)
Month and Day
ornl
5BSEATS.TC
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FIGURE 76

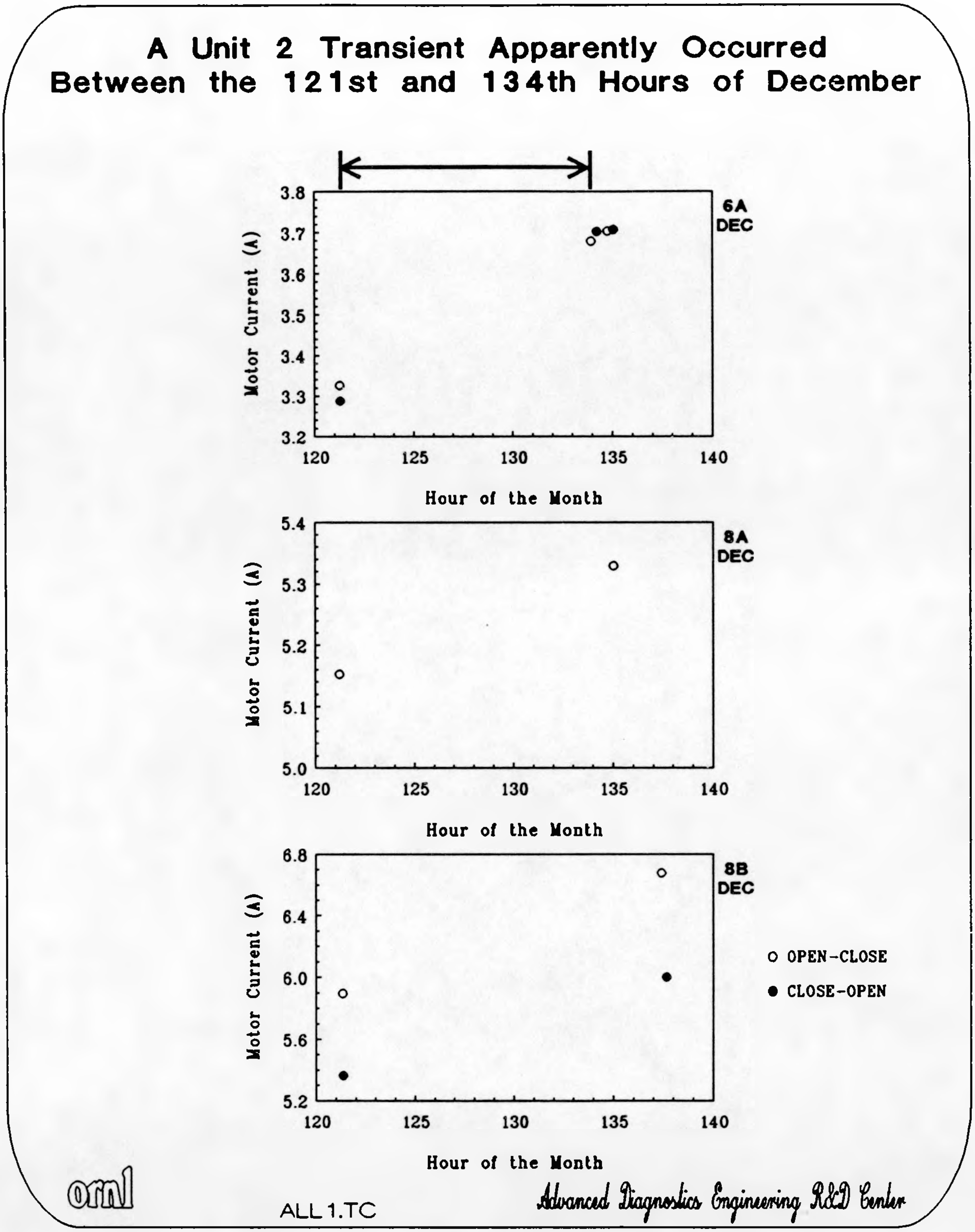
A Unit 2 Transient Apparently Occurred
Between the 121st and 134th Hours of December
Motor Current (A)
Hour of the Month
6A
DEC
8A
DEC
8B
DEC
OPEN-CLOSE
CLOSE-OPEN
ornl
ALL 1.TC
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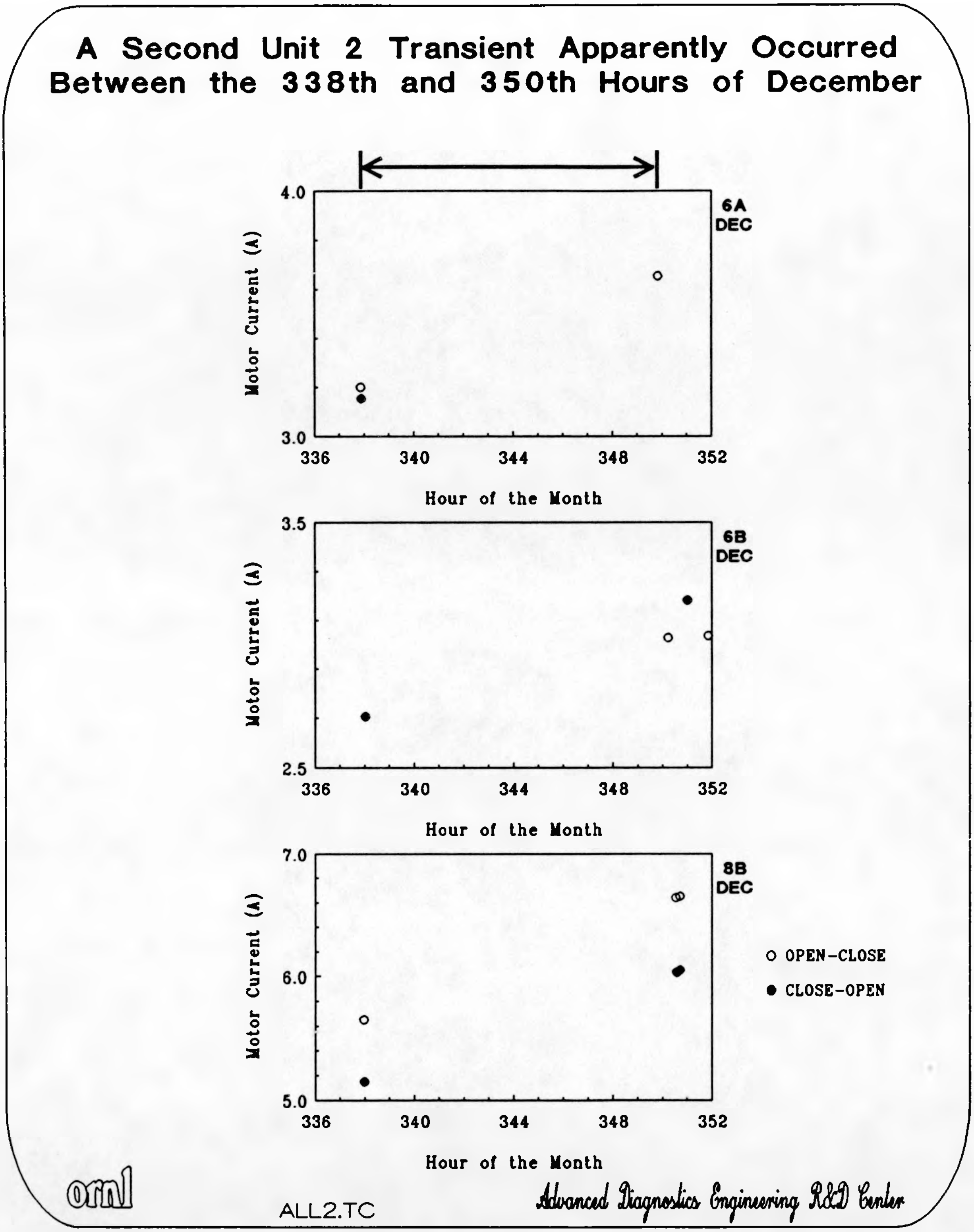
FIGURE 77



