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Simplified VISAR System

W. C. Sweatt, P. L. Stanton, and O. B. Crump, Jr.
Sandia National Laboratories
Albuquerque, NM 87185

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ABSTRACT

A simplified, rugged VISAR system has been developed using a non-removable delay element and an essentially non-adjustable interferometer cavity. In this system, the critical interference adjustments are performed during fabrication of the cavity, freeing the user from this task. Prototype systems are easy to use and give extremely high quality results.

INTRODUCTION

Laser Velocity interferometry is the modern standard for measurement of shock wave phenomena in solids. The first such system was the VISAR (Velocity Interferometer System for Any Reflector), developed by Barker and Hollenbach[1]. It consists of an unequal leg Michelson interferometer in which monochromatic light reflected from a target is split and traverses two legs. One leg has a longer delay time, but the distance along both paths appears to be the same, so when the to beams are recombined at the beam splitter mirror, interference is produced. The interferometer measures the Doppler-induced changes in the frequency of the light beam reflected off the moving target.

A major modification to the basic VISAR design was made by Hemsing, who constructed the first Push-Pull VISAR[2]. The Hemsing design uses a differential amplifier to sum both recombined beams from the beam splitter. The advantages of this design are a stronger signal, rejection of unwanted self-light from the target, and simplified data reduction.

A laser interferometer requires very precise alignment and adjustment of the optical elements. Most VISARs are built on optical bread-board tables, using commercial mounts for the optical elements. Frequent adjustment is required to maintain high contrast on the interference signals. The simplified system described here is based on a so-called "Fixed-Cavity" design in which the critical interferometer cavity elements are aligned and then permanently bonded together during assembly, thus providing a high quality interferometer cavity with a fixed velocity sensitivity which requires no further adjustment.

OBJECTIVES

The overall objective of this study was to develop a VISAR system which is easier to use while maintaining high quality velocity measurement performance. Since the key element was the fixed-cavity itself, the initial efforts were concentrated on determining whether as stable cavity could be produced. As development of the cavity progressed, it became apparent that in order to take full advantage of the fixed cavity concept, the entire system should be revised. The objectives then were expanded to include the development of a complete system based on the fixed-cavity concept.

FIXED INTERFEROMETER CAVITY

The essential elements of the velocity interferometer have been designed to fit together so they can be bonded into a single, permanent assembly. Such an assembly, illustrated in Figure 1, includes the glass delay bar, the beam splitter, the mirrors, and the eighth-wave plate. This section deals with the theory of the fixed-cavity system.

A VISAR is a speckle interferometer. For this particular configuration, the "object" is the exit face of the optical fiber that brings the light reflected off the target. As shown in figure 1, the coherent light exiting the fiber is "quasi-collimated" by a lens before it enters the interferometer. An amplitude beam splitter divides the light into two channels. These beams are recombined by the same beam splitter after reflecting off the end mirrors. A view back into the interferometer would present two images of the optical fiber. These images must be exactly superimposed on one-another for good interference. This means that they must be in registration both laterally and axially. Axial registration occurs when the reduced lengths of the two legs are equal[3] that is,

l(air)/n(air) = l(glass)/n(glass) + l(eighth)/n(eighth)

where l and n are the lengths and indices of the parts in the optical path. Given this condition, lateral registration occurs when the beam splitter and both end mirrors are all parallel to one-another.

Intensity changes occur in the output of the interferometer as the target velocity changes because 1.) the light reflected off the target is Doppler shifted, and 2.) there is an Optical Path Difference (OPD) between the two legs of the interferometer. The relative phase of the light from the two legs of the interferometer is equal to the OPD divided by the wavelength of the light. The Doppler effect changes the wavelength.

The OPD for this system is

OPD = l(glass)*n(glass) + l(eighth)*n(eighth) - l(air)

The target velocity that will cause a relative phase shift of 2*pi is called the Velocity Per Fringe

VPF = lambda*c/(2*OPD)

The purpose of the eighth wave plate, as in all VISAR systems, is to delay one polarization component of the beam relative to the other. The beam traverses the eighth wave plate twice, delaying the p-component by one-quarter of a wavelength relative to the s-component. Later, the two are analyzed separately to produce quadrature encoding of the interference phase.

Extreme precision is required in the assembly of the cavity. Proper spacing of the air leg and precise adjustment of the cavity mirrors are required to achieve high quality superposition of the two beams and produce high contrast. A combination of visual, mechanical and electronic observations is used during assembly to obtain good alignment.

The mirror at the end of the air delay leg is mounted on a commercial piezoelectric translator. The translator provides three valuable features for the VISAR system. First, translation is used during setup to simulate target motion. This enables the operator to determine the expected magnitude of the signal, which depends on the reflectivity of the target. This also provides a check on the quadrature of the system. Second, by application of a dc bias voltage to the translator, the mirror position, and thus the initial phase of the interference signals, may be selected. Although this adjustment is not required, it can be very useful in some applications. The third feature of the translator provides an added measure of precision adjustment to the cavity. In the PAZT translator, the mirror is actually mounted on a three point support, each of which is an independently controllable piezoelectric crystal. The dc bias to each crystal may be adjusted to provide a small tilt to the mirror, giving final trim to the interference superposition of the beams. In practice, this adjustment has been required only at the time of initial assembly and setup of the cavity. However, the adjustment remains available to permit later adjustment if, for example, the cavity should deform with age.

