PREPROTOTYPE MACHINE-MOUNTED RESPIRABLE DUST MONITOR

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
Pittsburgh Mining and Safety Research Center
Bruceton, Pennsylvania

by

Pedro Lilienfeld

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Burlington Road
Bedford, Massachusetts 01730

Final Report for the Period
29 June 1976 to 16 May 1977

on

Contract No. HO-166097
Machine-Mounted Respirable Dust Monitor

November 1977

DISCLAIMER NOTICE

ERRATA

PREPROTOTYPE MACHINE – MOUNTED RESPIRABLE DUST MONITOR

Final Report on Contract No. HO-166097

1. Paragraph 3 of Page 31 should read:

   "Figure 9 summarizes the data of Table 1 and depicts the error bars associated with the gravimetric reference determinations assuming a weighing error of twice ± 0.1 mg. The horizontal error bars associated with the M3X statistics are negligible in comparison; the calculated 2-sigma beta sensing errors are equal to ± 0.26 mg/m^3 for the 29-minute tests and about 0.15 mg/m^3 for the 89-minute tests. It should be noted that none of the 24 data points falls outside the theoretically predicted error band and that the correlation coefficient of the gravimetrical versus M3X data is 0.976. The least squares regression line has the equation $y = 1.281 + 0.891x$, where y represents the gravimetric values, and x the results obtained with the prototype instrument under scrutiny. The standard error of the estimate for the data set of Table 1 is 1.303 mg/m^3. Since the error band for most gravimetric reference determination was about ± 3.4 mg/m^3 (based on a weighing accuracy of twice ± 0.1 mg for a typical sampling time of 30 minutes), whereas as mentioned before the 2-sigma error band for the M3X was only ± 0.26 mg/m^3, most of the error of the estimate must be attributed to the gravimetric determinations

2. Figure 9, Page 33 – the legend should read:

   "$y = 1.281 + 0.891x$
   $r = 0.976$"

   The dashed line should be replotted accordingly

3. Paragraph 2, Page 34 – Replace the last sentence by:

   "Again, most points fall within the expected error band, and the correlation coefficient for these data is 0.978; the least squares regression line is $y = 0.098 + 0.884x$ and the standard error of the estimate for this data set is 0.146 mg/m^3.

4. Figure 10, Page 35 – the legend should read:

   "$y = 0.098 + 0.884x$"

   The dashed line should be replotted accordingly

5. Table 2, Page 34

   In the column "F-ratio" and the line "Temperature," replace the value 0.716 by 0.0716.

REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle PREPROTOTYPE MACHINE-MOUNTED RESPIRABLE DUST MONITOR		5. Report Date November 1977
		6.
7. Author (s) Pedro Lilienfeld		8. Performing Organization Report No. GCA-TR-77-27-G
9. Performing Organization Name and Address GCA Corporation GCA/Technology Division Burlington Road Bedford, Massachusetts 01730		10. Project/Task/Work Unit No.
		11. Contract or Grant No. HO-166097
12. Sponsoring Organization Name and Address U.S. Department of the Interior Bureau of Mines Pittsburgh Mining and Safety Research Center Bruceton, Pennsylvania		13. Type of Report Final Report
		14.
15. Supplementary Notes		

16. Abstract

This report describes a program to develop, design, fabricate and subject to environmental testing three prototype collection-sensing devices of an eventual mining-machine mounted automated monitor for the measurement of the respirable fraction of coal mine dust to determine both short-term as well as average mass concentrations over typical 8-hour shifts. The design of this instrument is based on collection by filtration and mass sensing by beta-radiation attenuation. The emphasis of this development program was to evolve a rugged, stable and reliable collection-detection head compatible with the environment to which the eventual monitor will be subjected.

Laboratory testing of this prototype instrument was performed over a representative range of temperature, humidity, dust concentration and composition, shock and vibration. The results of this testing program indicated that the operation of the prototype version is compatible with these environmental conditions and that further development of this configuration into a field operational device is justified.

