REPORT DOCUMENTATION PAGE

AD-A256 943

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE September 1992	3. REPORT TYPE AND DATES COVERED Preprint

4. TITLE AND SUBTITLE UHV-Compatible Electrostatically-Driven Tuning Fork Chopper	5. FUNDING NUMBERS PI: N00014-92-C-0196 R&T: S405029srr04
6. AUTHOR(S) Kebabian, Paul L.; Kallelis, Spiros; Nelson, David D. Jr.; and Freedman, Andrew	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Aerodyne Research, Inc. 45 Manning Road Billerica, MA 01821	8. PERFORMING ORGANIZATION REPORT NUMBER RR-944
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Sponsor: SDIO/IST Monitor: Office of Naval Research 800 N Quincy Street Arlington, VA 22217-5000	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

To be published in the Review of Scientific Instruments

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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14. SUBJECT TERMS Tuning fork chopper, ultrahigh vacuum, molecular beams	15. NUMBER OF PAGES 14
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

ARI-RR-944

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Accepted For Publication in the

Review of Scientific Instruments

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We have developed an electrostatically driven tuning fork chopper which is compatible with an ultrahigh vacuum (UHV) environment. Constructed with a commercially available tuning fork using stainless steel and alumina parts, the chopper is capable of operating while exposed to high temperature samples and corrosive gases. Operation in a UHV environment while modulating both optical and molecular beams is demonstrated.

INTRODUCTION

The development of beam modulating instrumentation that is compatible with the high level of cleanliness required in ultrahigh vacuum (UHV) systems ($P \leq 1 \times 10^{-8}$ Torr) presents a difficult problem. One possible solution is the magnetically driven tuning fork chopper which has been used for over thirty years in conjunction with phase sensitive detection to provide an enhanced means of signal recovery in systems using photon and molecular beams.[1-2] Commercial devices at moderate cost are available. Unfortunately, the use of plastics and epoxies in these devices is not appropriate to UHV systems. In addition, exposure of the chopping device to corrosive gases and heat generated by hot substrates rule out the use of simple encapsulating strategies. Experiments conducted in this laboratory require exposure of substrate surfaces to both atomic and molecular halogen gases at surface temperatures exceeding 1000K.[3,4] To solve this problem, we have developed an electrostatically driven tuning fork chopper constructed entirely of UHV-compatible metals and ceramics. Unlike other electrostatically driven systems,[5,6] this one achieves a large vibration amplitude (several millimeters).

DESIGN AND CONSTRUCTION

Design of an electrostatically driven chopper with a large vibration amplitude offers several problems. The drive electrodes and tuning fork can be thought of as forming a capacitive system under an applied voltage; in order to generate a driving force over a large excursion, the drive electrodes must be placed out of the plane of desired motion. When an AC drive voltage is applied to the drive electrodes, forces (proportional to the square of the voltage) both parallel and perpendicular to the desired plane of motion are generated which will induce motion both in- and out-of-plane at resonance. Any design must maximize the former and minimize the latter;

moreover, the fork and electrodes must stay in close proximity (a fraction of a millimeter) over the entire range of motion without shorting out the drive voltage.

Figure 1 presents a schematic of the mechanical details of the chopper assembly. The tuning fork proper consists of a set of tines to which vanes are attached. The nominal 500 Hz tine set, made from a carbon steel alloy, was purchased from Frequency Control Products[7]. The ends of the tines are enlarged, allowing for a set of slots in which the vanes can be attached. Stainless steel vanes (0.25 mm thick) were attached to the tines by spot welding them in the slots using a thin layer of platinum as a binder. The drive electrodes are located approximately 0.1 mm beneath the enlarged areas at the end of the tines. The ends of the electrodes are at the middle of the enlarged region. Thus, the **in-plane** motion of the tuning fork causes a change in the capacitance between the drive electrodes and the tines, exerting an in-plane electrostatic force. Note that the in-plane motion cannot cause the electrodes to short to the tines. Furthermore, the excitation of the **out-of-plane** (flapping) motion is minimized by the chosen location of the drive electrodes in that the out-of-plane stiffness of the tines is much greater than that of the vanes.