THE SYSTEM

Although the fixed interferometer cavity could be installed on almost any existing VISAR table, the fixed-cavity concept can be used to greatest benefit if the remainder of the system is redesigned to take advantage of its simplicity. This section provides a discussion of those redesign concepts.

The signal light reflected off the target can be routed to the cavity using an optical fiber, rather than lenses and mirrors. This permits the interferometer to be located away from the shock wave experiment and near the signal recorders. In the present system, the photomultiplier detector tubes are mounted adjacent to the cavity, providing a compact, rigid, close-coupled package shown schematically in figure 2. The package fits in a standard 5 inch tall rack module, and is completely enclosed.

The associated electronics for the interferometer includes individual dc power supplies for the four photomultiplier tubes and summing amplifiers for the outputs of the tubes. These are built into separate rack-mount modules. The PAZT translator requires a controller which is also built into a rack-mount module. The fixed-cavity VISAR system, including the interferometer module, the power supply module, the amplifier module, and the PAZT driver and a multi-channel high-speed digitizer are mounted in a single equipment rack.

Two additional optical modules are required. One is a laser light source module and the other is a module that sends the laser light to the target and collects the return light. These modules may be interconnected with optical fibers, allowing flexibility in location of the modules. The laser module would be typically located in a remote utility area where adequate power and cooling water are available. The target coupling module needs to be located near the target, which minimizes the eye hazard associated with a high-power laser beam.

The laser module includes an acousto-optic modulator (AO Cell) to limit light pulse duration. This modulation accomplishes two necessary functions. First, the photomultiplier circuits must be operated a low duty cycle to maintain specified average current and linearity. Second, the average power in the optical fibers must be limited to prevent heat damage to the fiber optics and the target sample.

The target coupling module is shown in figure 3. It directs the laser light from the laser module to the target and collects the return signal. It also contains a TV camera for alignment and focusing. The out-going and return light from the target are coaligned using a mirror with a small hole through it. The outgoing light passes through the hole and most of the return light reflects off the mirror. The returning laser light reflects from a dichroic mirror and is focused into a fiber for transmission to the interferometer module. The rest of the return light spectrum is transmitted through the dichroic to the TV camera.

To complete the system, a computer is used to acquire the data records from the digitizers, store the data, and perform the data processing to convert the data to interference phase and velocity records. The data reduction follows the general procedure outlined by Hemsing[2]

REPRESENTATIVE RESULTS

The fixed cavity VISAR system has been used successfully to record velocity histories from several types of explosive devices. A typical application is the study of electrical slapper detonator subassemblies. The thin plastic flyer is accelerated by an electrically exploded metal foil. The data from representative shot is shown in figure 4. The signal-to-noise ratio is obviously large during the acceleration of the flyer. The two data traces are clearly in quadrature, as seen from figure 5, where they are plotted in an x-y plane with time as the parameter. The plot is very nearly circular and very nearly centered about the origin, indicating a well balanced system with nearly equal amplitude signals from each of the photomultipliers.

This plot also required no time-shifting because a multichannel digitizer with common time bases was used to record the two data records. As a result, the analysis is very easy, and conversion from the raw data to a velocity record requires a fraction of a second on a small computer. The resulting velocity record is shown in figure 6. Included in figure 6 is the displacement history integrated from the velocity record. It can be seen that the flyer had displaced approximately 0.25 mm at 2 microseconds into the record. At that time, the amplitude of the data traces began to decrease substantially (fig. 4) and the circle plot radius began to diminish (fig. 5). This result is typical of slappers and suggests that the plastic film may be changing reflectivity.

Another representative example of data is shown in figure 7. A 0.005 inch thick steel plate driven by a detonating column of high explosive accelerates to about 2.8 km/s and is tracked for a displacement of several millimeters. The ringing in the records is the shock wave reverberation through the steel plate. It should be noted that the initial velocity jump, from zero to about 1.88 km/s, was due to an explosive-driven shock in excess of 40 GPa. Shocks of this type cannot be tracked by photomultipliers, amplifiers and digitizers of current technology. It was necessary to add missing fringes to this velocity record, at the first jump only. In this regard, the fixed interferometer cavity is not limited, but only the auxiliary electronics. The fixed cavity could be used with ORVIS[4] or the the streak camera recording method of Hemsing[5] and Paisley[6]

DISCUSSION

The main purpose of this design effort was to develop a VISAR system that is easy to operate. Thus the time required for setup and operation is minimized and the required skill level of the operator is reduced. To this end, the sensitivity to drift and rough handling has been minimized and the need for most of the adjustments in earlier systems has been removed.