A Second Unit 2 Transient Apparently Occurred Between the 338th and 350th Hours of December
4.0
3.0
Motor Current (A)
6A DEC
336
340
344
348
352
Hour of the Month
3.5
2.5
Motor Current (A)
6B DEC
336
340
344
348
352
Hour of the Month
7.0
6.0
5.0
Motor Current (A)
8B DEC
OPEN-CLOSE
CLOSE-OPEN
336
340
344
348
352
Hour of the Month
ornl
ALL2.TC
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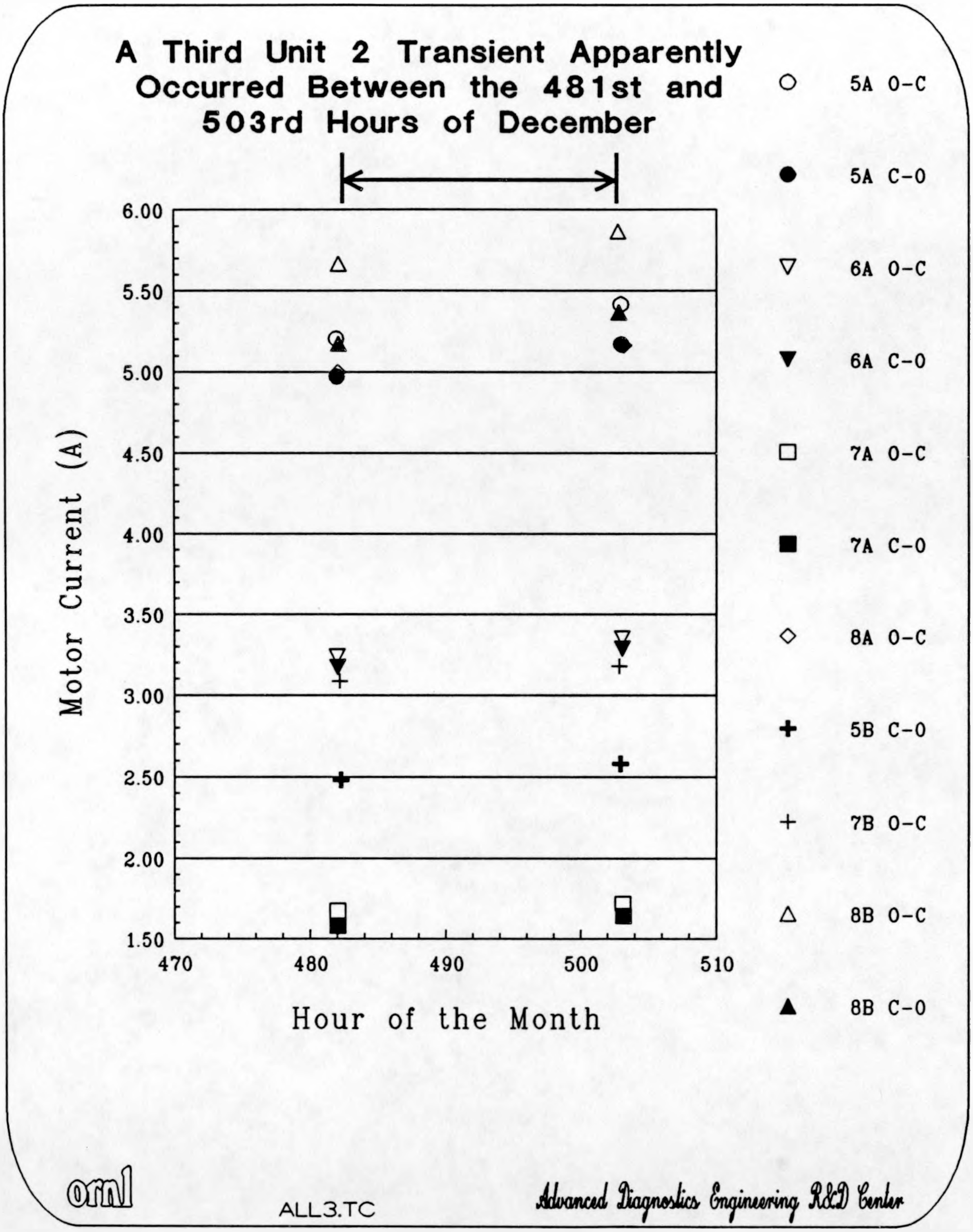
FIGURE 78



A Third Unit 2 Transient Apparently Occurred Between the 481st and 503rd Hours of December
Motor Current (A)
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
470
480
490
500
510
Hour of the Month
5A O-C
5A C-O
6A O-C
6A C-O
7A O-C
7A C-O
8A O-C
5B C-O
7B O-C
8B O-C
8B C-O
ornl
ALL3.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 79