17. Originator's Key Words		18. Availability Statement	
19. U.S. Security Classif. of the Report UNCLASSIFIED	20. U.S. Security Classif. of This Page UNCLASSIFIED	21. No. of Pages	22. Price

FOREWORD

This report was prepared by GCA Corporation, GCA/Technology Division, Burlington Road, Bedford, Massachusetts 01730, under USBM Contract Number HO-166097. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Dr. Welby Courtney acting as the Technical Project Officer. Ms. Elizabeth Rexroad was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period 29 June 1976 to 16 May 1977. This report was submitted by the authors on 30 November 1977.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION AND SUMMARY

The overall objective of this instrument development program is to initially evolve a preprototype respirable dust monitor and then eventually, within a follow-on program, produce a practical field-compatible device capable of being mounted onto a typical coal mining machine such that both the peak as well as the shift-averaged dust concentration exposure of the machine operator can be assessed on a routine basis. The method of measurement is based on a combination of filter collection and beta radiation attenuation mass sensing, and the program described in this report was restricted to the development of a laboratory prototype system capable of defining and demonstrating the feasibility of this approach for the reliable assessment of the mass concentration of respirable dust within the coal mining environment.

The importance of this instrument development program becomes apparent when one examines the vast number of personal samplers presently utilized in the mining environment for the purpose of routine, daily surveillance and the staggering logistics operation required for the assessment of the collected samples.[1,2] The present program is directed at alleviating the performance of this mission entrusted to MESA, to improve its reliability as well as to determine excess dust exposures over short-term time periods, information which so far is completely unavailable within the current routine personal sampler surveillance program.

This initial instrument development program consisted of two principal work phases: the design of the preprototype instrument, and the fabrication and testing of three preprototype units. The design was aimed at developing a device with which the overall feasibility of the concept could be tested under a variety of conditions simulating the operating environment to which the monitor was expected to be exposed. The program objective was limited to the development of an instrument that could be tested in the laboratory without being a complete and self-contained entity. Thus the effort was concentrated on the design of two main elements: a collection-detection head, and the supporting control, computation and recording electronics. A flow controller and pump were additional auxiliary elements of the system. No attempt was made at either incorporating all these elements into a single package or to provide the required operating voltages which are expected to be supplied by external bench type sources.

The design effort itself involved two principal disciplines: electromechanical design and electronics design. The former was applied to the collection-detection head whereas the latter was required for the control, and signal processing circuitry development. A major part of the effort of this program was directed at the sensing head design and fabrication since the electronic hardware was a modified version of circuitry previously developed by GCA. A significant programming effort was, however, required to adapt the existing hardware to the requirements of the new machine-mounted monitor.

The testing phase involved a carefully selected series of combinations of the rather numerous parameters to be varied in order to evaluate the performance of the instrument under a variety of conditions. Temperature, relative humidity, dust concentration, type of dust, shock, and vibration were the testing variables to which the instrument was subjected. In addition the performance and compatibility of several different filter media were evaluated both in relation to the instrument under development as well as with respect to subsequent analysis of the quartz content in the collected sample.

INSTRUMENT DESIGN

The basic operating principles, design criteria and detailed description of the Preprototype Machine-Mounted Respirable Dust Monitor (henceforth called M3X for Machine Mounted Monitor Preprototype) are presented in this section of the report. The basic measurement approach is based on a two-stage particle collection: a size selective cyclone prec-llector for the retention of the large nonrespirable particle size fraction, followed by a total respirable dust filter-tape collection stage combined with a moveable beta source-detector mass sensing configuration. These elements, in combination with the tape advance and source-detector assembly rotation mechanisms constitute the collection-sensing head. In addition the M3X includes a mass flow controller, a pump, and the electronic control, signal processing and data recording subsystem.