While simplicity and ruggedness are gained with this system, flexibility is compromised. With a fixed cavity system, the VPF is obviously fixed when the parts of the interferometer are glued together. With a table top system, almost any velocity range can be measured.

To handle different velocity ranges, fixed cavities with VPF's of 1.0 km./sec. and 2.3 km./sec have been built. Others have been designed, including one with a VPF of 0.3 km./sec. The VISAR system accuracy is optimized when about two to five fringes are developed at the target's maximum velocity.

CONCLUSIONS

The concept of a fixed cavity VISAR has been demonstrated to provide a simple, rugged, precision system for measurement of shock related velocity changes. While the fixed interferometer cavity may be incorporated into most existing VISAR systems, it can be better used if the entire system is modified to take advantage of the fixed cavity. Other improvements to the system are in development, including conversion to a laser diode light source.

References:

1. L. M. Barker and R. E. Hollenbach, "Laser Interferometry for Measuring High Velocities of Any Reflecting Surface," J Appl Phys 43:11 (Nov, 1972).

2. W. F. Hemsing, "Velocity Sensing Interferometer (VISAR) Modification," Rev Sci Instrum 50:1 (Jan 1979).

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4. D. D. Bloomquist and S. A. "Sheffield "Optically Recording Interferometer for Velocity Measurements with Subnanosecond Resolution," J Appl Phys 54:4, (Apr, 1983)

5. W. F. Hemsing, "VISAR: Interferometer Quadrature Signal Recording by Electronic Streak Camera," Proceedings of the Eighth Symposium (International) on Detonation, Albuquerque, 1985.

6. N. I. Montoya, D. L. Paisley, D. B. Stahl, I. A. Garcia, and W. F. Hemsing, "Velocity Interferometry of Miniature Flyer Plates with Sub-Nanosecond Time Resolution," Procedings of SPIE High Speed Conference, San Diego, 1990.

