DRAFT

30

The APS X-ray Undulator Photon Beam Position Monitor and Tests at CHESS and NSLS

D.Shu, B.Rodricks, J.Barraza, T.Sanchez, and T.M.Kuzay

Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439, U.S.A.

Abstract

The advent of third generation synchrotron radiation sources, like the Advanced Photon Source (APS), will provide significant increases in brilliance over existing synchrotron sources. The APS x-ray undulators will increase the brilliance in the 3-40 KeV range by several orders of magnitude. Thus, the design of the photon beam position monitor is a challenging engineering task. The beam position monitors must withstand the high thermal load, be able to achieve sub-micron spatial resolution while maintaining their stability, and be compatible with both undulators and wigglers.

A preliminary APS prototype photon beam position monitor consisting of a CVD-diamond-based, tungsten-coated blade was tested on the APS/CHESS undulator at the Cornell High Energy Synchrotron Radiation Source (CHESS) and on the NSLS X-13 undulator beamline. Results from these tests, as well as the design of this prototype APS photon beam position monitor, will be discussed in this paper.

1. Introduction

Currently underway at Argonne National Laboratory is the design and construction of the 7-GeV Advanced Photon Source (APS) that will generate high brilliance and intense synchrotron radiation from its insertion devices (IDs), which include a variety of wigglers and undulators.

One of the many challenging tasks in the engineering of the APS insertion device beamlines is the design of the photon beam position monitor (PBPM) for the front end. The APS beamline front-end design [1] specifies the installation of two PBPMs that will be installed on each front end to measure position and slope of the photon beam emanating from an insertion device. In addition, the PBPMs on the front end will provide feedback information to the storage ring for the particle beam correction [2]. Of the many different types of PBPMs, the type that uses photo-electron emission and is UHV compatible is the most suitable.

Since 1985, various photo-electron-emission-type PBPMs with tungsten blades have been designed and tested by Mortazavi and others [3] on the soft x-ray undulator beamlines (such as X-17T and X-1) of the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. In 1988, a new compact NSLS PBPM design, which improved the monitor performances significantly, was reported by Johnson and Oversluizen [4]. To address the PBPM problems related to undulators designed with large deflection parameter, K, changeability for the Advanced Light Source at Berkeley, California, a new PBPM was developed and tested on the NSLS X-13 undulator beamline in 1990 by Warwick and Shu [5]. The APS PBPM design benefited from these earlier developments. However, none of these earlier designs is able to satisfy the requirements of a PBPM for the APS because of the extremely high power density of the x-ray beams coming from the APS insertion devices and also because of the specific spatial constraints imposed by the PBPM placement in the front end.

An APS PBPM design in which CVD diamond is used as the blade material [6] is presented here. (Note, however, that a man-made diamond manufactured by any other technique should be equally functional.) The results from tests of the CVD-diamond blade in this APS prototype PBPM on the undulator beamlines at CHESS and NSLS are also discussed in this paper.

2. Design Requirements

At APS, a typical third generation synchrotron radiation facility with very powerful IDs, the desired sensitivity from the PBPMs is on the order of 0.5-1 µm. These values are determined to provide the requisite particle beam correction feedback to achieve sensing to

10% of both the undulator beam opening angle and the beam spatial size if the two PBPMs are placed on the front end within a 4-m distance.

The 5-m long APS Undulator A generates 10 kW total power with a power density in excess of 1250 W/mm^2 at the position of the first PBPM (approximately 15.5 m from the source). The design criteria are such that, during normal operations, the PBPM blades will only be illuminated by the VUV and soft x-ray part of the x-ray undulator radiation. Thus, the blades usually will not touch the "hot center" of the undulator beam. However, the blades should still function even if directly impinged by a missteered beam center.

Another special design requirement for the APS PBPM is compatibility with all the planned undulators and wigglers. The design must provide freedom for users to install an undulator or wiggler into the same straight section and have either type of x-ray radiation available on the their beamline and in the experiment station.

High mechanical stability, ultra-high vacuum compatibility, and maintenance convenience are the other requirements.

3. The APS PBPM Design

To meet the above requirements, a series of technical conditions have been identified in the design of the APS PBPM:

(1) Choice of a photo-electron-emission-type monitor because of its proven performance with UHV compatibility, high sensitivity, and easy maintenance.

(2) Use of CVD diamond as the blade material because of its superior thermo-physical properties, such as high thermal conductivity, a low thermal expansion coefficient, and good mechanical strength and stiffness under heat.

(3) Use of metal coating materials, which are capable of forming a good bond with the diamond blade surface, for good photo-emission yield.

(4) Use of rolling-wedge or triangle-bar shapes to provide horizontal blade gap adjustments to suit the undulator and/or wiggler operation.

(5) Use of a geometry comprising three blade pairs to solve the "shadowing" problem between the two PBPMs.

As shown in Fig. 1, the APS prototype PBPM assembly consists of eight components. The monitor assembly (2) is mounted on a water-cooled base (1), which is the bottom part of the vacuum vessel (5). On top of the vacuum vessel, there are electrical feedthroughs (3) for signal output, and a motion feedthrough (4) for horizontal blade gap control. The vacuum vessel is kinematically supported by a set of stepping-motor-controlled stages (7), which provide precise horizontal, vertical, and yaw motions for fine alignment and calibration of the PBPM. The stages are mounted on a support made of materials with low thermal expansion coefficients for position stability.

The geometric arrangements of the blades for the upstream and downstream PBPM monitor assemblies are shown in Fig. 2. The upstream monitor has two pairs of vertical and one pair of horizontal blades. The downstream monitor, on the other hand, has one pair of vertical and two pairs of horizontal blades. This design avoids the shadowing effect of the upstream PBPM blades on the downstream PBPM blades. Figure 3 shows the blade clamping and cooling structure. To electrically isolate the diamond blades from the monitor base assembly and the water-cooled base, a special ceramic shim or coating will be used that is chosen to possess good electric insulation and thermal conduction properties.

A preliminary finite element analysis with ANSYS on the diamond blade design has been carried out. The results indicate that a CVD-diamond blade will survive a direct hit by the beam from the 2.5 m long APS Undulator A that would cause physical damage to any other metallic blade of choice. A more detailed analysis of this case, an analysis of the case for a beam from the 5 m long

Undulator A, as well issues such as the structural detail for horizontal blade adjustment, etc., will be the subject of another study.