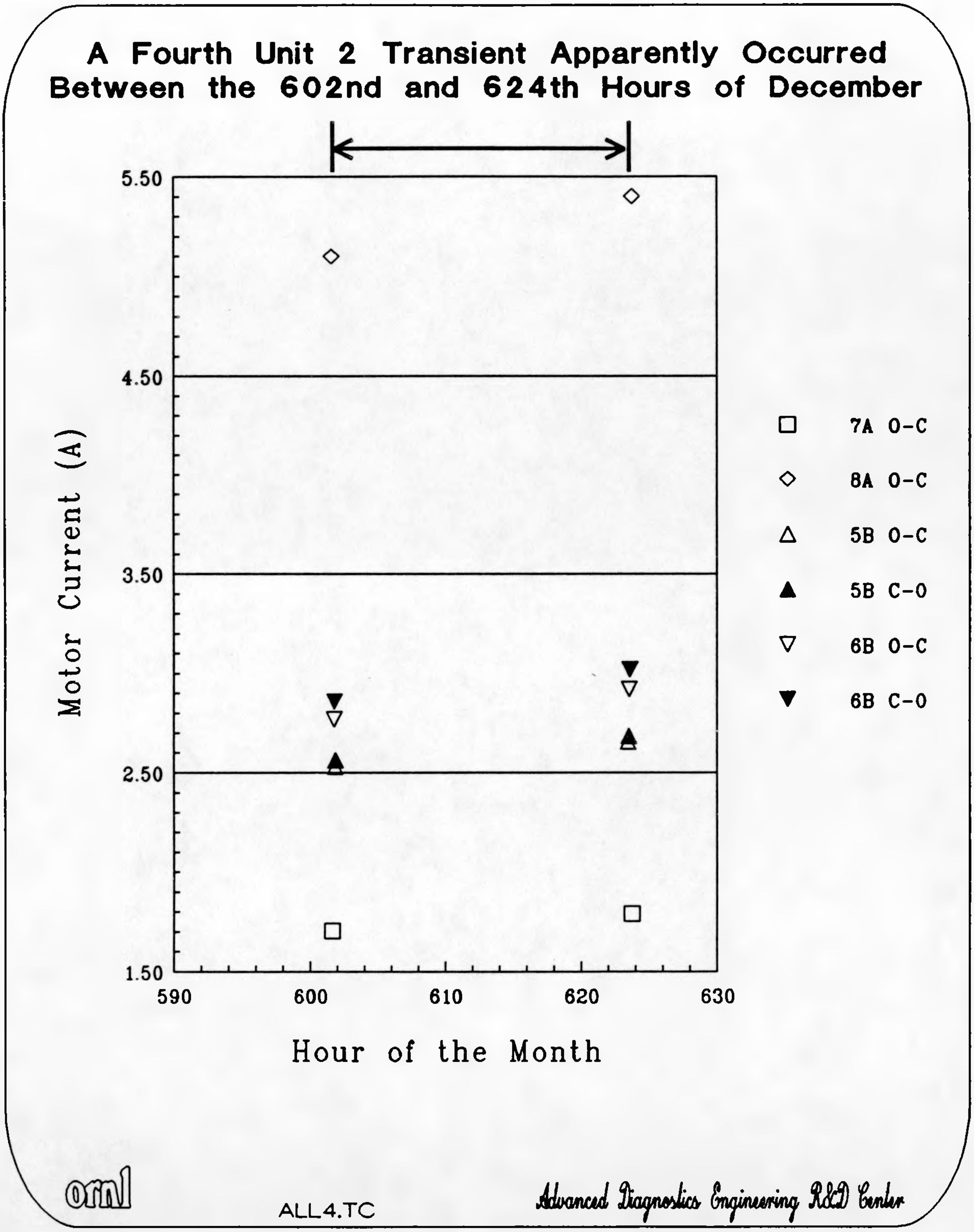
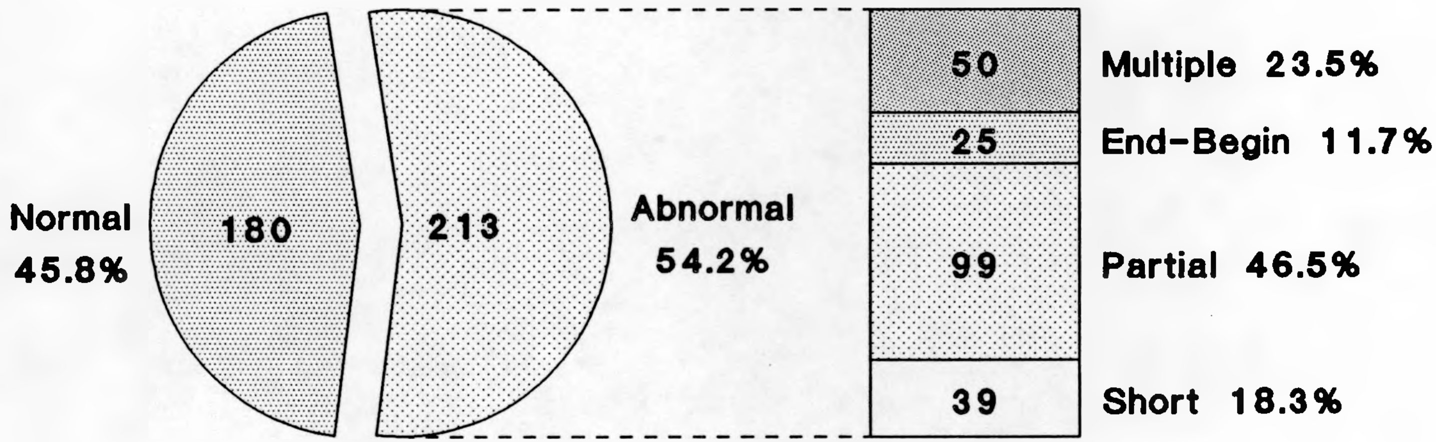

A Fourth Unit 2 Transient Apparently Occurred Between the 602nd and 624th Hours of December
5.50
4.50
3.50
2.50
1.50
Motor Current (A)
590
600
610
620
630
Hour of the Month
7A O-C
8A O-C
5B O-C
5B C-O
6B O-C
6B C-O
ornl
ALL4.TC
Advanced Diagnostics Engineering R&D Center

FIGURE 80

Breakdown of Abnormal Runs Acquired in December

Most abnormal runs occurred as a result of starting another valve stroke too soon after one had ended or actuating more than one valve at a time



Multiple : Occurs when more than one valve is running at the same time

End-Begin : End of one stroke followed by the beginning of another stroke – Results from starting another valve stroke too soon after one had ended

Partial : End of one stroke (partial run) – Results from starting another valve stroke too soon after one had ended

Short : Short run that occurs when a valve actuation is terminated manually (before motor operator switch trip)