Figure Captions

Figure 1. Fixed Interferometer Cavity

Figure 2. Fixed Cavity Module

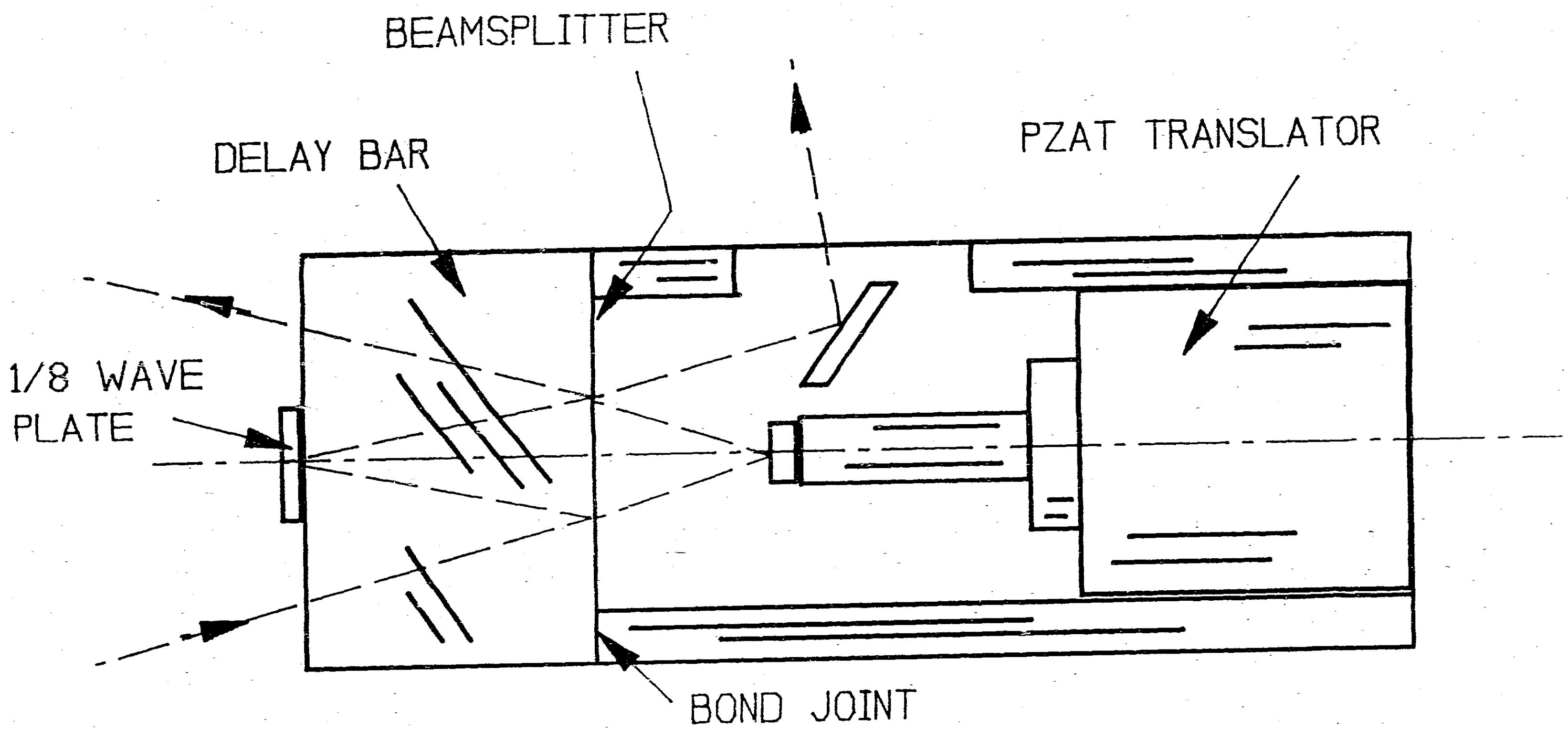
Figure 3. Target Coupling Module

Figure 4. Data Traces from Electrically Accelerated Flyer, using Fixed-Cavity VISAR

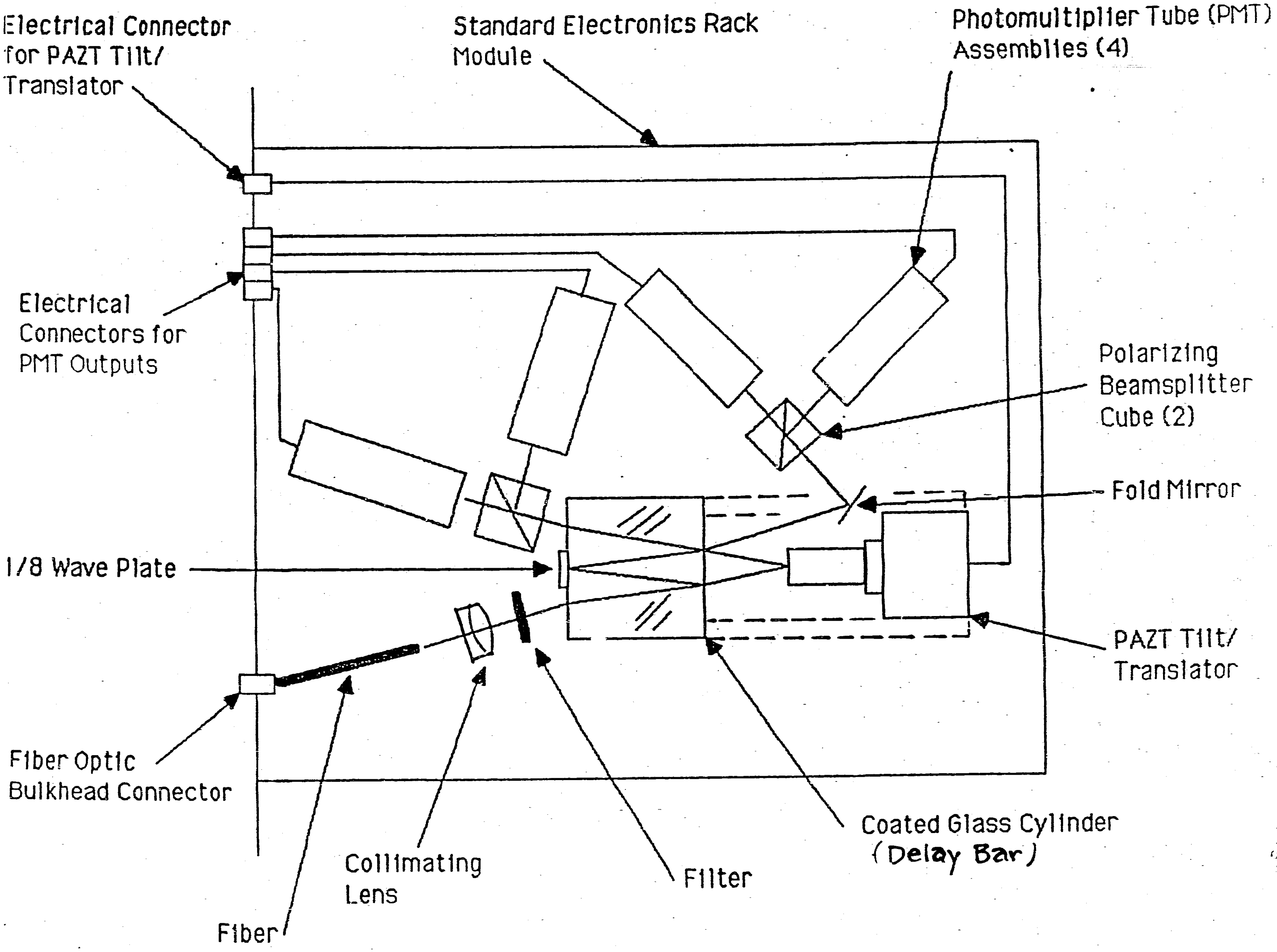
Figure 5. X-Y Plot of Data Traces from Previous Figure

Figure 6. Velocity Record Obtained from Previous Two Figures

Figure 7. Data Traces and Resulting Velocity Record from Explosively Driven Thin Steel Plate.