4. Purpose of the Prototype Test

To optimize the APS PBPM design, a preliminary prototype beam position monitor was designed and constructed to:

(1) Experimentally prove that the soft x-ray part of a hard x-ray undulator beam can determine the beam center position.

(2) Test the monitor sensitivity.

(3) Assess the bending magnet synchrotron radiation contamination.

(4) Check the blade gap adjustment operation in UHV and its reproducibility.

(5) Assess if two vertical pairs of blades will provide good horizontal beam position information.

The unit was designed to suit the specific requirements of the APS/CHESS undulator [7] at CHESS (Cornell University). The monitor assembly (Fig. 4) consists of three pairs of vertical photoemission blades, two for the undulator beam and one for the engulfing bending magnet beam [8]. A CVD-diamond-based, tungsten-coated blade (DBWC) was used and set against a matching molybdenum blade as a pair so that comparative performance data was obtained in photoemission. The test unit included a UHV-compatible water-cooled base, a digitally controlled UHV feedthrough, and a mechanism for precise control of the vertical blade gap (Fig. 5).

5. CVD Diamond Blade Tests at NSLS

Prior to the CHESS tests, a CVD-diamond blade coated with a 3-μm tungsten layer (DBWC) was tested on the X-13B soft x-ray undulator beamline of the NSLS using a ALS/LBL photon beam position monitor test chamber equipped with micro-motion stages. A molybdenum blade was also mounted on the same monitor base block and paired with the diamond blade for vertical motion. The NSLS test results roved that there was no notable difference between the diamond blade and the conventional molybdenum blade in their total photo-electron yield (Fig. 6). A series of 5-μm test stage jumps clearly demonstrated that the DBWC blade provided sub-micron position resolution similar in performance to the matched molybdenum blade (Fig. 7).

6. CVD Diamond Blade Tests at CHESS

The APS/CHESS x-ray undulator is a 2-m, 123-pole, 3.3-cm period Nd-Fe-B hybrid insertion device. The undulator produced the expected brightness at 5.437 GeV with the fundamental x-ray energy ranging from 4.3 to 7.9 KeV corresponding to a change in gap from 1.5 to 2.8 cm [7]. The test monitor was installed on the undulator beamline front end at a distance of 8.3 m from the source. The monitor was supported on a CHESS optical table. A optical encoder, which attached to the CHESS optical table, provided 0.1-micron motion sensitivity. Figure 8 shows the block diagram for the monitor control and data acquisition set up.

For most of the tests, the undulator magnet gap setting was 1.5 cm. The monitor dynamic range and sensitivity were tested for a variety of vertical blade gaps. The test results show that the photo-emission blades can be kept far enough away from the high power density beam while still providing good spatial resolution. On the CHESS undulator front end, when the APS PBPM monitor blade gap was 6.75 mm (the RMS size of the high power beam is only about 1 mm at the same location), the monitor still had about 2 mm linear dynamic response range and sub-micron sensitivity as shown in Figs. 9 and 10.

The CHESS tests established that the CVD-diamond-based, tungsten-coated (DBWC) blade had a photo-emission response in an x-ray undulator beam similar to the matching molybdenum blade (Fig. 9). This conclusion agrees with the other diamond blade test data that was obtained on the NSLS X-13 soft x-ray undulator beamline (described above).

After the APS prototype PBPM operated for five weeks on the CHESS x-ray undulator beamline front end with a maximum 5.437 GeV, 100 mA electron beam current and at a range of 15 mm - 24 mm undulator magnetic gaps, the monitor was challenged to a "worst case" test during the last hour of the CHESS undulator run. The DBWC blades were brought in direct contact with the central part of the white undulator beam (5.437 GeV), 120 mA, and 15 mm undulator magnetic gap). The monitor remained fully functional during this worst case. A visual inspection was carried out after this worst case test, and no changes were observed on the DBWC blade [9]. The close proximity of the beam left a searing footprint on the matching molybdenum blade during the same test. Because the CVD diamond has about 10 times higher thermal conductivity than the molybdenum, it has a much better chance of surviving intact following the worse case scenario (i.e., when the beam missteering occurs and the beam center hits the blades).

The CHESS tests also established that the bending magnet synchrotron radiation will not be a serious source of contamination for the hard x-ray undulator position monitor. The photoemission signal from the bending magnet beam blade is 10-20 times less than the signal from the undulator beam.

The test also showed that the horizontal position sensitivity of the four vertical-blade system is about 3-4 times lower than the vertical sensitivity.

A side benefit of the CHESS tests was the design and the operating experience obtained with a precision-blade gap-control stage that is reliable and totally UHV compatible. The tests demonstrated that a 5-µm blade gap adjustment reproducibility was possible.

7. Discussion and Conclusions

It is possible to use the soft x-ray portions of a beam from a hard x-ray undulator source to determine the center position. This means that, with high power density, the monitor blade gap can be set much wider than the undulator beam's central core width. Sub-micron vertical beam position sensitivity is attainable, as demonstrated in the CHESS tests.

The CVD diamond is a superior blade material for high power load PBPMs. The conventional metallic PBPM blades cannot match the performance of the diamond blade in material strength, stiffness, thermal conductivity, or thermal expansion under heat.

The CVD-diamond blade gives the user a choice of coating metal for the best photoemission properties, provided that the coating metal can be bonded to the CVD diamond. The test results at NSLS and CHESS also show that the metal-coated blade had the same photoemission response as the metal blades.

The bending magnet synchrotron radiation did not prove to be a serious contamination source for the hard x-ray undulator PBPM.

The horizontal position sensitivity of the four vertical-blade system was about 3-4 times lower than the vertical sensitivity. Thus, the APS engineering design for a working PBPM may be modified to include a movable horizontal blade stage. Now that we have successfully designed and operated a precision UHV-compatible vertical blade-gap adjustment mechanism, we do not expect any major surprises in designing a horizontal one.

Acknowledgements:

We acknowledge technical input to this work from Drs. Eric K. Johnson (NSLS), Tony Warwick (ALS), and Mr. Chuck Henderson (CHESS), and help from various CHESS and NSLS staff members during the tests. The preliminary analysis on the PBBM blade was carried out by Mesrs. Zhibi Wang and H. L. Thomas Nian of the APS.