The pickoff electrodes are located over the vanes at the outer end at a spacing of a few tenths of a millimeter. This location maximizes sensitivity to in-plane motion and minimizes pickup from the drive electrodes. An electrostatic shield covers the drive electrodes to minimize pickup of the drive voltage, but this remains a problem whose solution is discussed below. All insulating bushings are constructed from non-porous alumina; the base and supporting structure are made from stainless steel. The chopper is situated so that the beam passes through the region between the ends of the pickoff electrodes. At rest, the gap between the vanes is 1.5 mm.

Mechanically, there is relatively weak coupling between the two tine/vane assemblies. Thus, to achieve the highest mechanical 'Q', they must be set to the same resonant frequency. This was done by sweeping the drive frequency (using the drive circuitry described below), while observing the vanes under a microscope. The vane on the side having the lower resonant frequency was ground down until the resonant frequencies were matched. At this point, the vibration of the tuning fork is decoupled from the base and maximum mechanical Q results. We were able to achieve $Q \cong 1000$ at 323 Hz. This value of Q is somewhat lower than one usually sees for magnetically driven forks in this frequency range; we believe that the cause of this is mainly imperfect matching of the frequencies. We emphasize that the ultimate performance of the chopper is dependent on matching the size and weight of the vanes as closely as possible. For less critical conditions, solder is typically used to match the weight the of the vanes so as to provide the desired frequency and high 'Q' typical of such choppers, an inappropriate option for UHV work.

Figure 2 presents a schematic of the circuitry used to drive the fork and monitor its motion. The drive voltage is typically 6 kV peak-to-peak. The force on the tines is proportional to the square of the drive voltage and thus the drive frequency is set to half the resonant frequency. The sensor electrodes are biased at 90V DC; the motion of the vanes, when C_{sense} is varied, causes a signal current proportional to dC_{sense}/dt at the resonant frequency. A much larger current, at the drive frequency, is present as a result of the coupling through stray wiring capacitance. To cancel this, potentiometers R1 and R2 add in-phase and quadrature signals at the drive frequency. Depending on the phase shift introduced by the amplifier and transformer, it might be necessary to invert the drive voltage to R1 and/or R2; this was not the case for our apparatus. The output is displayed as a Lissajous pattern on the oscilloscope; at resonance, a typical signal of 30 mV p-p is observed.

To operate the chopper, the oscillator is first set slightly off resonance and R1 and R2 are adjusted to minimize coupling at the drive frequency. Then, the frequency is slowly swept through resonance until a signal at twice the drive frequency is observed. This pattern is the sum of a component at twice the drive frequency (parabolic shape) and a component at four times the drive frequency. We ascribe the latter component to an out-of-plane motion caused by the center of mass of one or both of the vanes being above or below the point of attachment to the tines. One could synchronously detect the signal component at twice the drive frequency and use that to stabilize the oscillator frequency. We have not found this to be necessary as the chopper operation has been sufficiently stable for periods up to an hour.

We have noted that the maximum chopper excursion is greatly reduced at atmospheric pressure. This results from the fact that a sufficiently high voltage cannot be used to drive the chopper due to electrical breakdown from the driving electrodes to the tines.

PERFORMANCE

The tuning fork chopper was tested in a molecular beam apparatus used to study the chemistry of surfaces under ultrahigh vacuum conditions. It comprises three chambers: the first houses the sample manipulator and various beam sources, both neutral and ionic; the second contains surface analysis diagnostics (X-ray photoelectron spectrometer and low energy electron diffraction); and the third contains a differentially pumped quadrupole mass spectrometer (Extrel). The last chamber is maintained at a pressure 300 times lower than the sample chamber when a molecular beam is being used to irradiate the sample. The tuning fork chopper is mounted at the opening to the mass spectrometer chamber so as to provide for phase sensitive detection of species emanating from the surface. This arrangement is suitable for both beam scattering and surface desorption experiments.

The first test on the tuning fork chopper under vacuum was an optical one. A HeNe laser beam was directed through the aperture of the tuning fork chopper, into the mass spectrometer chamber and out through a Pyrex window, where it was monitored by a silicon diode. Figure 3 presents the signal obtained. Note that the attenuation of the laser beam amounts to 80-90% at an operating voltage of 6 kV. Attempts to increase the voltage and thus the range of travel of the vanes failed due to electrical breakdown between the tines and electrodes. The limited peak-peak amplitude of 3mm may be due in part to the relatively low Q, as well as the limited extent of the enlarged regions at the ends of the tines where the driving force is applied.