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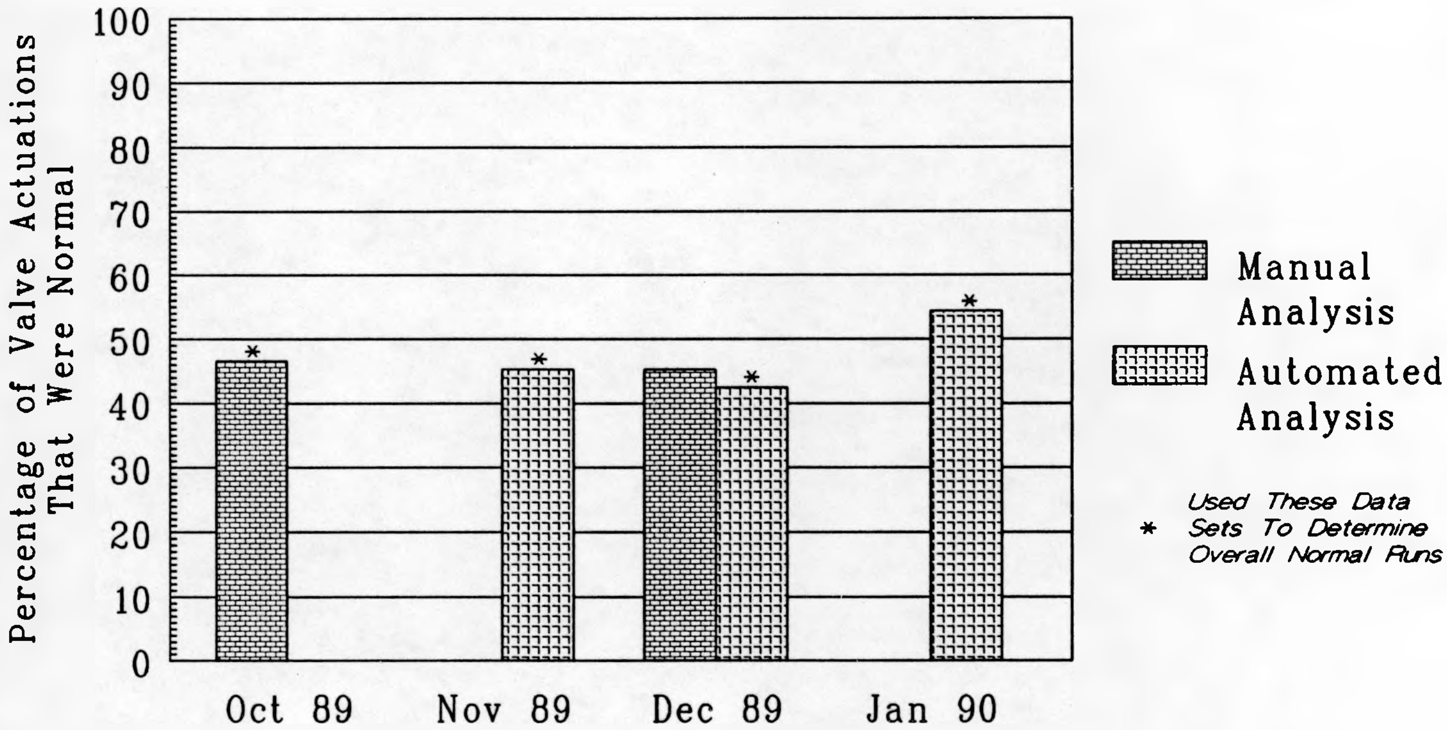
FIGURE 81

Over the Last 4 Months, The Majority of Valve Actuations Have Been Abnormal

1222 Total Valve Strokes   569 Normal (46.6 %)   653 Abnormal (53.4 %)*

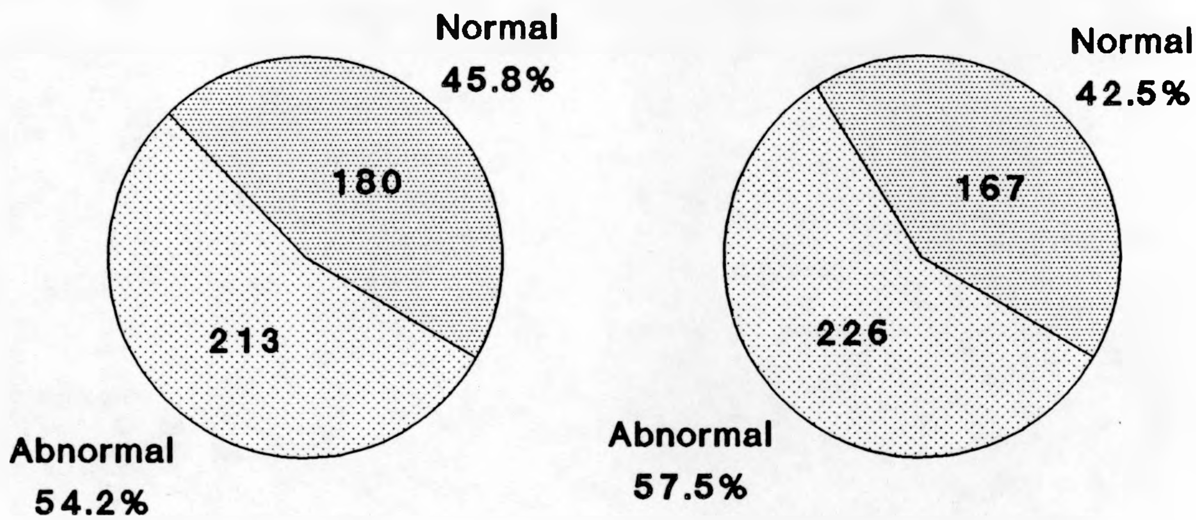


ornl   NTREND.TC   Advanced Diagnostics Engineering R&D Center

FIGURE 82

Fraction of Normal and Abnormal Runs During December, 1989 as determined by Manual and Automated Data Analysis Methods

(Total Runs = 393)



Manual Analysis | Using "RESOLVE"

MVRDEC.TC

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FIGURE 83

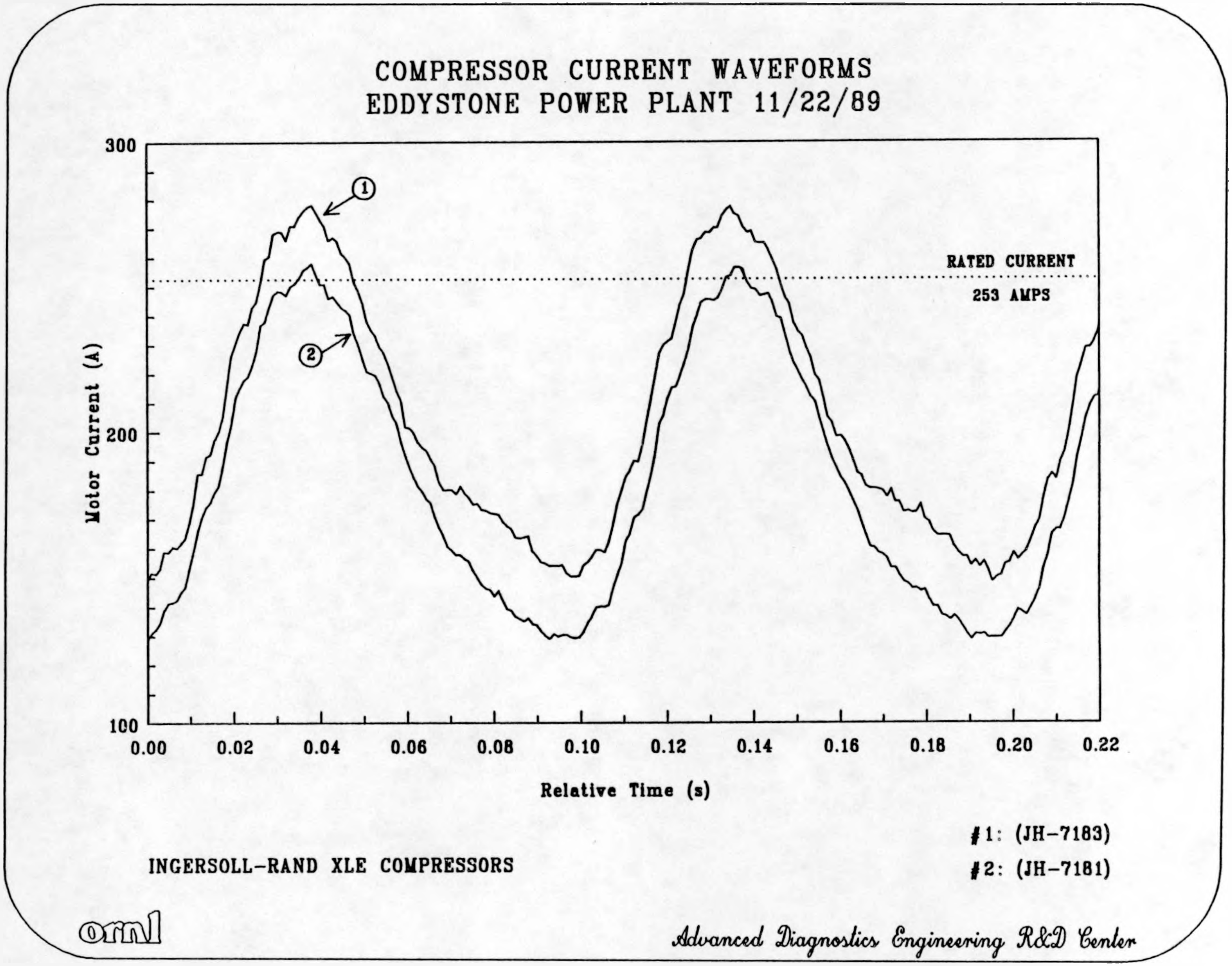
COMPRESSOR CURRENT WAVEFORMS
EDDYSTONE POWER PLANT 11/22/89
300
200
100
Motor Current (A)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
Relative Time (s)
1
2
RATED CURRENT
253 AMPS
#1: (JH-7183)
#2: (JH-7181)
INGERSOLL-RAND XLE COMPRESSORS
ornl
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FIGURE 84