References

1. D. Shu, J. Barraza, T. Sanchez, R. W. Nielsen, J. T. Collins, and T. M. Kuzay, "Front End Designs for the 7-GeV Advanced Photon Source," presented at the 7th Nat. SRI Conf., Baton Rouge, LA, 1991

2. J. N. Galayda, Invited talk at the 7th Nat. SRI Conf., Baton Rouge, LA, 1991

3. P. Mortazavi, M. Woddle, H. Rarback, D. Shu, and M. Howels, Nucl. Instrum. Methods A 246, 389 (1986)

4. E. Johnson and T. Oversluizen, Rev. Sci. Instrum. 60 (7), p. 1947 (1989)

5. T. Warwick and D. Shu, presented at the 4th Int. SRI Conf., Chester, England, 1991

6. Patent Applied for APS/ANL, October 1991.

7. D. Bilderback, E. Blum, P. Viccaro, K. Robinson, et al., Rev. Sci. Instrum. 60 (7), p. 1419 (1989)

8. E. Johnson, (private communication)

9. C. Henderson, (private communication)

Fig. 1 Schematic view of the APS photon beam position monitor: (1) water cooled base, (2) monitor assembly, (3) electric feedthroughs, (4) motion feedthrough, (5) vacuum vessel, (6) welded bellows, (7) Stages, and (8) Support.

Fig. 2 Geometric arrangements for the APS PBPM blades.

Fig. 3 APS PBPM blade clamping and cooling structure. (1) clamping screw, (2) OFHC plate, (3) (4) (8) ceramic mnsulator, (5) OFHC colector, (6) diamond blade, (7) Monitor cooling base.

Fig. 4 Monitor assembly for APS diamond blade test at CHESS.

Fig. 5 Monitor assembly with water cooled base and vertical blade gap control mechanism for APS diamond blade test at CHESS.

Fig. 6 Total photo-electron yield output test for APS diamond and molybdenum blades at NSLS X-13B soft x-ray undulator beamline.

Fig. 7 5 μm jump test for APS diamond blade at NSLS X-13B.

Fig. 8 Block diagram of the PBPM test for APS at CHESS.

Fig. 9 Total photo-electron yield output test for APS diamond and molybdenum blades using APS/CHESS x-ray undulator at CHESS.

Fig. 10 5 μm jump test for APS diamond blade at CHESS.

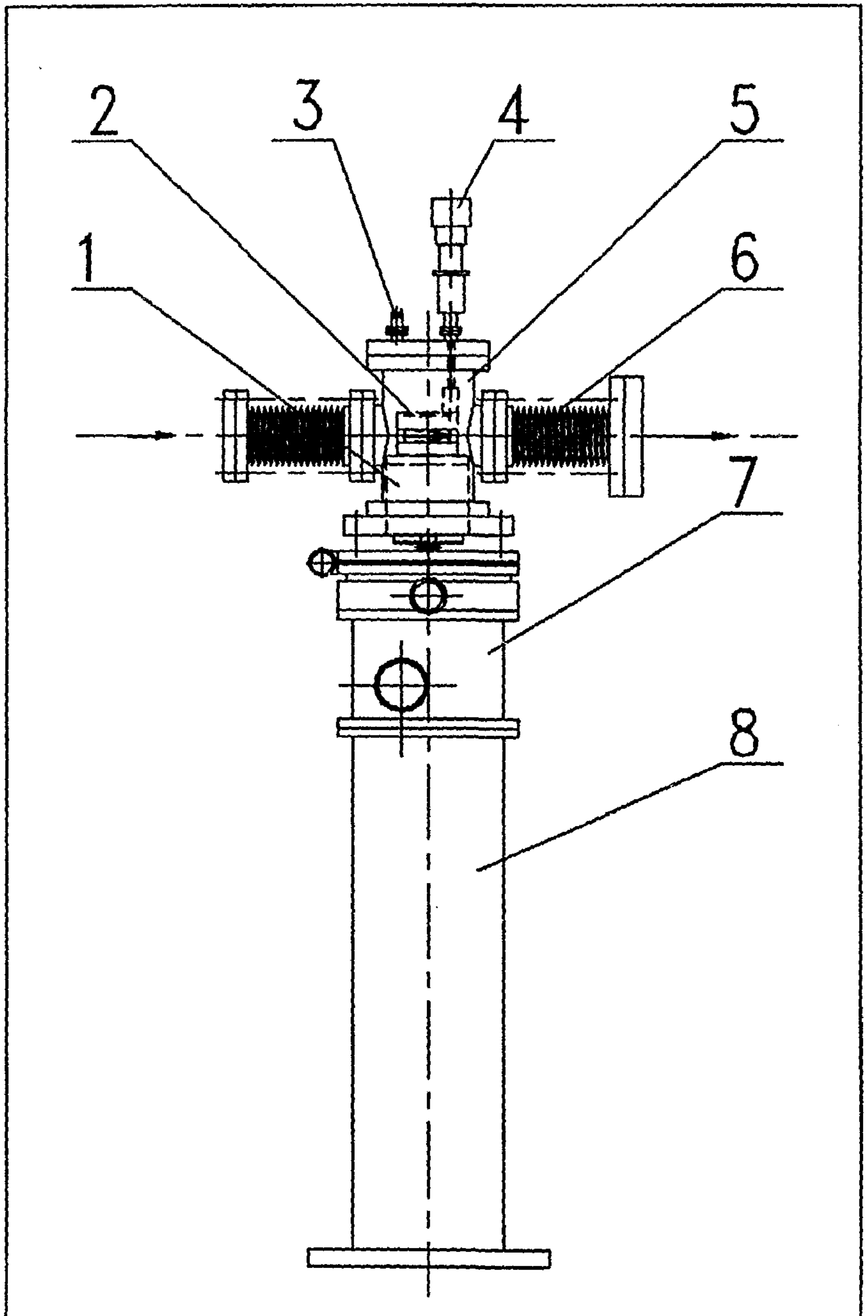
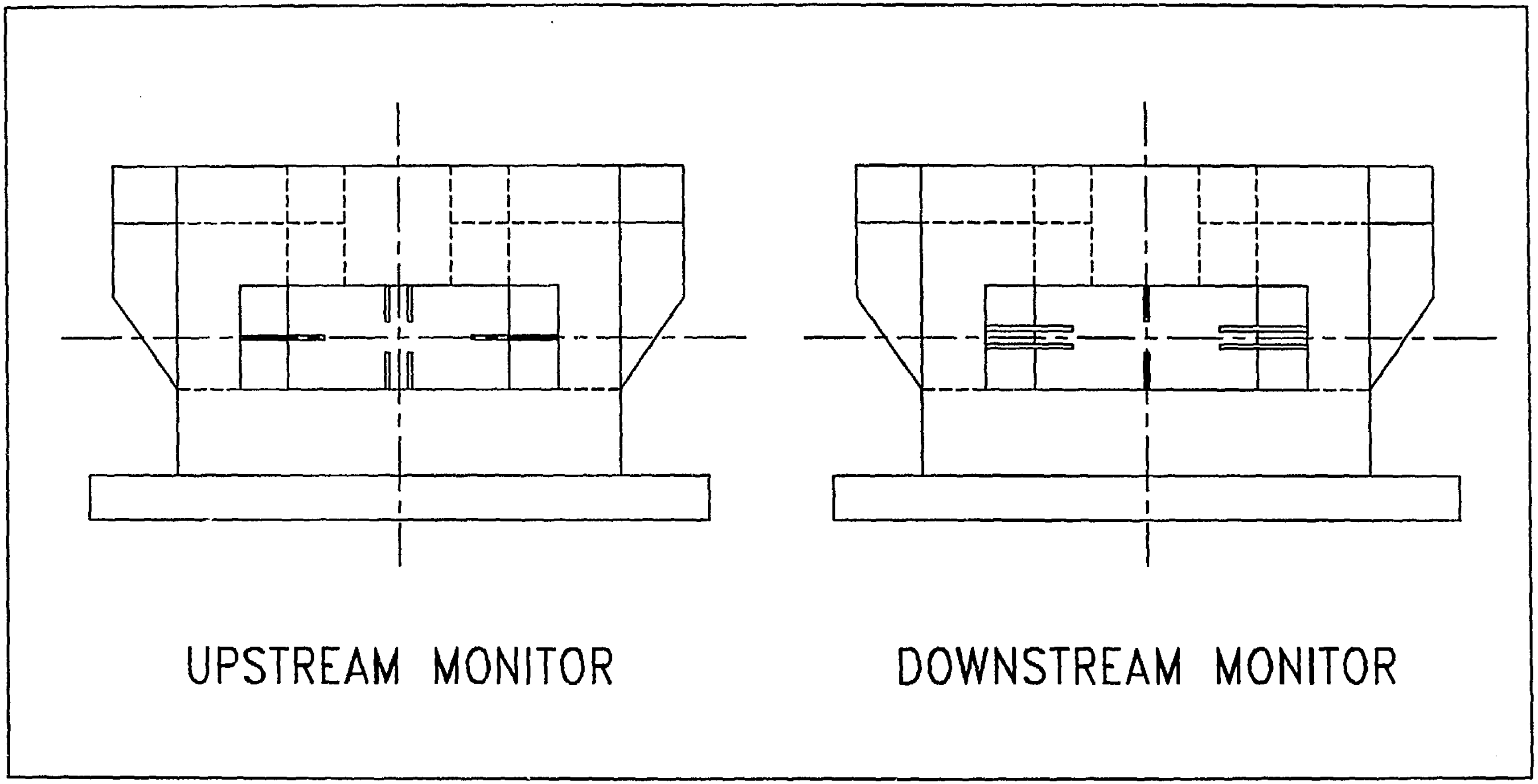