The next test involved scattering a thermal effusive beam of argon off a polished and annealed GaAs wafer (Litton) into the mass spectrometer. The argon beam was detected at mass 40 using the Extrel quadrupole filter and Channeltron particle multiplier (Galileo) in a pulse counting mode. The individual pulses were amplified and converted to TTL pulses by a discriminator, and were routed to dual 4MHz counters on a LabMaster board (Scientific Solutions) interfaced with an 80286 personal computer. Three other counters on the board are used to trigger and gate the counters used to record signals from the mass spectrometer. This allows two counting windows to be established within each chopper cycle. The width and location of each cycle is adjustable under computer control to match the characteristics of a given chopper. One can establish two large windows coincident with the chopper being open and closed and thereby operate in a digital lockin amplifier mode. Alternatively, one can establish two small windows and scan their time delay to acquire the shape of the waveform.

Figure 4 presents results obtained in the latter mode of operation by collecting signal as a function of phase angle with respect to the chopper drive frequency and signal averaging for a period of an hour. We note that given the distance between the beam aperture and chopper (10 cm), the bulk of the signal comprises ionization of background gas that has entered the detector chamber without passing through the chopper. The modulation depth of 4% is in accord with the signal expected after taking into account the strength of the scattered beam, the background pressure, and the geometry of the apparatus. The chopper has also been shown to properly function when a substrate heated to 1000K (a 500W heat source) is placed within two centimeters distance while a beam of 5% fluorine in argon is irradiating the sample.

In conclusion, we have developed an electrostatically driven tuning fork chopper for modulation of molecular and optical beams that is compatible with an ultrahigh vacuum environment. Constructed of only stainless steel and alumina parts (except for the tuning fork itself which is of a non-stainless steel), the chopper has been operated in an environment which contains corrosive gases and high temperatures.

ACKNOWLEDGMENTS

This work was supported by the Strategic Defense Initiative Organization / Office of Innovative Science and Technology (managed by the Office of Naval Research).

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FIGURE CAPTIONS

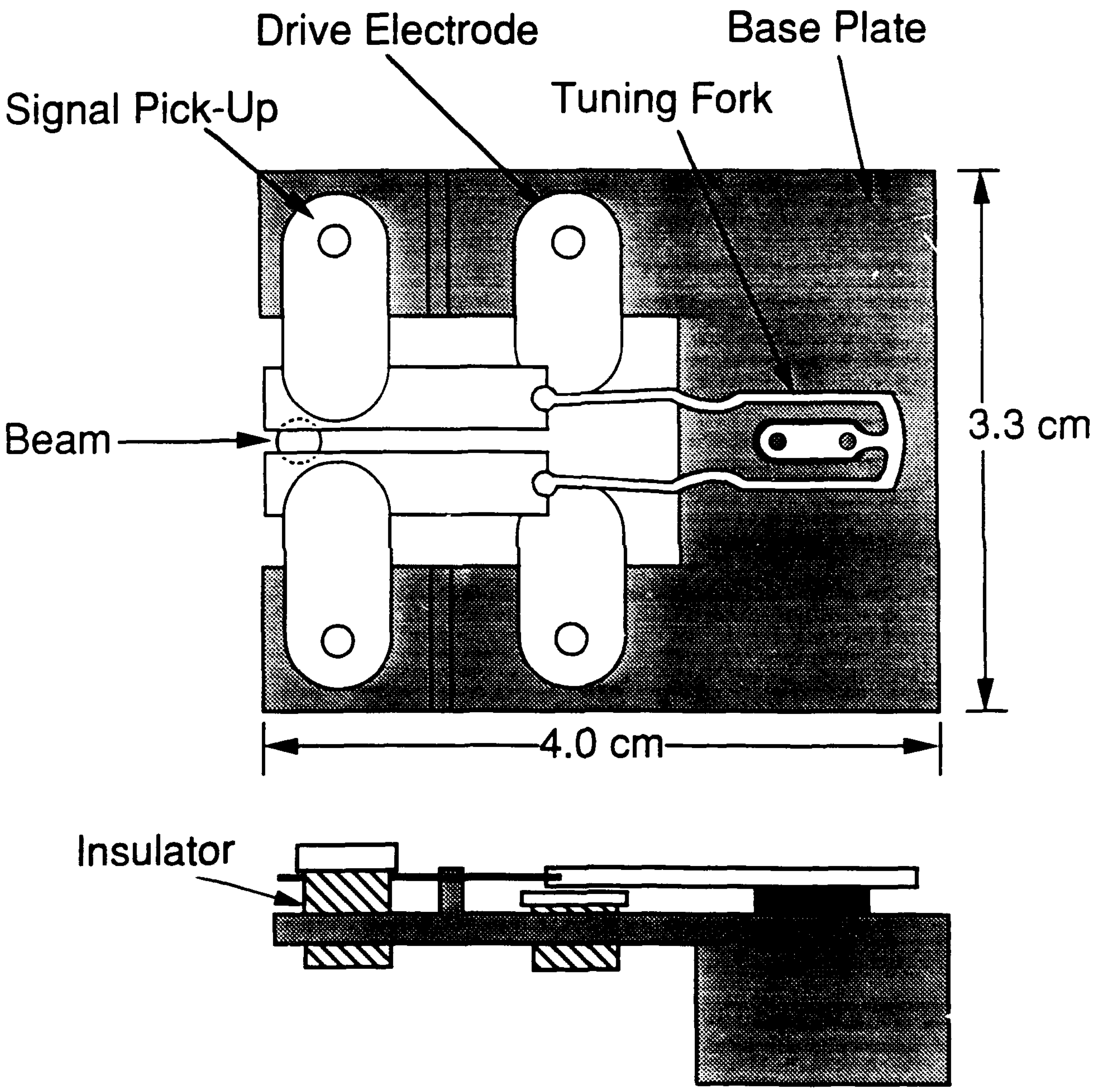
1. Schematic of mechanical assembly of tuning fork chopper.