Design Criteria and Theory

Several different configurations were considered for the design of a filter collection-beta attenuation dust monitor. Two conflicting requirements had to be met within this design approach: maximum collection area density to optimize short-term dust sensing sensitivity and at the same time minimization of the number of collection areas or spots over a typical long-term 8-hour monitoring period. A filter tape approach was selected in preference to a cassette system because of the increased mechanical complexity of the latter and the increased filter storage capacity of the former. The other design variation was related to the relative placement of the mass sensing source-detector pair with respect to the dust collection point. Two principal configurations were considered: combined dust collection and mass sensing, and separate collection and sensing. The first approach utilizes a special head design wherein the collection area and the beta sensing area are combined such that the filter medium does not have to be translated during each of the measurement periods, and tape motion occurs only after completion of a given measurement to restart the operation at a clean spot. The alternate solution is based on either a single or a double beta sensing configuration[3,4] wherein the filter tape is beta-tared at one site and collection occurs at another. The latter solution, separate collection and sensing, is preferable for ambient monitoring (i.e., microgram/m^3 concentrations) because it permits the reduction of the effects of temporal air density fluctuations by minimizing the source-detector distance. This solution, however, not required for concentrations exceeding about 0.1 mg/m^3 would have resulted in a considerable increase in instrument complexity and in the stringency of the precision requirements of the filter tape advance system. The solution actually incorporated in the M3X is a novel approach combining the advantages of the two alternatives discussed above. The principal advantage of this solution being that the filter tape is not subjected to any motion or displacement between the time the reference and the final beta transmission sensing are performed. The detailed description of this design approach will be presented in a later section of this report.

The objectives to be achieved with the instrument under consideration can be summarized as follows:

- The ultimate program emphasis is on the development of an 8-hour exposure monitor with enforcement potential.

- The number of collection spots per 8-hour shift should be minimized to facilitate subsequent dust analysis.

- The collection spots of at least five shifts should be preserved after collection has taken place.

- The device will use the 10 mm cyclone and will thus operate at a nominal flowrate of 2 liters/minute.

- The short-term measurement range should be 2 to 20 mg/m^3.

- The short-term measurement accuracy should be equal to or better than ± 25 percent (2-sigma).

- The long-term or average dust concentration measurement range over the 8-hour shift should be 0.2 to 5 mg/m^3.

- The long-term measurement accuracy should be equal to or better than ± 15 percent (2-sigma).

- The environmental conditions under which the collection-detection head must meet these specifications are: temperature: 32 to 120^oF; relative humidity; 10 to 95 percent; vibration: MIL standard, Method 514; shock: idem, Method 516.

The minimization of the number of collection spots per shift and the duration of the short-term measurement are conflicting requirements such that a compromise solution had to be evolved. This solution was based on consecutive short-term samples deposited on the same spot until a maximum loading is achieved and the filter tape is then made to advance to a new spot.

The relevant calculation must be based on the fact that as the dust deposit increases on a given spot the beta radiation attenuation increases reducing the accuracy of the measurement as a result of the lower number of counted beta pulses. Thus the calculation must be based on the stipulated accuracy objective for the last short-term measurement on a given spot; i.e., when the dust deposit is the heaviest. Obviously all preceeding measurements on that spot will have a higher accuracy (for the same dust concentration) because the amount of deposited dust is less than for the final measurement period. On this basis it is possible to calculate the required collection area which is one of the crucial design parameters.

The calculation of the relevant design parameters and the resulting values is based on the following equations:

$$(2\ \sigma_c) = \frac{2A\sqrt{2}}{\mu_m\ QT\sqrt{N}} \qquad (1)$$

$$N = N_o \exp(-\mu_m\ \delta) \qquad (2)$$

$$\delta = \frac{m}{A} \qquad (3)$$

The definition of the terms used above and their values based on the above compromise solution and the relevant contractual specifications are:

$(2\ \sigma_c)$ = two-sigma error of short-term mass concentration measurement = 0.5 mg/m^3

A = filter collection area

μm = beta absorption coefficient = 0.262 cm^2/mg (for ^{14}C)

Q = sampling flowrate = 2 liters/min

t = short-term sampling period = 30 minutes

T = long-term collection period = 480 minutes (8 hours)

N_o = initial beta count (with clean filter) = 10^5

N = final beta count after long-term collection period

m = collected mass

The first step is to calculate N, by combining equations (1) and (2):

$$\sqrt{N}\ \ell n\ N_o/N = \frac{2\sqrt{2}\ C_{av}\ T}{(2\ \sigma_c)\ t} = 226$$

which results in a two-valued position for N : 8×10^3 and 2.1×10^4, the average of which, $N = 1.45 \times 10^4$, represents the maximum value for $\sqrt{N}\ \ell n\ N_o/N$ for $N_o = 10^5$ and is thus an optimum solution.