1
2
3
4
5
6
7
8

Fig. 2



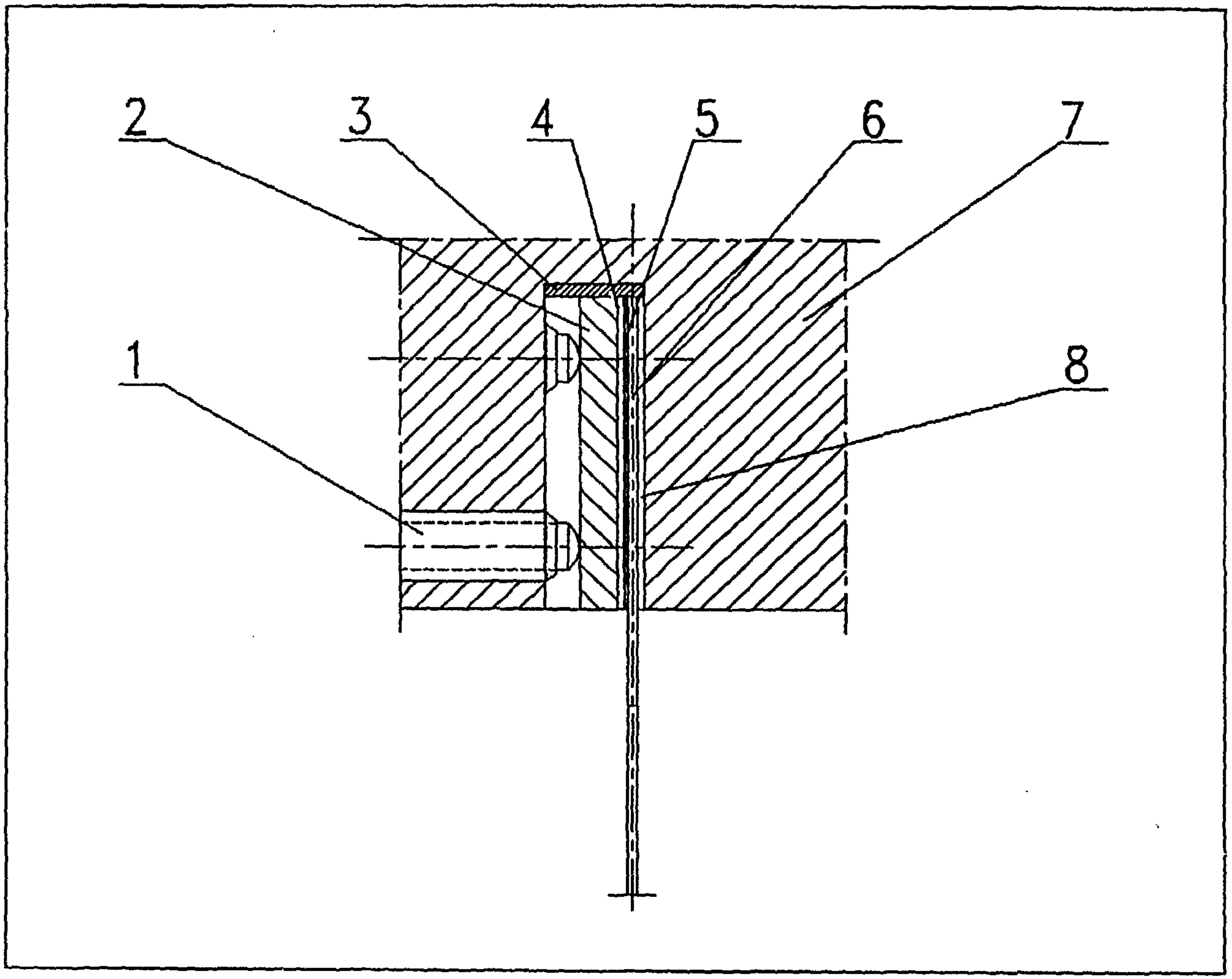

2
3
4
5
6
7
1
8

FIG 4