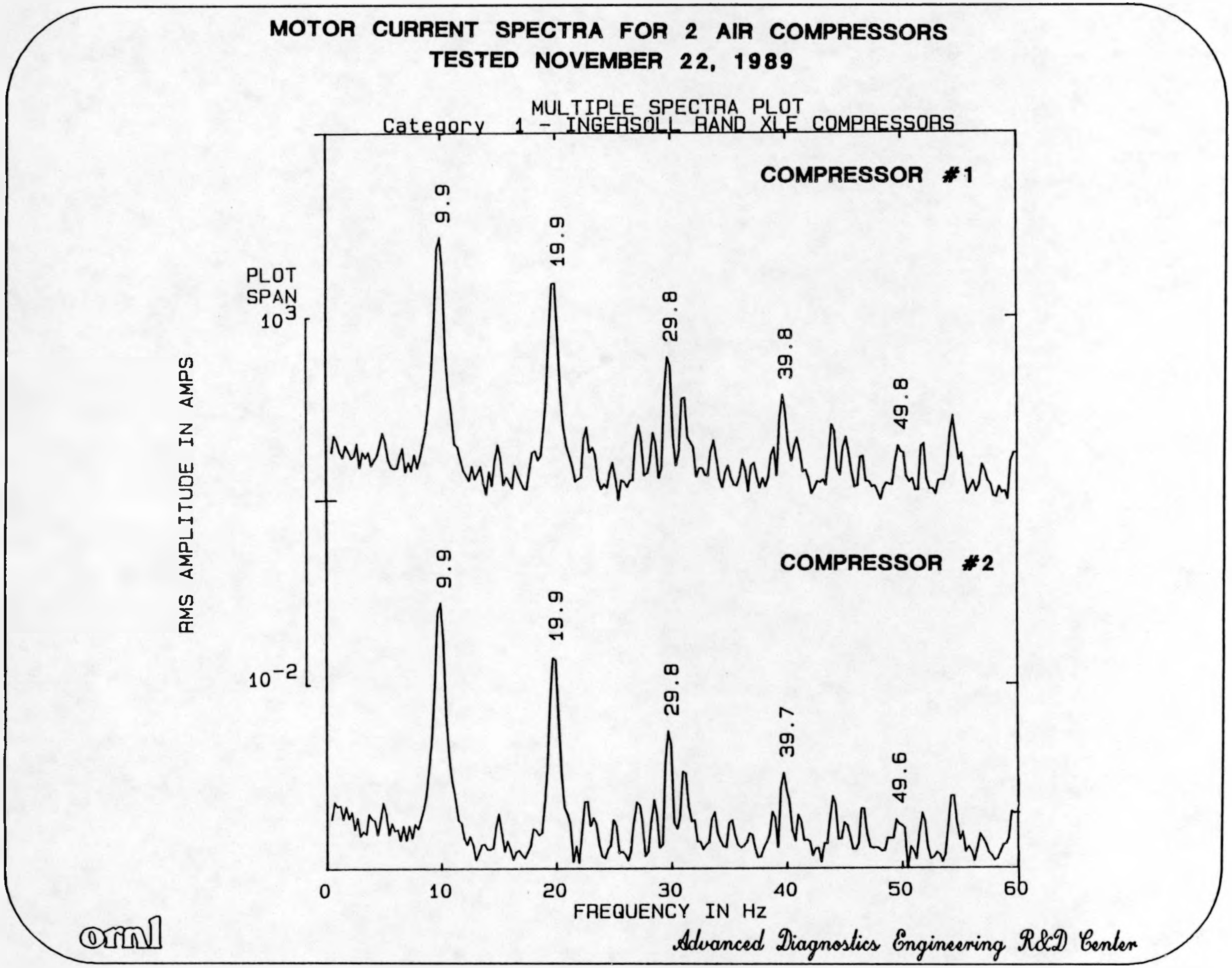
MOTOR CURRENT SPECTRA FOR 2 AIR COMPRESSORS
TESTED NOVEMBER 22, 1989
MULTIPLE SPECTRA PLOT
Category 1 - INGERSOLL RAND XLE COMPRESSORS
COMPRESSOR #1
9.9
19.9
29.8
39.8
49.8
PLOT
SPAN
10^3
10^{-2}
RMS AMPLITUDE IN AMPS
COMPRESSOR #2
9.9
19.9
29.8
39.7
49.6
0
10
20
30
40
50
60
FREQUENCY IN Hz
ornl
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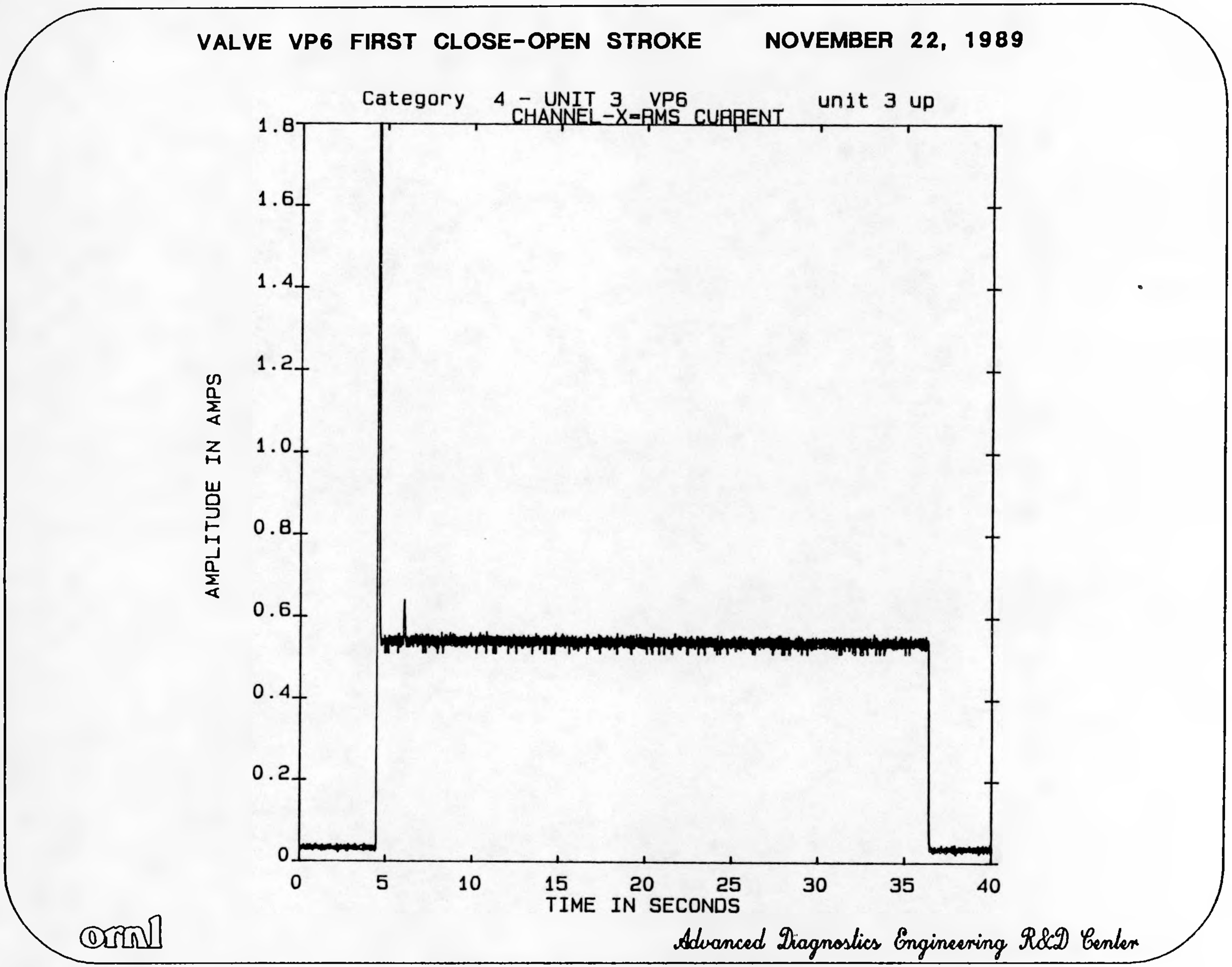
FIGURE 85