Replacing these values in equation (2) we obtain δ 7.5 mg/cm^2; i.e., the maximum deposit per unit area acceptable before beta absorption becomes excessive. From equation (3) we then obtain

$$A = \frac{C_{av}\ QT}{\delta} = 0.32\ cm^2$$

and thus the collection spot diameter becomes d = 0.64 cm and the face velocity at the collection spot is V = Q/A = 1.04 m/s.

The long-term measurement accuracy; i.e., the accuracy of the average of the short-term measurements would then be:

$$\overline{(2\ \sigma_c)} = \frac{(2\ \sigma_c)}{\sqrt{n}} \qquad (4)$$

where n = number of short-term measurements.

For t = 30 minutes and a total shift duration of 480 minutes, n = 16 and thus for an average shift concentration of 5 mg/m^3 the long-term measurement accuracy would be better than 2.5 percent, whereas for a minimum average concentration of 0.2 mg/m^3, for which N remains very nearly equal to N_o throughout the entire measurement period, as far as counting accuracy is considered, the accuracy would be about 20 percent, or conversely, an accuracy of 15 percent would be maintained down to about 0.3 mg/m^3. Although this constitutes a slight deviation from the original accuracy objective, it is considered to be an acceptable compromise in order to achieve all other centrally important objectives.

Based on the above calculated maximum value of δ_{max} = 7.5 mg/cm^2 and for A = 0.32 cm^2 the maximum mass to be collected on a single filter spot becomes

$$m_{max} = \frac{\delta_{max}}{A} = 2.4 \text{ mg}$$

This value of mass would constitute the beta attenuation criterion for advancing the filter tape. In practice, however, a flow-leakage pressure drop constraint was found to be the governing factor in determining the maximum permissible mass loading on a given filter spot. This maximum is dependent on the dust composition; i.e., certain dusts increase the filter pressure drop more rapidly than others. Thus a maximum spot loading of about 1 mg was found to be acceptable for coal dust but somehwat marginal for Arizona road dust. As a conservative compromise a maximum mass value of 0.5 mg was incorporated in the control software. This particular value can, of course, be modified by a simple programming modification if so desired. After completion, and outside of the development program described in this report, an improved filter-tape sealing design was evolved which should permit the collection of a larger mass of dust on each spot, of the order of 1 to 1.5 mg, without flow leakage problems. This new design would be incorporated in the follow-on field prototype of this instrument.

Selection of Radioactive Source and Detector

The criteria for the selection of the radioactive source and the radiation detector have been discussed in the literature,[5,6,7] and will be treated only briefly within the present document. Very few beta-radioactive isotopes are compatible with the requirement imposed by this type of application: low beta energy ($<$ 300 keV), long decay time (half life $>$ 10 years), absence of gamma radiation, physical and chemical stability, specific activity $>$ 1 millicurie/milligram, low cost and easy availability. Carbon-14 fulfills all these requirements and has been used extensively in similar instrumentation. The construction of the actual source is of crucial importance in the design and operation of dust monitoring field instrumentation. The source incorporated in the M3X is an extremely rugged and reliable carbon-14 beta source of unique design (described in more detail in the final report of another U.S. Bureau of Mines project).[7] This design has been optimized based on 5 years of field experience with GCA's RDM-101, RDM-201 and RDM-301 instruments. Furthermore, because of its low total activity (100 microcurie), the source does not require AEC user licensing. Extensive field utilization, both in industrial as well as mining environments, during the last several years have demonstrated the mechanical ruggedness and long-term structural and chemical imperviousness of the optimized source design.