2. Circuit diagram for drive electronics for tuning fork chopper.

3. Trace of signal obtained from a modulated HeNe laser beam which has been bounced off a substrate and through the tuning fork chopper.

4. Mass spectrometer signal at mass 40 obtained from modulation of an argon beam which has been bounced off a substrate. The chopper is situated between the substrate and mass spectrometer entrance. The level of modulation represents recovery of the beam signal from background signal.

TUNING FORK CHOPPER



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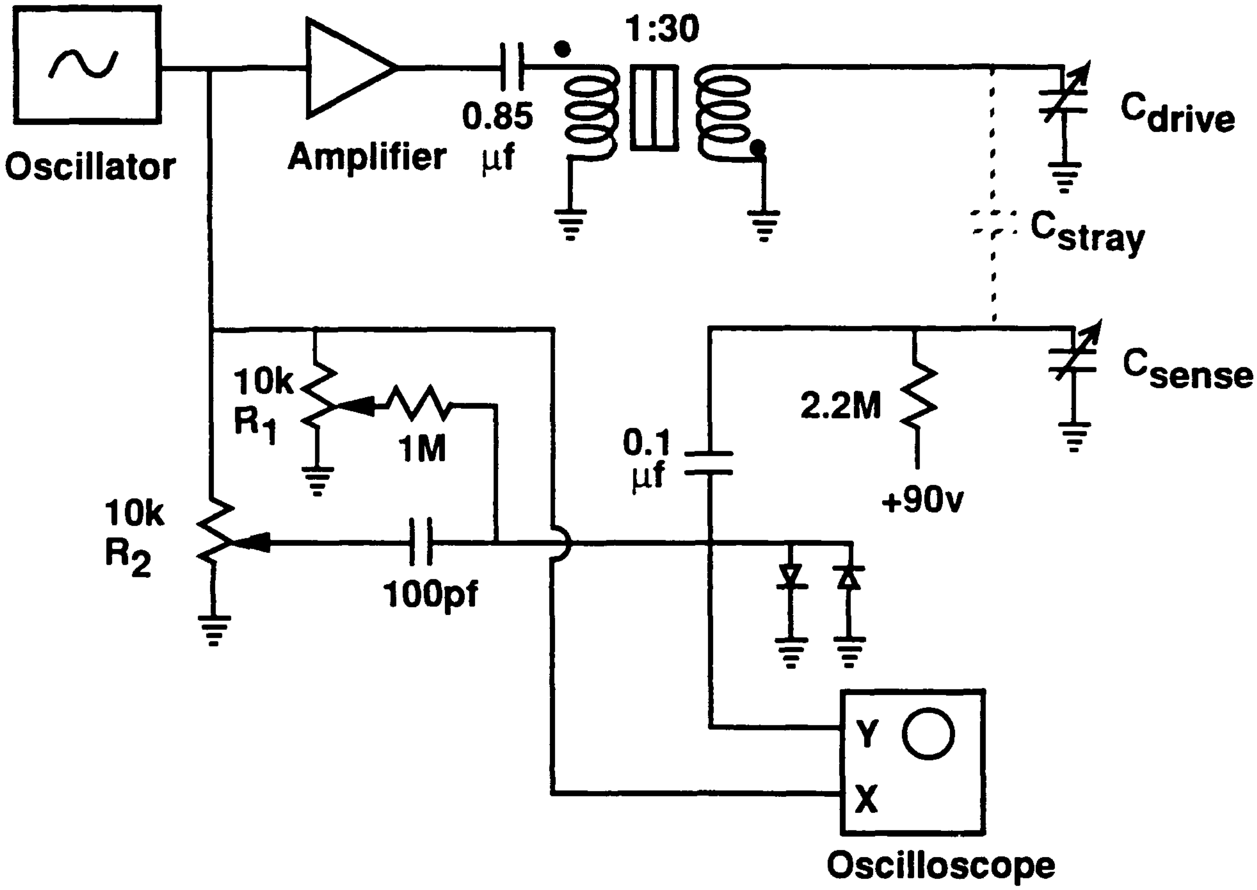