VALVE VP6 FIRST CLOSE-OPEN STROKE NOVEMBER 22, 1989
Category 4 - UNIT 3 VP6 unit 3 up
CHANNEL-X=RMS CURRENT
AMPLITUDE IN AMPS
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0 5 10 15 20 25 30 35 40
TIME IN SECONDS
ornl
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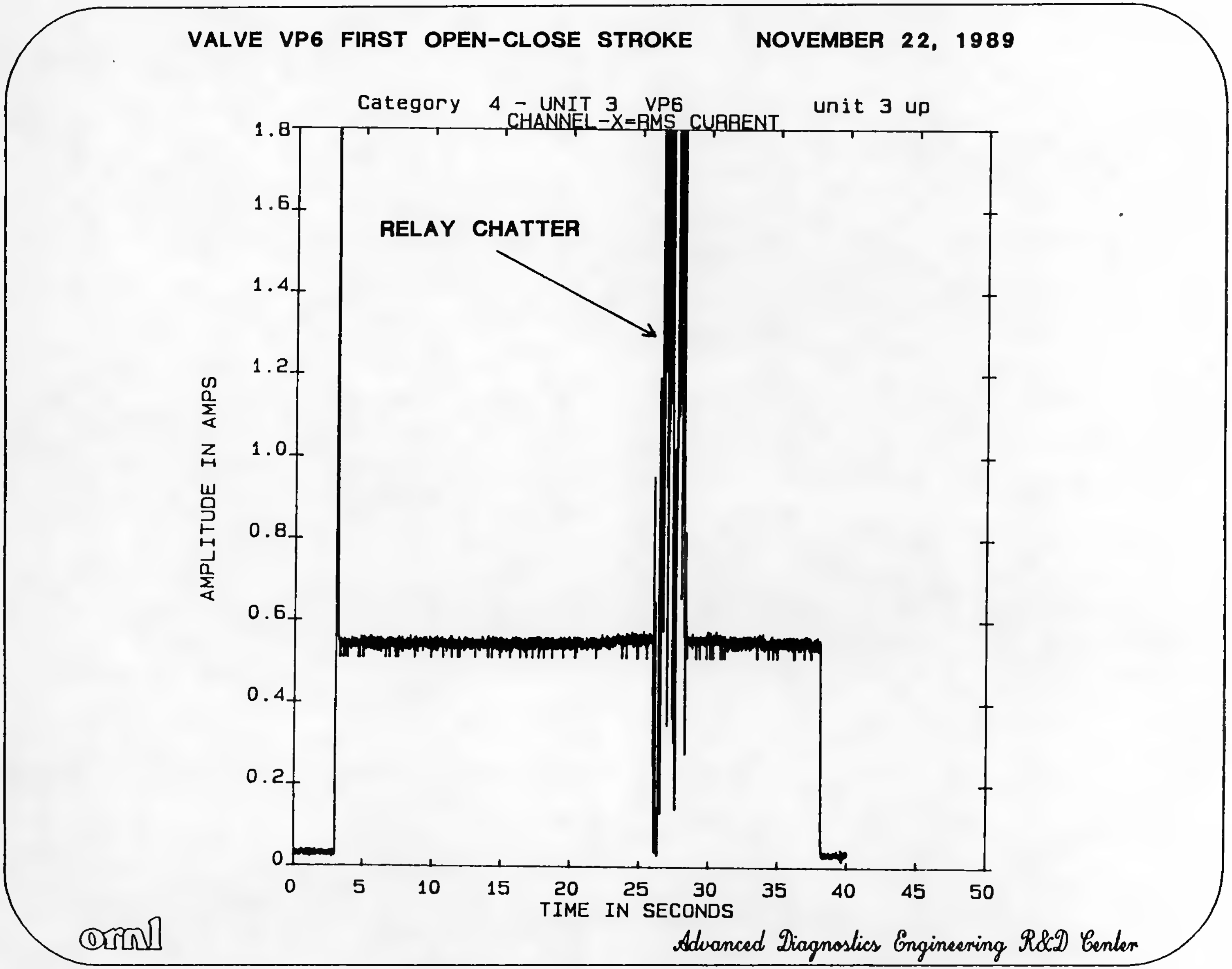
FIGURE 86