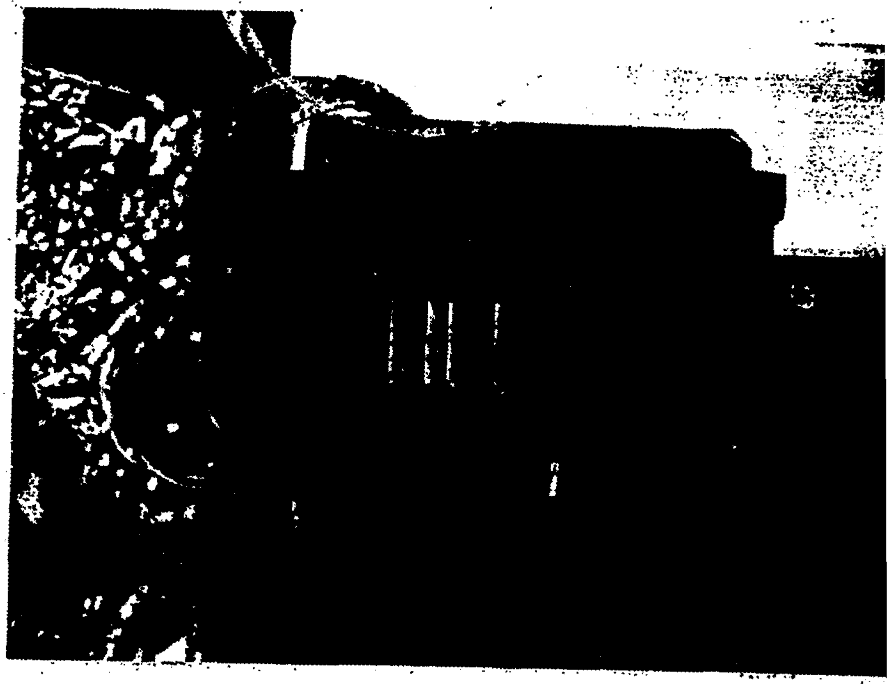
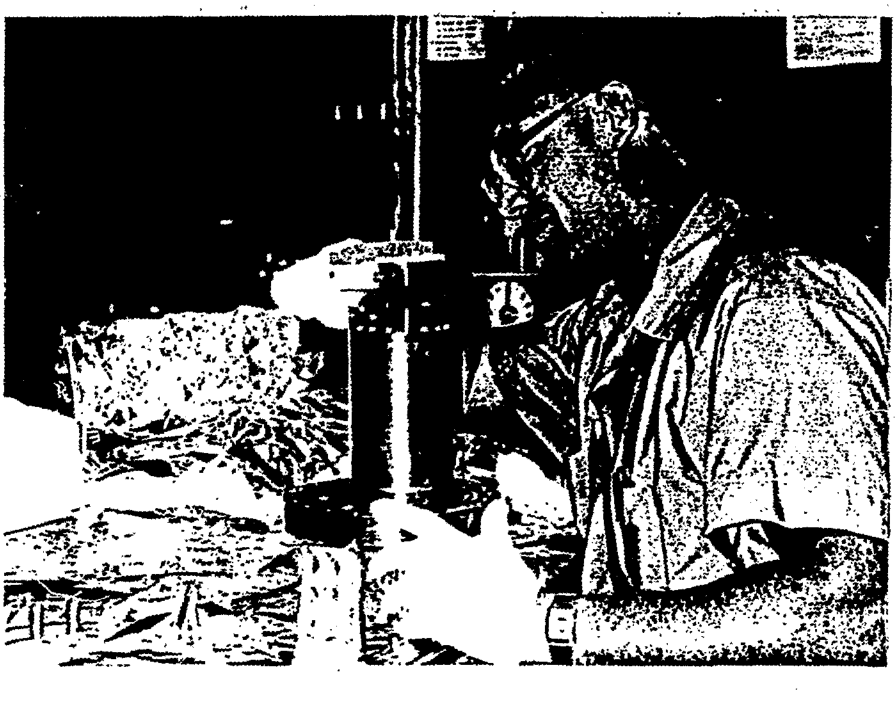
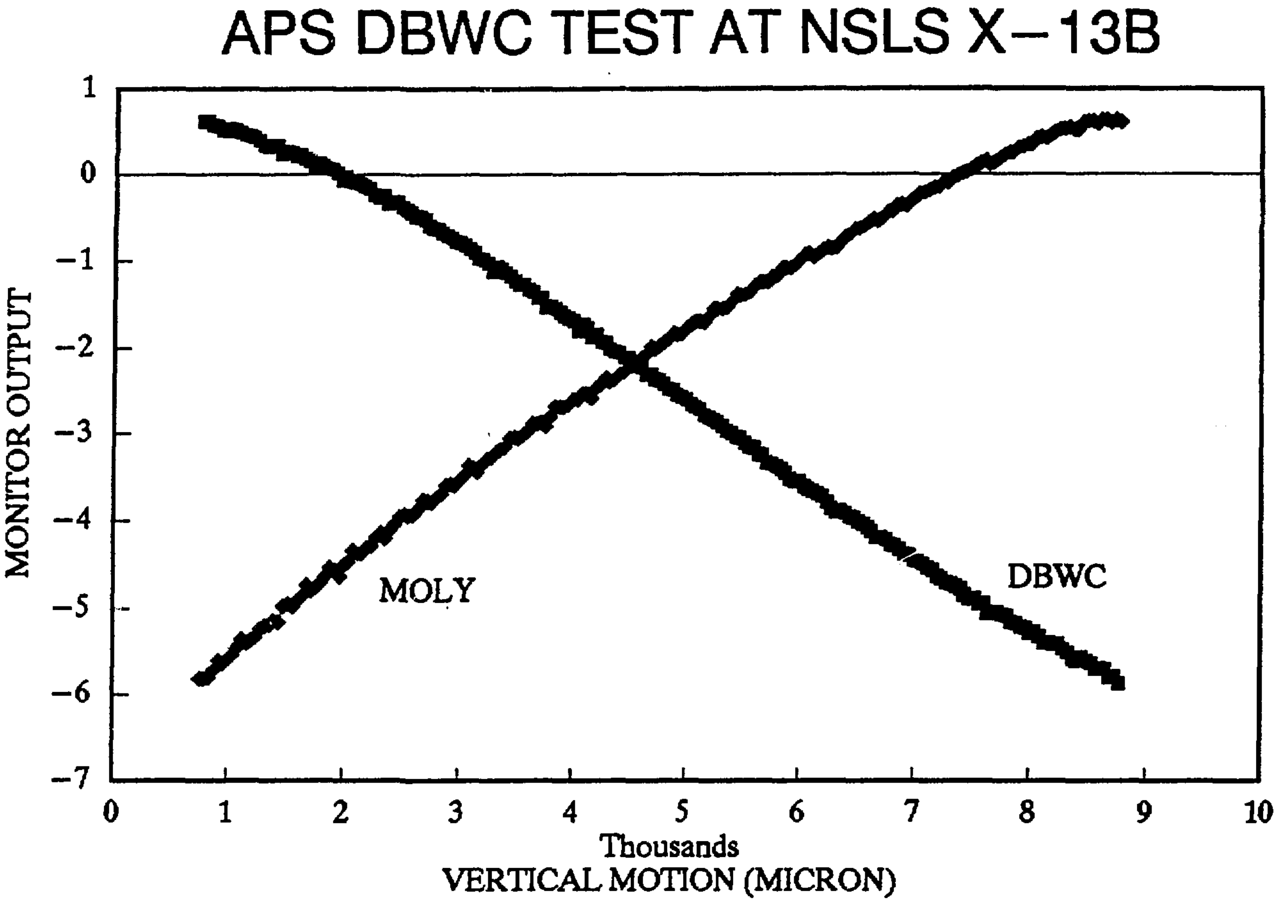