The selection criteria for the beta radiation detector have been discussed elsewhere,[4,6] and here as in other similar applications, the selected device is an end window, halogen-quenched, miniature Geiger-Muller detector whose design has been optimized over a period of several years. This miniaturized detector used on several of the commerically-produced GCA instruments is extremely rugged and is capable of very long continuous or quasi-continuous operation, an important characteristic for the presently considered application.

Within the collection-detection configuration selected for this instrument the beta detector had to be mounted downstream of the filter tape. As a result, its thin mica window is exposed to the decreased pressure prevailing at that side of the filter which can drop to about one-half of one atmosphere. The detector window must, therefore, withstand such pressure variations (from about 10^5 to 0.5×10^5 newtons/m^2 without rupture. A detector of the type described above was subjected to repeated pressure changes of nearly a full atmosphere (from 10^5 to about 0.05×10^5 newtons/m^2) without affecting the structural integrity of the window. This imperviousness is a result of the very small window area (< 0.01 cm^2) of this type of detector. The advantage of using such a small detector tube is that it permits to minimize the source-detector separation within the selected geometry, thus minimizing any errors resulting from atmospheric air density changes during a measurement period, without significant flow interference downstream of the filter collector.

Selection of Filter Medium

The filter medium utilized on this instrument had to fulfill several conditions and its selection represented a significant effort within this development program.

The criteria for the filter medium selection were:

- Nonhygroscopicity
- Collection efficiency $\geq$ 99 percent for particles > 1 μm in diameter.
- Alpha-quartz content of collection area < 5 μg.
- Adequate structural strength for mechanical transport and compatibility with manufacturing in the shape of a tape.

- Flow resistance of < 7000 Newtons/m^2 per m/sec (2 in. Hg/m sec^{-1}).

- Mass/area of clean filter < 6 mg/cm^2.

Initially, two filter media appeared to meet the criteria listed above: a polyvinylchloride-acrylonitrile copolymer with integral nylon support matrix commercially available as Acropor (Gelman), and a Teflon-impregnated two-layer glass fabric (Pallflex type TX40A30). Both these media were tested extensively within this program and both exhibited adequate characteristics of particle collection efficiency, mechanical strength, beta transmissivity, pressure drop at rated face velocity, etc. Both of these materials are also manufacturer specified as being virtually quartz-free, a requirement imposed by the need for subsequent dust analysis for quartz content. The mass per unit area of these two media was determined to be: 5.4 mg/cm^2 for the Acropor material (5 μm pore size) and 6.0 mg/cm^2 for the TX40A30 filter. The pressure drop of these media (without dust) was determined to be: 9500 newtons/m^2 (2.8 in. Hg) for the 5 μm Acropor material, and 3600 newtons/m^2 (1.05 in. Hg) for the Pallflex medium, within the M3X configuration; i.e., at a flowrate of 2 liters/min through a collection area of 0.45 cm^2, corresponding to a face-velocity normalized flow resistance of 12,800 and 4,900 kg $m^{-2} sec^{-1}$, respectively. It is obvious that the Pallflex material possesses a considerably lower flow resistance than the 5 μm Acropor and was thus preferred because of its greater dust retention capacity before clogging ensues. The TX40A30 medium has the following manufacturer specified efficiency characteristic: 95 percent for 0.3 μm particles, 99 percent for 0.5 μm and > 99 percent at 1 μm. In order to confirm these specifications, a qualitative test was performed with coal dust using a membrane filter downstream of the filter material under evaluation. While the upstream collection on the TX40A30 was determined to be several milligrams, no detectable collection was observed on the back-up filter.

Mechanical Design

Operating Principles

The mechanical design of the sensor head has been based on the following premises:

1. For minimal dust losses upstream of the collection site and for optimal dust distribution across the filter spot, no beta source or detector should be located in the flow path during collection.

2. For accurate location of the filter medium, relative to the detection pair, the filter must be clamped to the mechanical structure locating the detection pair for the duration of the count-collect-count cycle.

3. For comparable readings before and after dust collection, the same detector-source pair should be used for both readings.

4. For maximum filter tape and collection spot storage and simple transport design, a capstanless tape reel system is superior to other alternatives.