VALVE VP6 FIRST OPEN-CLOSE STROKE NOVEMBER 22, 1989
Category 4 - UNIT 3 VP6
unit 3 up
CHANNEL-X=RMS CURRENT
RELAY CHATTER
AMPLITUDE IN AMPS
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0 5 10 15 20 25 30 35 40 45 50
TIME IN SECONDS
ornl
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FIGURE 87

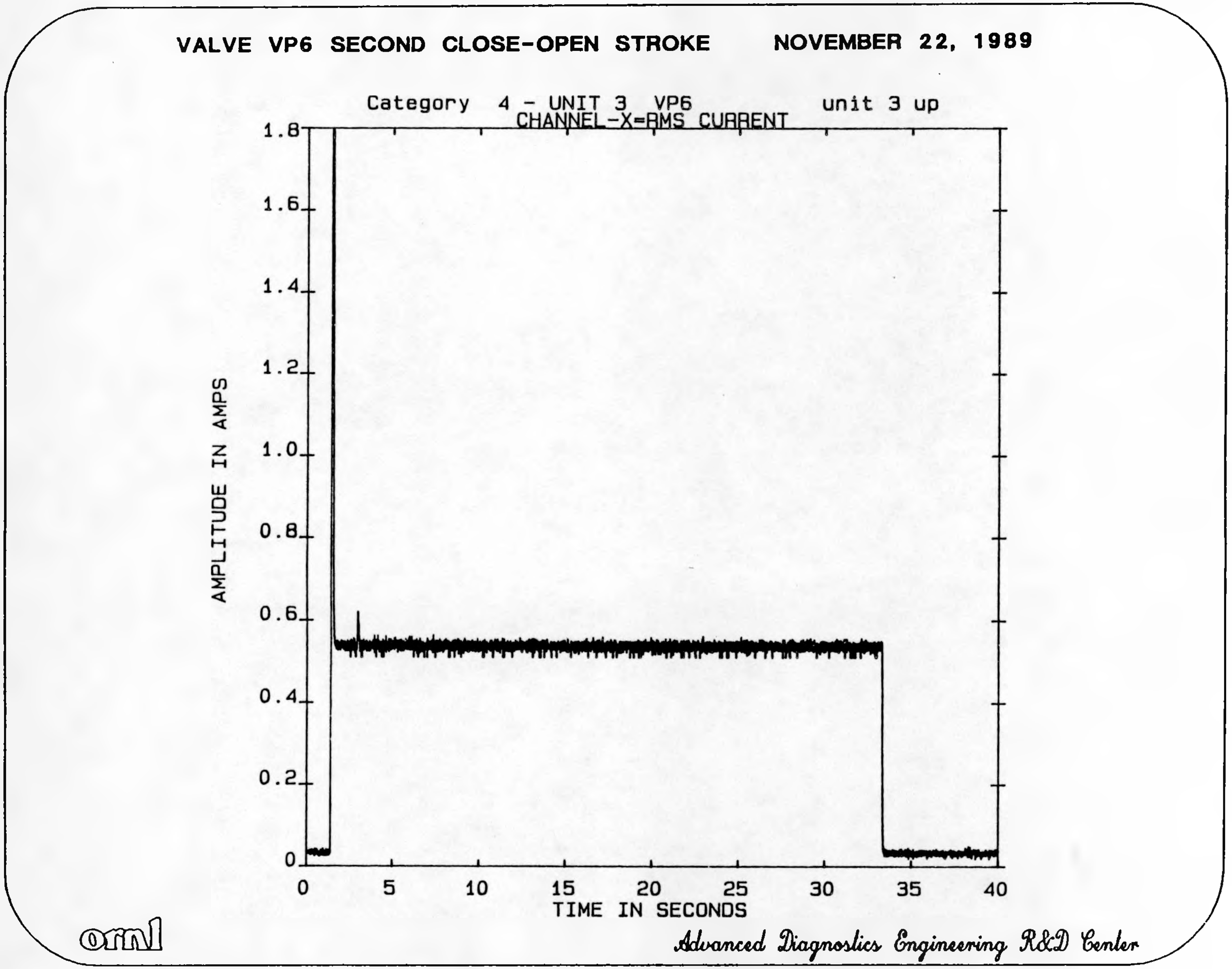
VALVE VP6 SECOND CLOSE-OPEN STROKE NOVEMBER 22, 1989
Category 4 - UNIT 3 VP6 unit 3 up
CHANNEL-X=RMS CURRENT
AMPLITUDE IN AMPS
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
TIME IN SECONDS
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 88