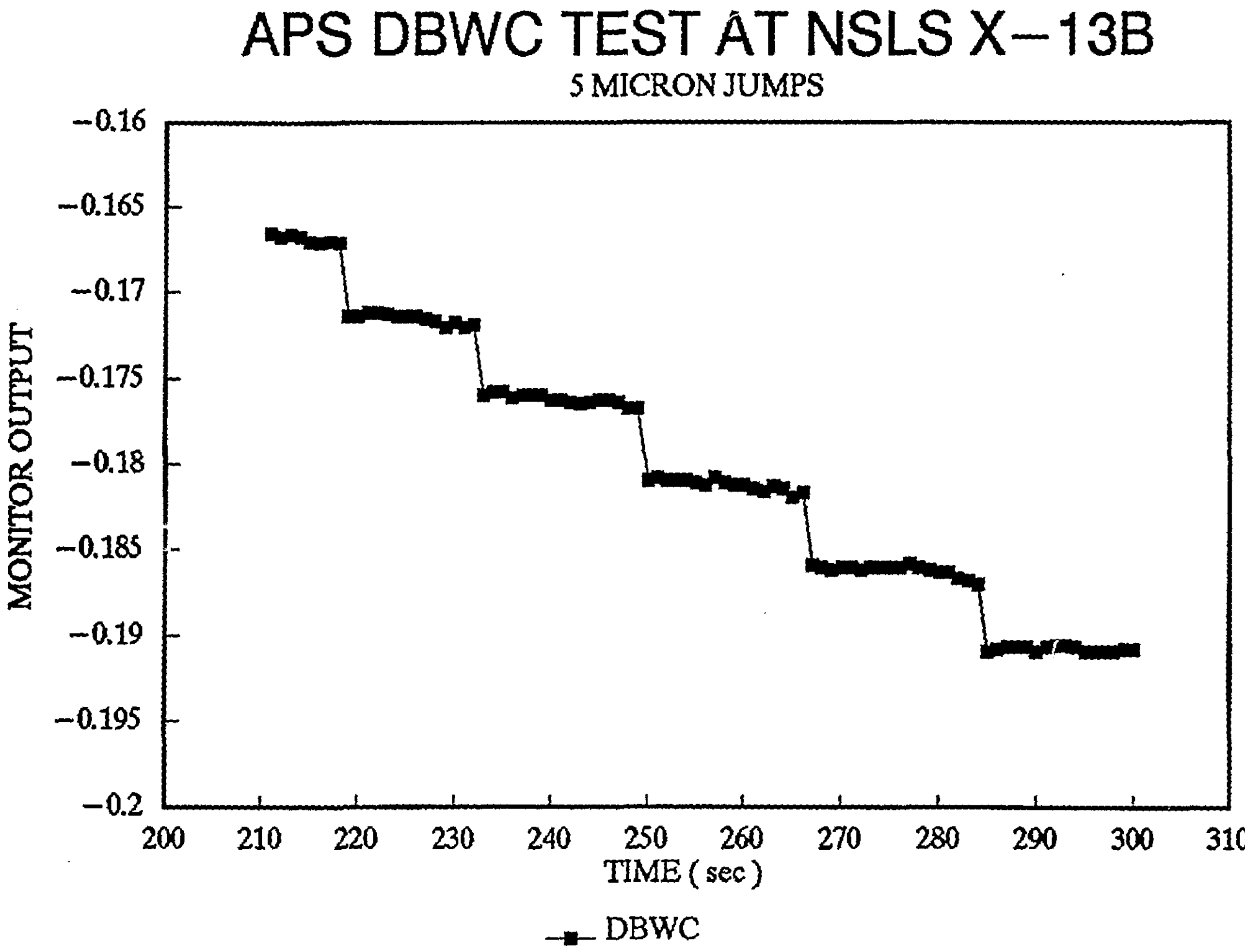
FIG. 5.