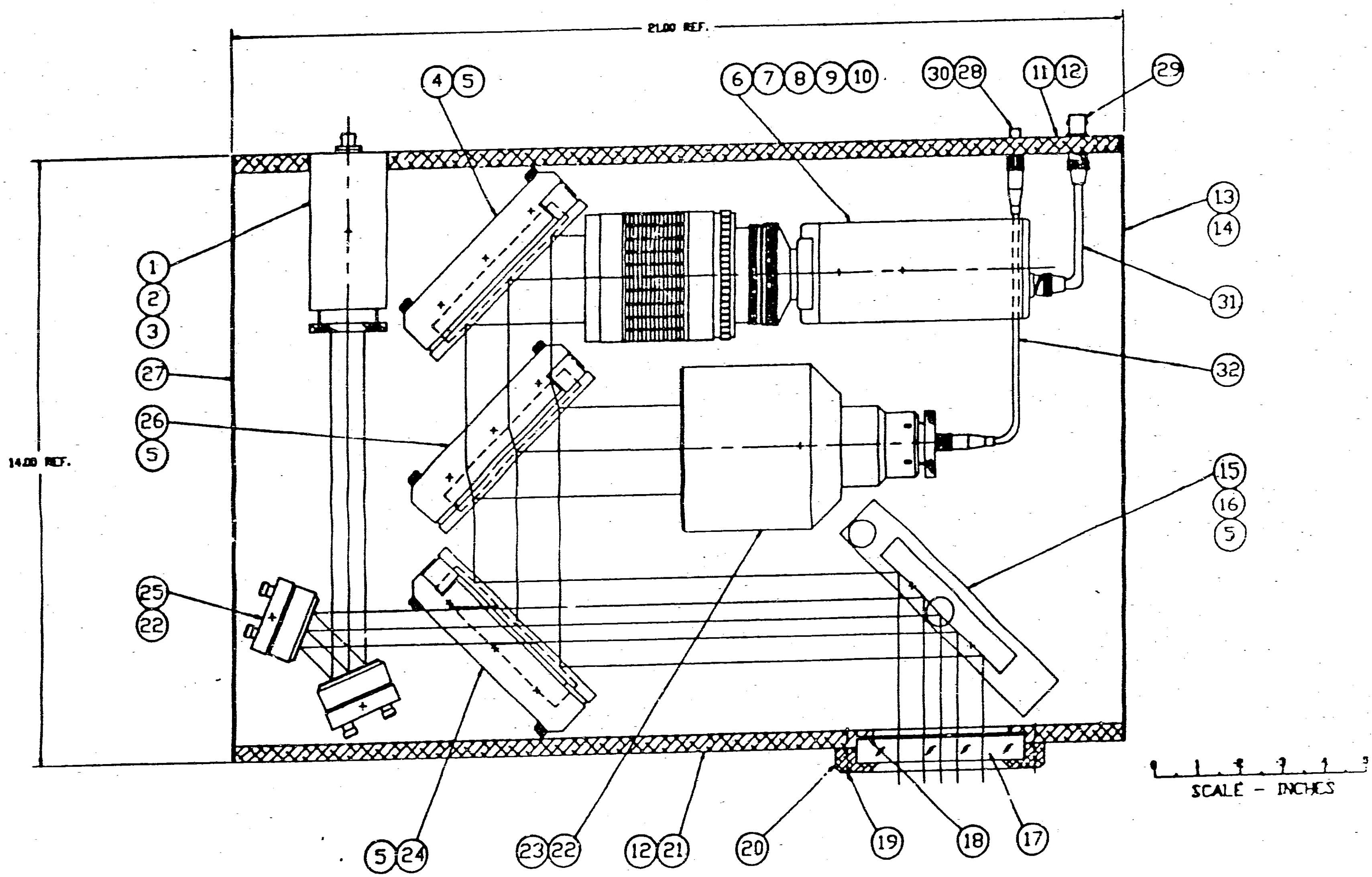


FIXED INTERFEROMETER CAVITY



SCHEMATIC BLOCK DIAGRAM

Figure 2



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14.00 REF.
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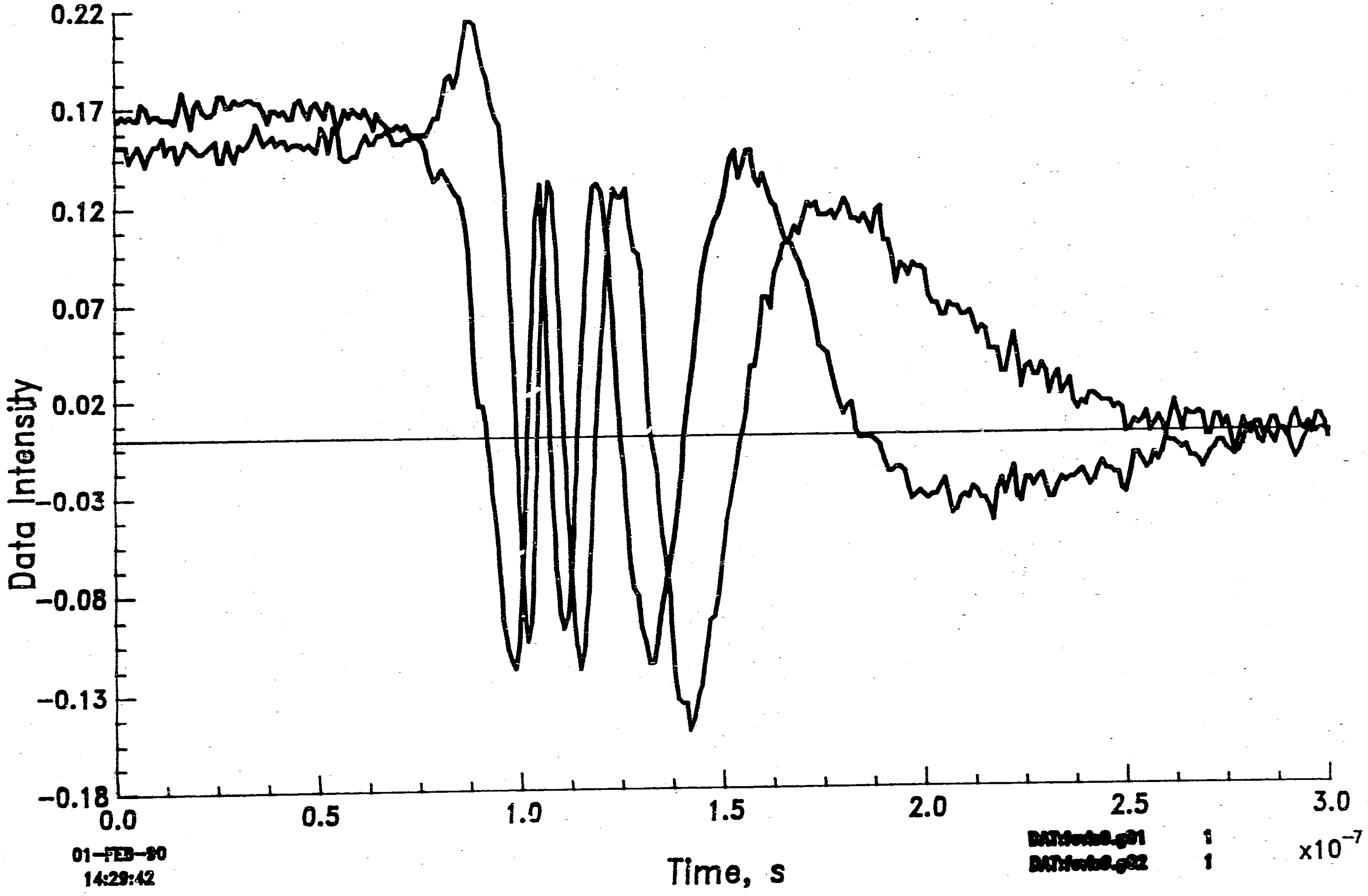