5. For simplest filter sealing, a nonmoving seal can be achieved on the downstream side by pumping the entire cavity below the filter. To achieve rapid flow stabilization after every pump start-up, the pumped volume should be as small as possible.

6. To ensure that shock and vibration do not disrupt the alignment of the moving source-detector mount, a counter-balanced configuration of operating lever masses should be employed. This reduces solenoid and spring size requirements.

The following discussion on the mechanical design and operation will make reference to the assembly drawings of Appendix A* as well as to the photographs of figures 32 to 36. The overall instrument is constituted by the following physically-separated components or assemblies: the collection-detection assembly, the electronic control and signal processing unit, the flow controller, and the pump. The design and functional description of each of these elements as well as of the entire system will follow within this and subsequent sections of this report.

The configuration of the collection-detection assembly incorporating the criteria resulting from the above premises is one in which the filter tape is transported through a sampling head which alternately deposits and senses the sampled dust. The tape is held immovable by a clamping mechanism during all deposit and reading cycles in order to ensure that the detection pair will be

*Detail drawings have been submitted separately because their large number made their inclusion in the body of this report impractical.

precisely aligned to the same filter spot during each measurement cycle. The beta source-detector mass sensing pair is designed as a rotating assembly which swings into the sensing position during the beta counting periods before and after each sample collection period. The C14 beta source is on the upstream side of the filter tape, whereas the detector is on the downstream side within a small sealed chamber within which it swings into and out of the beta counting position. This overall design meets the criteria listed above with a minimum of complexity and was implemented with a high degree of positional repeatability and structural stability.

Sensing of the filter mass is initiated by energization of the read solenoid (Ledex 171707-008) which raises the inlet tube holder (Appendix A drawing) and moves the source-detector pair into the read position. When a beta-count of the clean filter tape has been taken (approximately 1 minute), the read solenoid is deenergized, moving the mass sensing pair out of the sampling region, and lowering the inlet tube holder so that it seals the inlet tube to the filter tape. The pump is then switched on, reducing the air pressure in the detector enclosure, and causing atmospheric air to be drawn into the inlet tube, through the filter and into the enclosure. When the pumping period is completed (approximately 29 minutes), the read solenoid is again energized so that the detection pair is returned to the reading position to count beta pulses through the deposit.

If a predetermined maximum filter deposit has been reached the microprocessor provides a command and the tape transport mechanism advances the filter. If the deposit is less than the preadjusted maximum, the read solenoid is disengaged and another 29-minute deposit cycle begins on the same spot.

In order to provide a smooth inlet passage from ambient air to the filter face, a moving seal block (inlet tube holder, Appendix A drawing) carries a flexible tube which straightens when the block moves to the sealing position. The block is pivoted so that it is moved counterclockwise (upward) by the read solenoid Ledex 71707-008 to clear the source carrier as it moves into the read position.

The downstream seal is made by the filtration screen which forms a flat surface over which the tape passes. The underside of this screen is open to a small chamber in which the beta detector is mounted with freedom to move out of the air flow.

When the flow is to be initiated, the read solenoid is deenergized allowing the spring LE-037E-1 to pull the inlet tube holder downwards, pressing the filter tape between it and the support screen.

The filter tape transport mechanism consists of a stepper-controlled supply reel, a take-up reel, torqued by a stalled DC motor, and a solenoid-actuated clamp to hold the tape stationary during the deposit-and-read cycle.

Tape advance occurs at the end of a read cycle, while the read solenoid is energized and the inlet seal is raised. The microprocessing control system pulses the supply reel stepper, rotating the supply reel 30° clockwise, and energizes the clamp solenoid (Ledex 174610-031) allowing slack in the filter tape to be taken up by the take-up reel. The two solenoids are then deenergized by the controller, clamping the tape and bringing the source-detector pair into position for another reading.

The tape advance mechanism was designed such that several (10 to 15 typically) dust collection spots can be preserved for subsequent inspection and removal, without mechanical friction or abrasion against rollers, capstan, etc.