APS DBWC TEST AT NSLS X−13B
MONITOR OUTPUT
1
0
−1
−2
−3
−4
−5
−6
−7
0
1
2
3
4
5
6
7
8
9
10
Thousands
VERTICAL MOTION (MICRON)
MOLY
DBWC

Fig.7



APS DBWC TEST AT NSLS X-13B
5 MICRON JUMPS
MONITOR OUTPUT
-0.16
-0.165
-0.17
-0.175
-0.18
-0.185
-0.19
-0.195
-0.2
200
210
220
230
240
250
260
270
280
290
300
310
TIME (sec)
DBWC

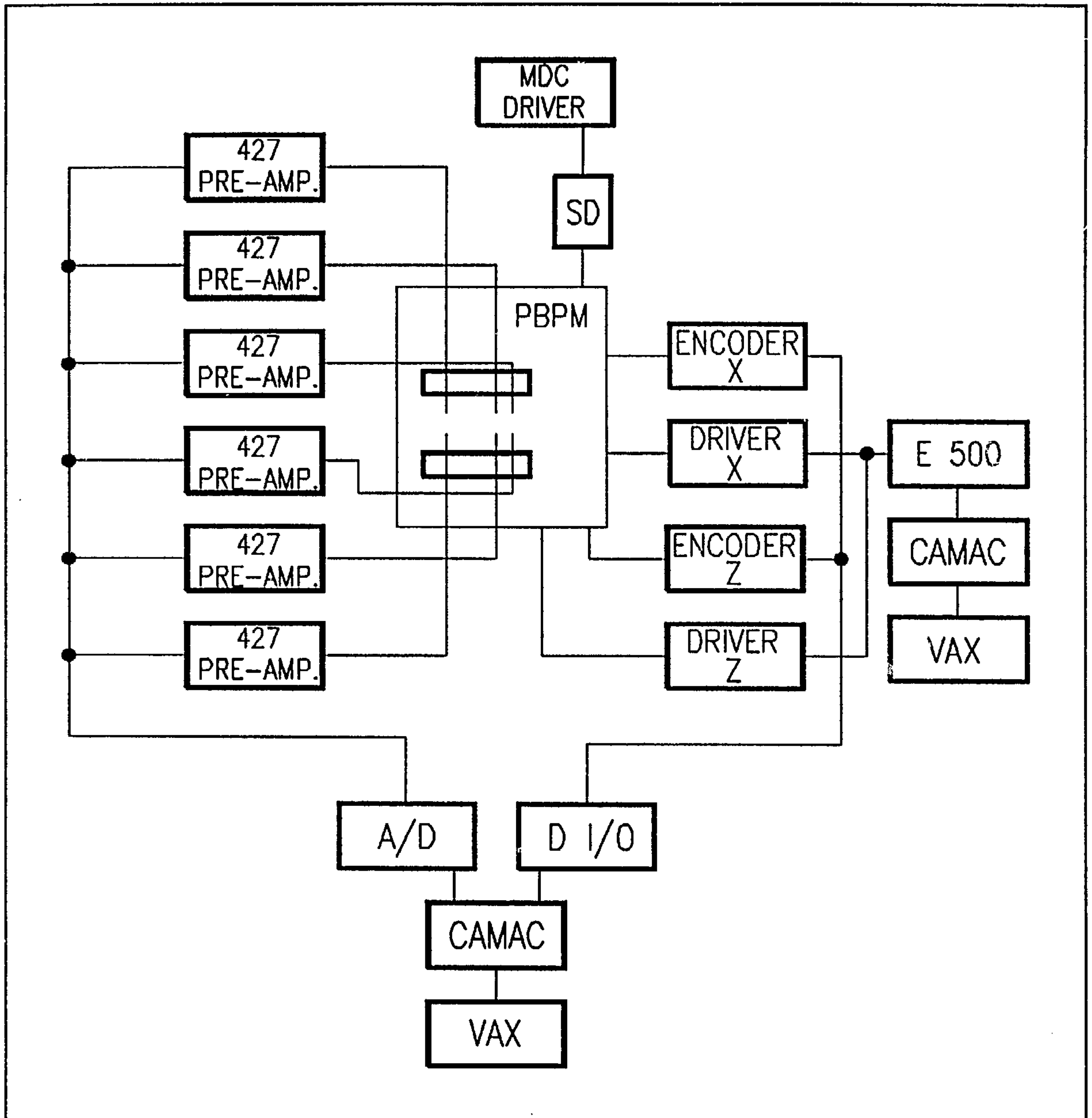

MDC DRIVER
SD
PBPM
427 PRE-AMP.
427 PRE-AMP.
427 PRE-AMP.
427 PRE-AMP.
427 PRE-AMP.
427 PRE-AMP.
ENCODER X
DRIVER X
ENCODER Z
DRIVER Z
E 500
CAMAC
VAX
A/D
D I/O
CAMAC
VAX