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0.02
−0.03
−0.08
−0.13
−0.18
Data Intensity
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1.5
2.0
2.5
3.0
x10^-7
Time, s
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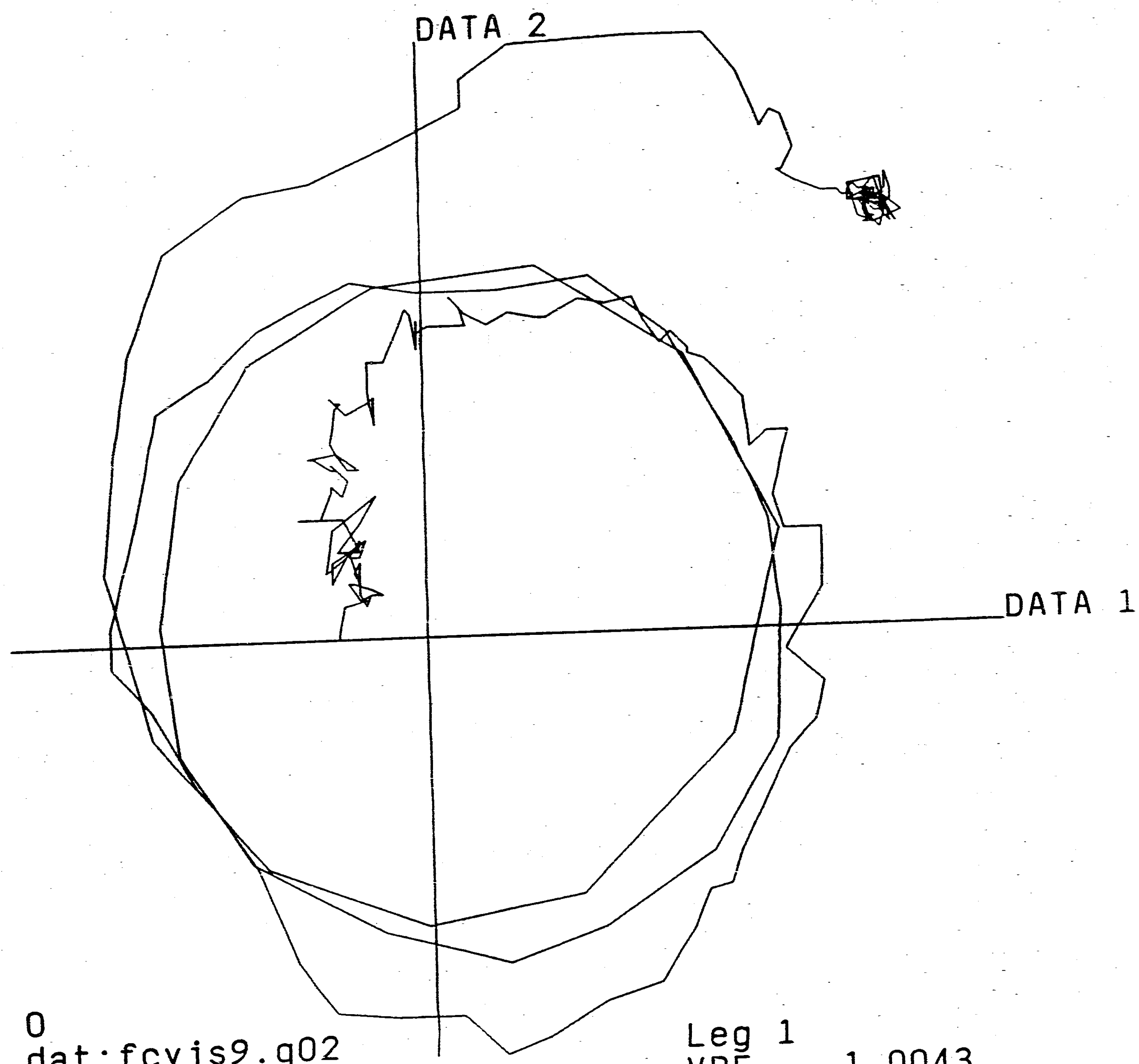
14:29:42