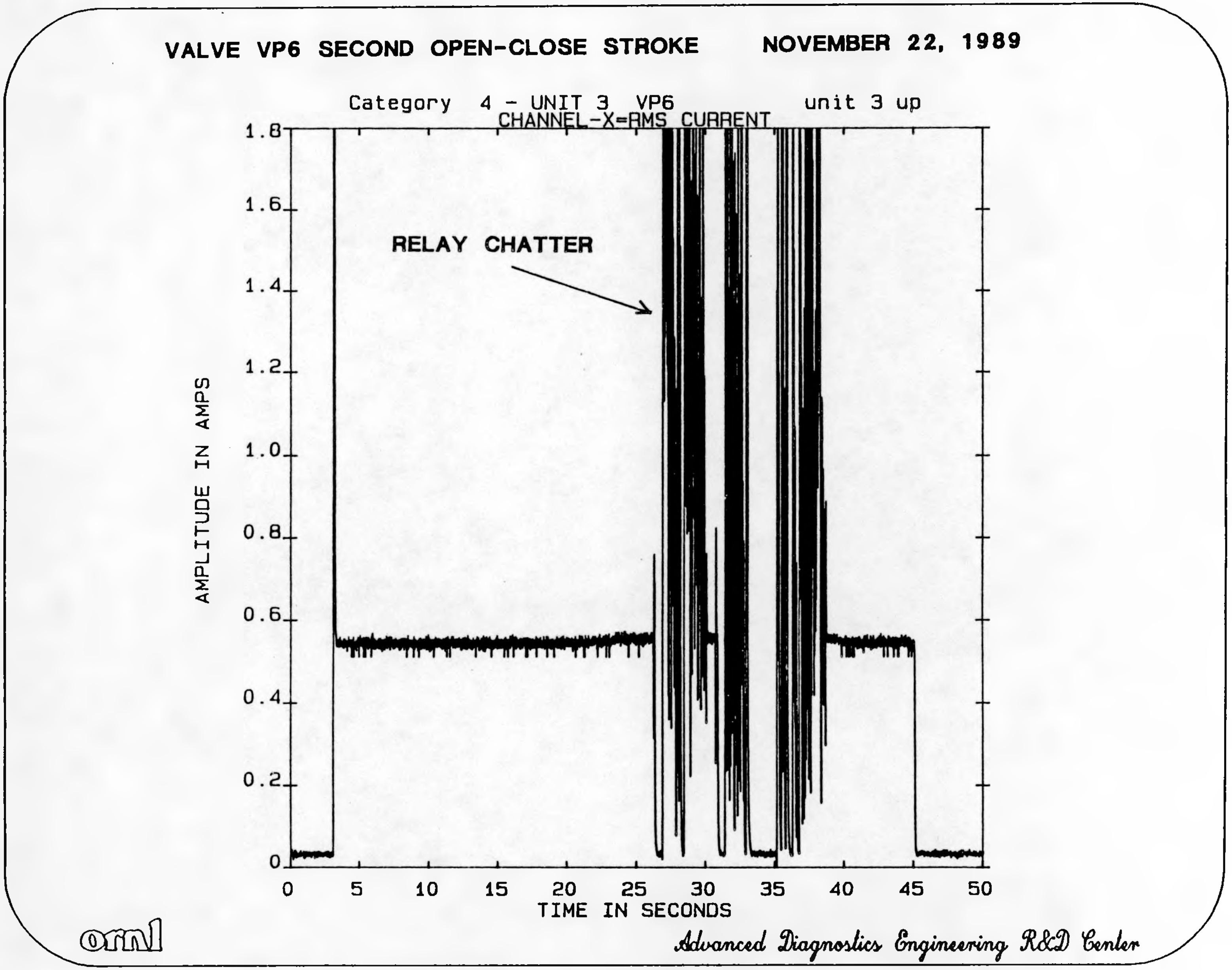
VALVE VP6 SECOND OPEN-CLOSE STROKE NOVEMBER 22, 1989
Category 4 - UNIT 3 VP6 unit 3 up
CHANNEL-X=RMS CURRENT
RELAY CHATTER
AMPLITUDE IN AMPS
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0 5 10 15 20 25 30 35 40 45 50
TIME IN SECONDS
ornl
Advanced Diagnostics Engineering R&D Center

FIGURE 89

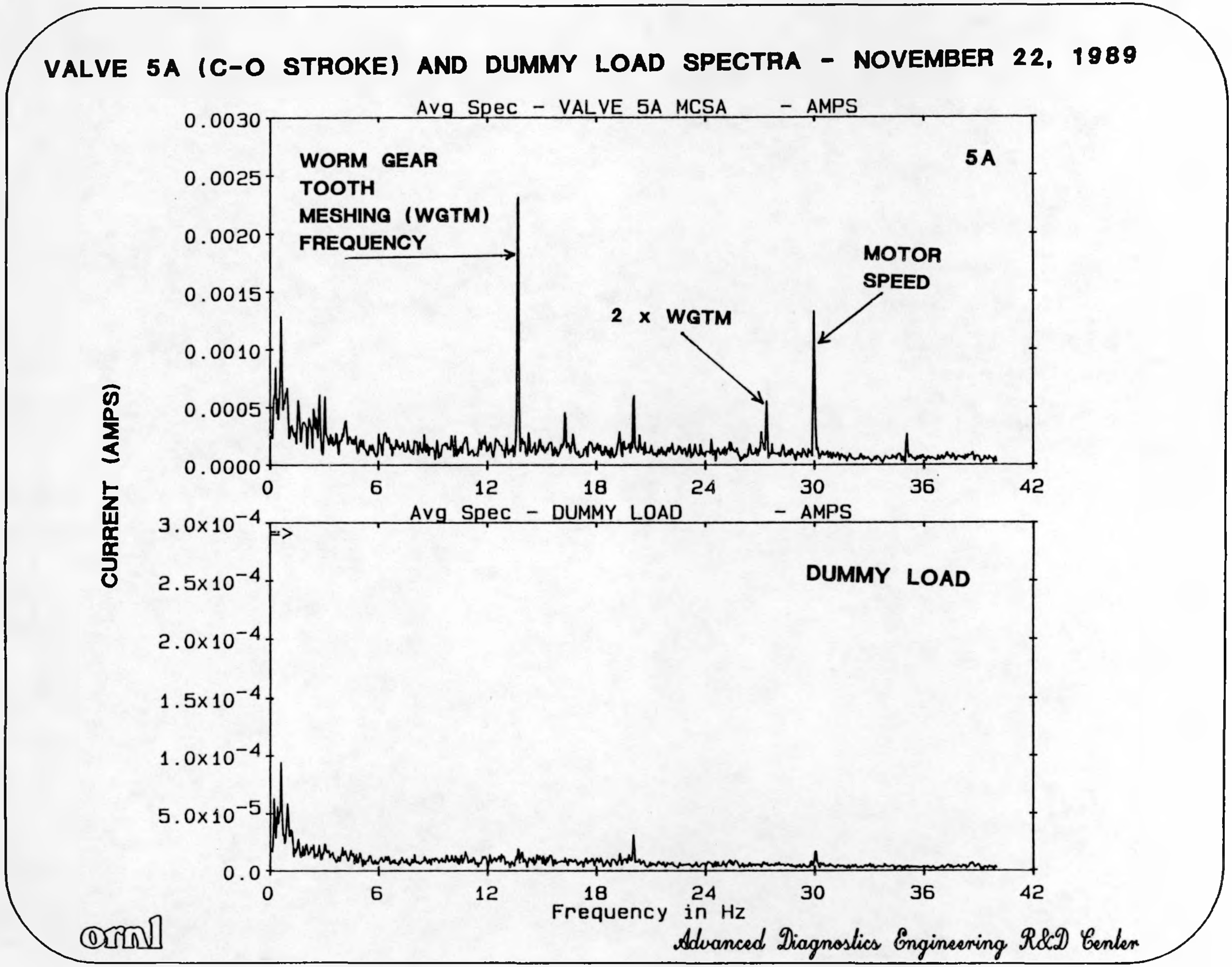
VALVE 5A (C-O STROKE) AND DUMMY LOAD SPECTRA - NOVEMBER 22, 1989
Avg Spec - VALVE 5A MCSA - AMPS
WORM GEAR
TOOTH
MESHING (WGTM)
FREQUENCY
5A
MOTOR
SPEED
2 x WGTM
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0
6
12
18
24
30
36
42
Avg Spec - DUMMY LOAD - AMPS
DUMMY LOAD
CURRENT (AMPS)
$3.0x10^{-4}$
$2.5x10^{-4}$
$2.0x10^{-4}$
$1.5x10^{-4}$
$1.0x10^{-4}$
$5.0x10^{-5}$
0.0
Frequency in Hz
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FIGURE 90