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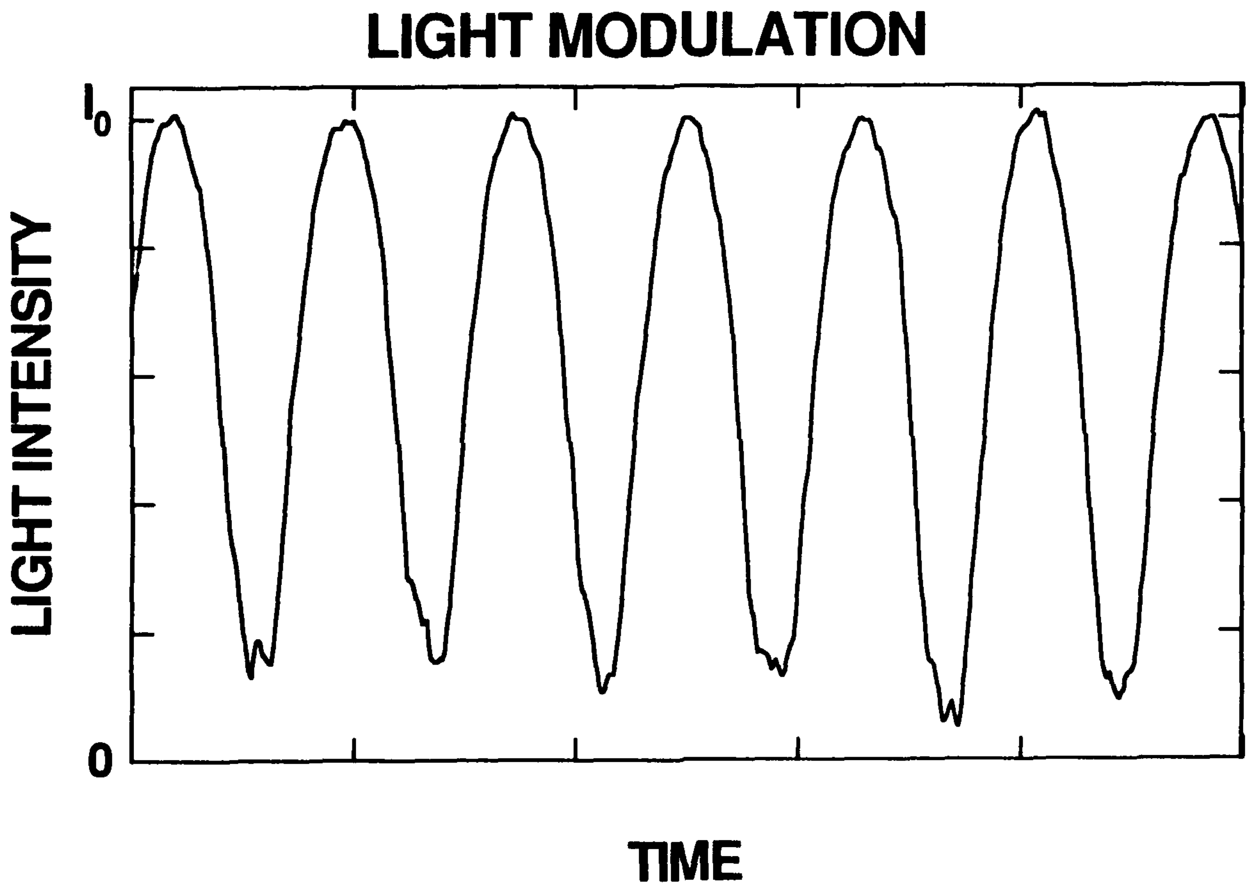
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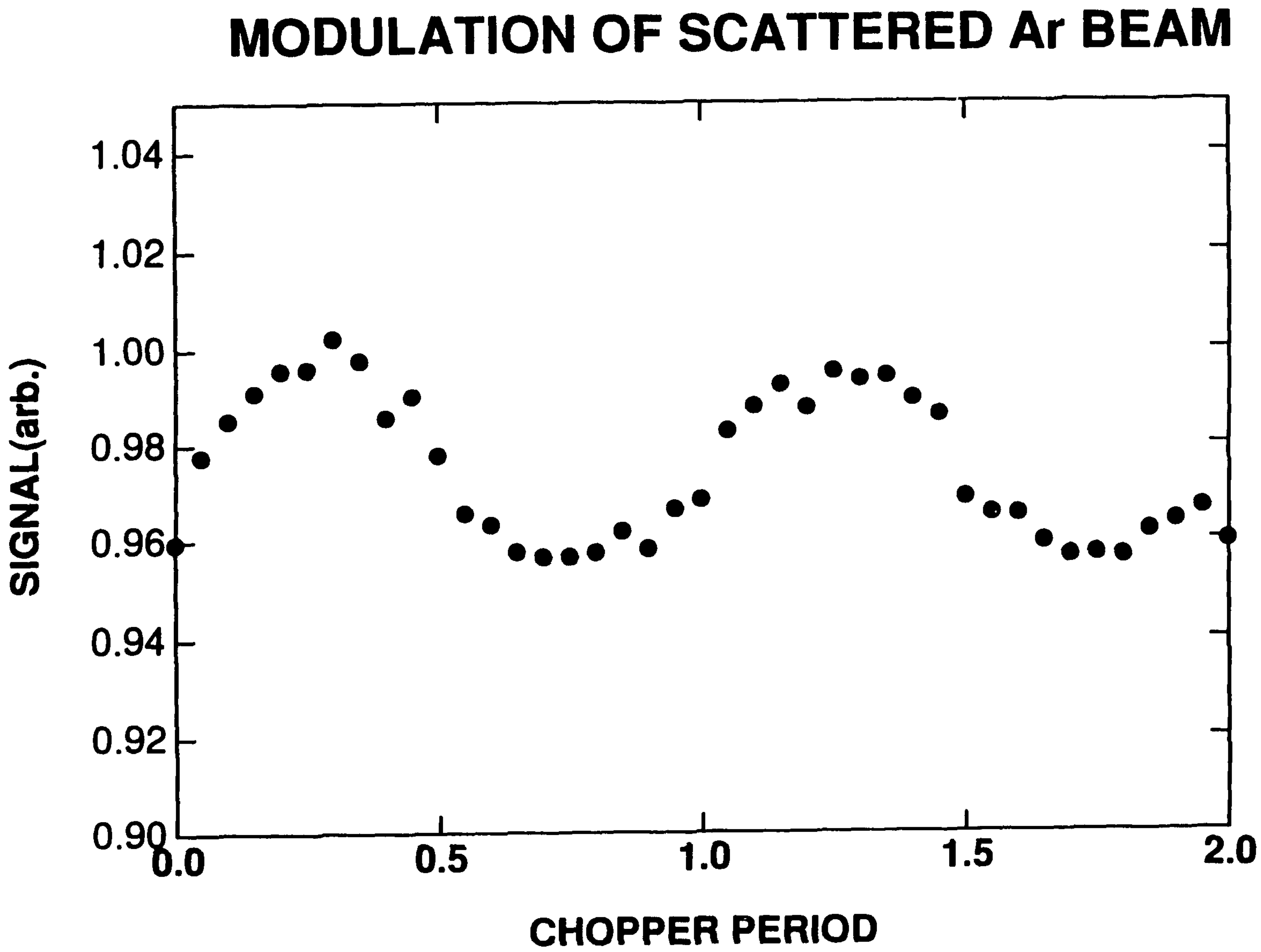
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