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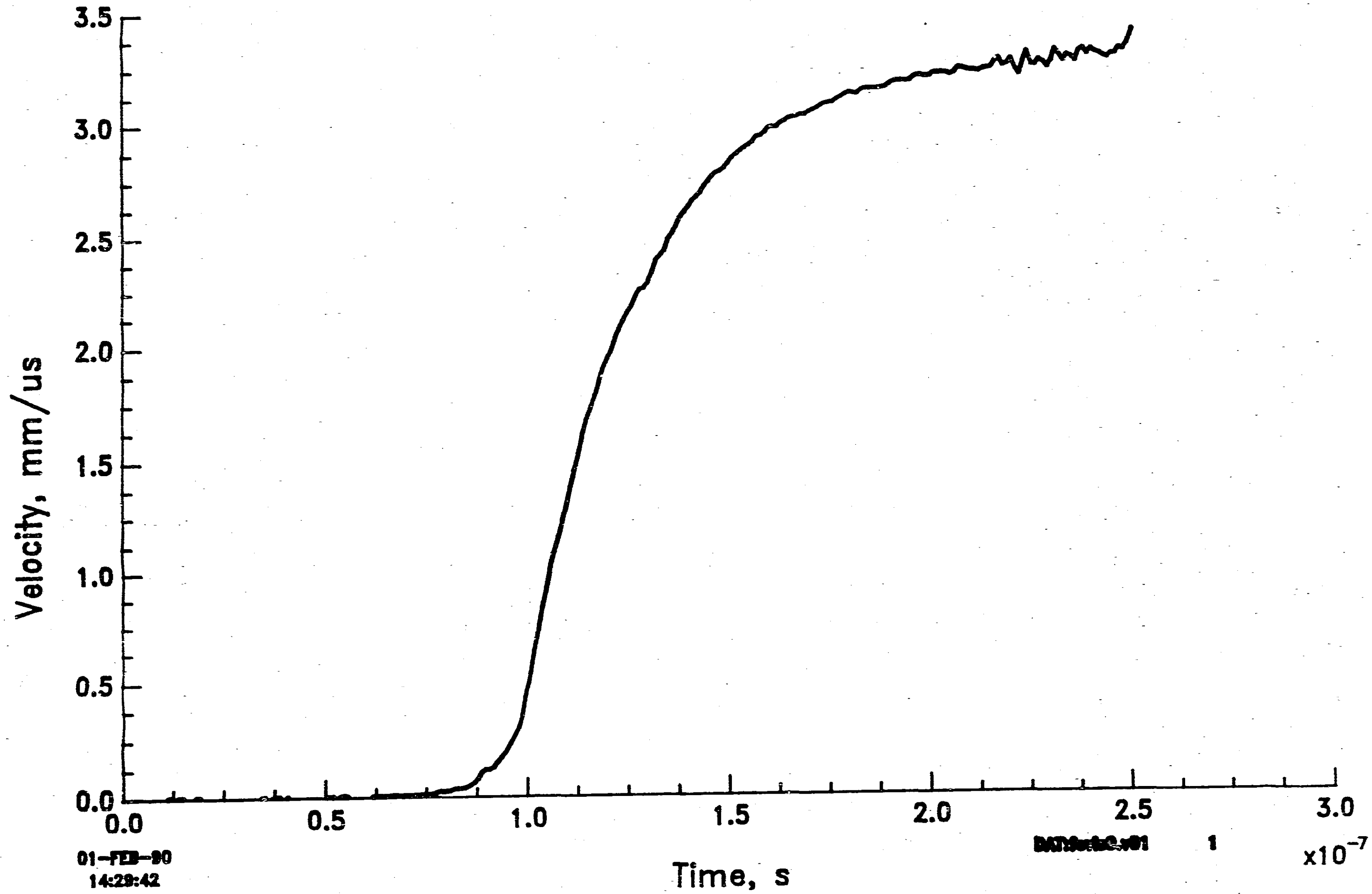