Fig. 9

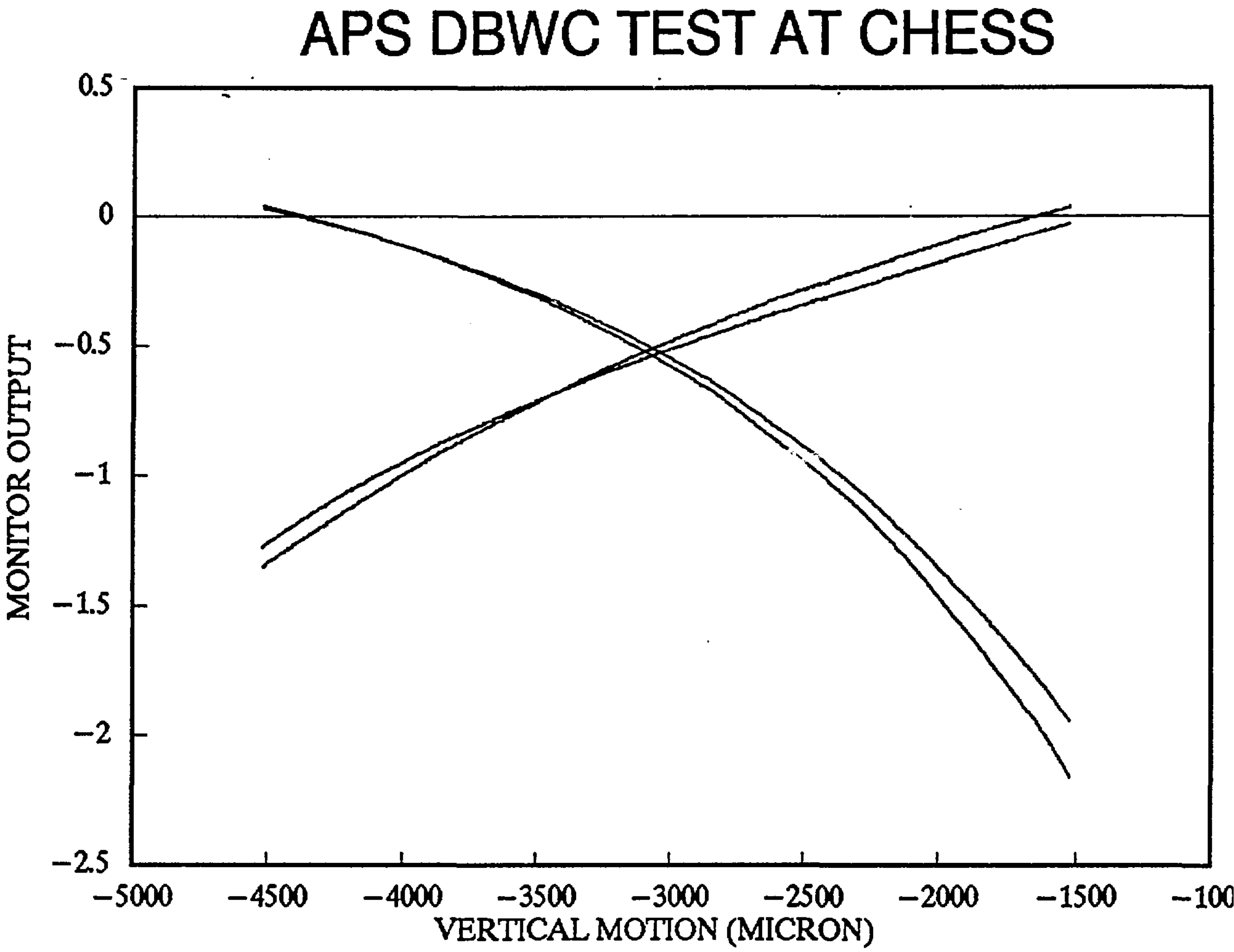
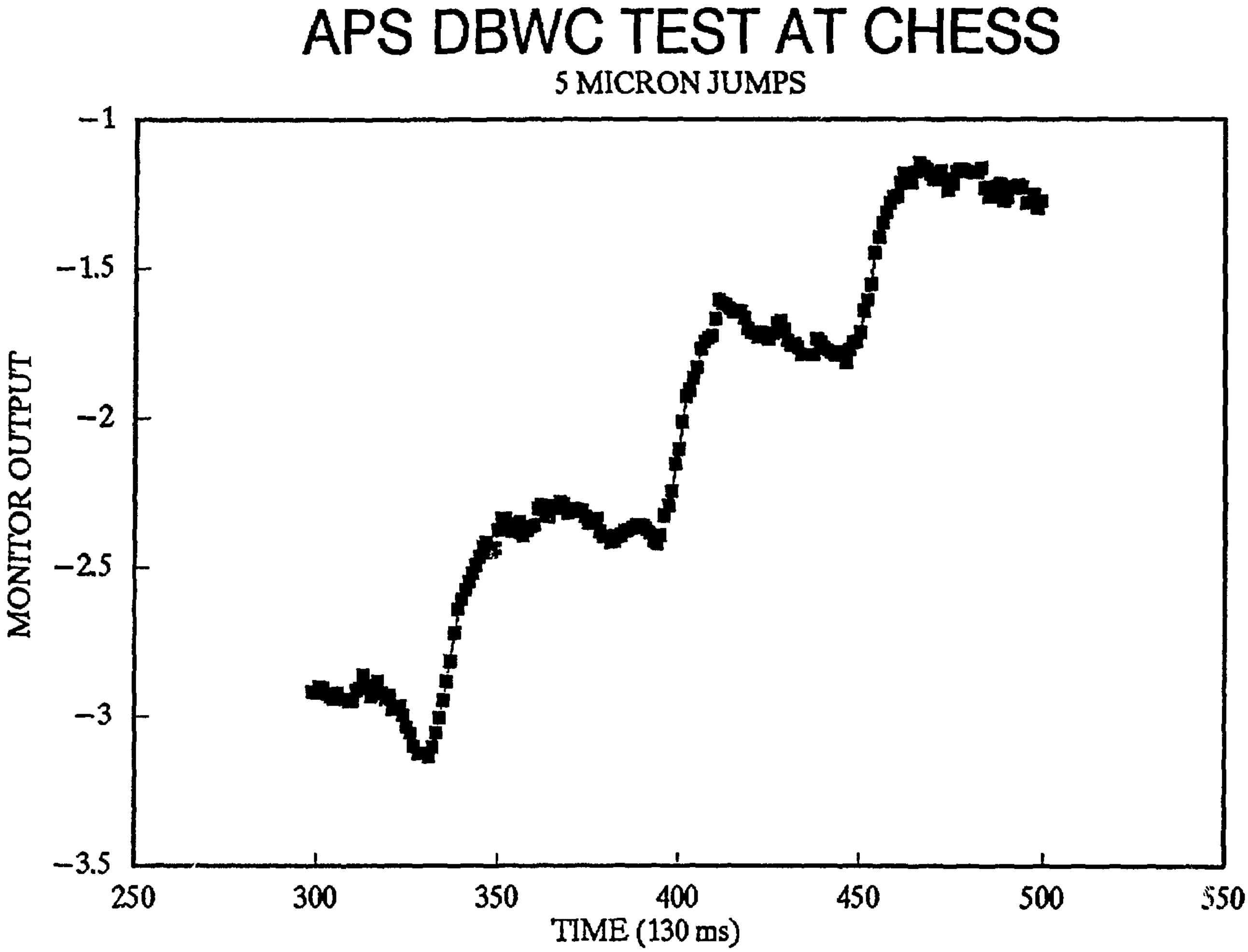

APS DBWC TEST AT CHESS
0.5
0
−0.5
−1
−1.5
−2
−2.5
MONITOR OUTPUT
−5000
−4500
−4000
−3500
−3000
−2500
−2000
−1500
−100
VERTICAL MOTION (MICRON)

Fig.10


APS DBWC TEST AT CHESS
5 MICRON JUMPS
MONITOR OUTPUT
-1
-1.5
-2
-2.5
-3
-3.5
250
300
350
400
450
500
550
TIME (130 ms)