Velocity, mm/us
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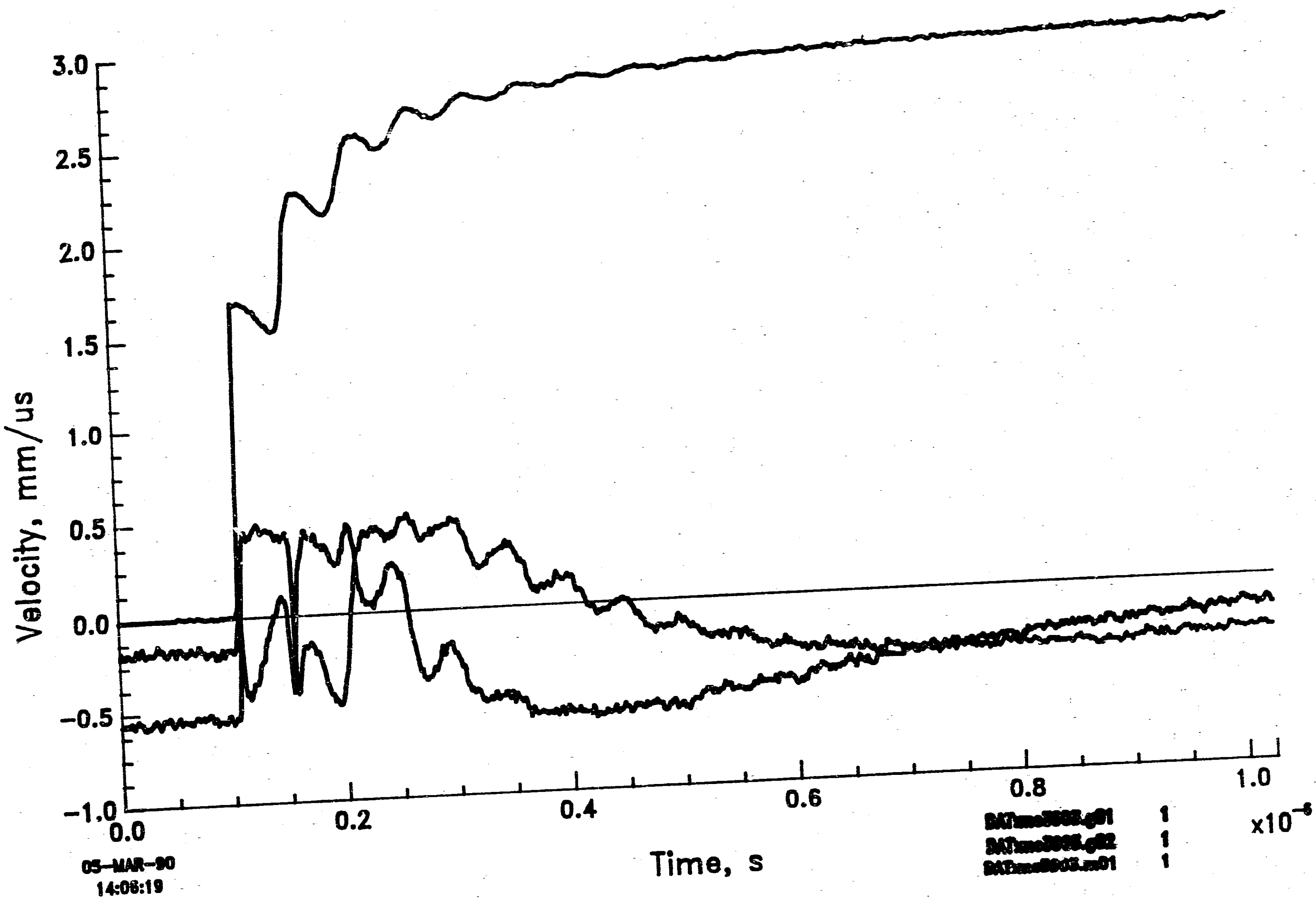
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
x10^-7
Time, s
01-FEB-90
14:29:42
1


3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
Velocity, mm/us
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0.4
0.6
0.8
1.0
x10⁻⁶
Time, s
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END

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