The primary requirement governing the design of the source-detector mount is that this pair return precisely to the same position, relative to the filter, each time the beta counting takes place. A secondary, but important, requirement is that the beta-source remain accurately aligned with the detector. In addition, the moving mount must be sealed where it passes through the wall of the downstream seal cavity, and its motion must be linked to that of the upstream seal block in such a way that the motion occurs without interference.

The source-detector mount is supported by preloaded ball bearings having a pivot axis normal to the main plate. Preloading eliminates hsake and endfloat from the bearings. The read solenoid Ledex 171707-008 pulls the detector mount against a stop surface within the seal cavity (1917) to establish a repeatable read position.

The mount is divided into a source bracket and a detector bracket, bolted together at the o-ring sealing surface where the mount penetrates the wall of the downstream seal cavity.

A spring-loaded brush contact carries the high voltage to the detector tube, allowing contact at both positions without the necessity of using a flexing wire conductor.

Flow Subsystem

In addition to the collection-detection head described previously in this report the machine-mounted monitor preprototype includes a mass-flow controller and a pump as part of the flow subsystem of the instrument.

The purpose of the mass flow controller is to maintain a constant sampling flow rate at the inlet of the instrument compensating automatically for the changes in system pressure drop as a result of dust collection on the filter tape, and differences in intrinsic flow resistance of different sections of the filter material. Because this flow controller must be located downstream of the collection; i.e., at a variable pressure sensing point within the flow system, flow sensing cannot be based on volume but on mass. It should also be noted that for the same reason; i.e., large excursions of pressure with respect to atmospheric pressure, the use of critical orifices, at that point is ruled out. The mass-flow controller used on the M3X is a thermal transfer device* which, in addition to its flow control functions, provides an output signal proportional to flow rate for display and/or recording purposes. Although the controller repeatability is manufacturer specified to be ± 0.2 percent of full scale (± 0.2 percent of 10 liters/min for the type of controller selected, corresponding to a ± 2.5 percent repeatability over a practical temperature range

*Model FC-261, Tylan Corp., Torrance, California.

of 4 to 32°C at the operational flowrate of 2 liters/min), the flow constancy for the overall system is of the order of ± 5 percent at the operating level of 2 liters/min due to finite leakages at the filter seal and other minor error contributions. The flow controller operating temperature range is specified at 4 to 43°C (40 to 110°F), and the power requirements are ± 15 volts at 4 watts maximum. The specific operating flow rate is obtained by applying a control voltage (0 to 5 volts) to the specified terminal of the device. Proper flow control exists when the output voltage from the controller equals the externally applied control voltage.

The air driving pump is of the rotary vane type* with a 12-volt d.c. motor.

In this context it should be considered that neither this pump motor nor certain of the other electrical and electro-mechanical components selected for this preprototype instrument are expected to meet applicable intrinsic safety regulations since the intent of this program was the development of a laboratory device. The overall design, however, is such that these elements can be replaced without basic modifications by components conforming to such safety guidelines as will be required for the follow-on field prototype instruments.

Figure 1 depicts the performance characteristics of the flow-controller and pump combination for the three controller-pump groups assembled for delivery within this project. The motor voltage was maintained at 11.5 volts, rather than 12 volts to simulate a condition that would exist near the end of a battery charge. The increasing vacuum load condition was obtained by adjustment of a valve upstream of the flow controller simulating the increasing pressure drop caused by dust collection on the filter tape. All controller-pump combinations maintained a constant 2 liter/min flowrate for pressure drops up to about 54 to 58 kN/m^2 (16 to 17 in. Hg) (at a pump voltage of 12 volts these values were about 58 to 60 kN/m^2 or 17 to 18 in. Hg).

Flow rates were monitored during numerous tests using a reference rotameter; day to day variations at the same controller setting were observed to be of the order of ± 2 percent or less at 2 liters/min.

The use of a mass flow controller implies that for large altitude changes; i.e., in excess of about 300 m (1000 feet) the flow control voltage requires readjustment because of the corresponding air density change. Typically, the mass flow must be decreased by 14 percent for an altitude increase from sea level to 1500 m (5000 feet) in order to maintain the same volumetric flow rate.

*Model 0333, Gast Manufacturing Corp., Benton Harbor, Michigan.

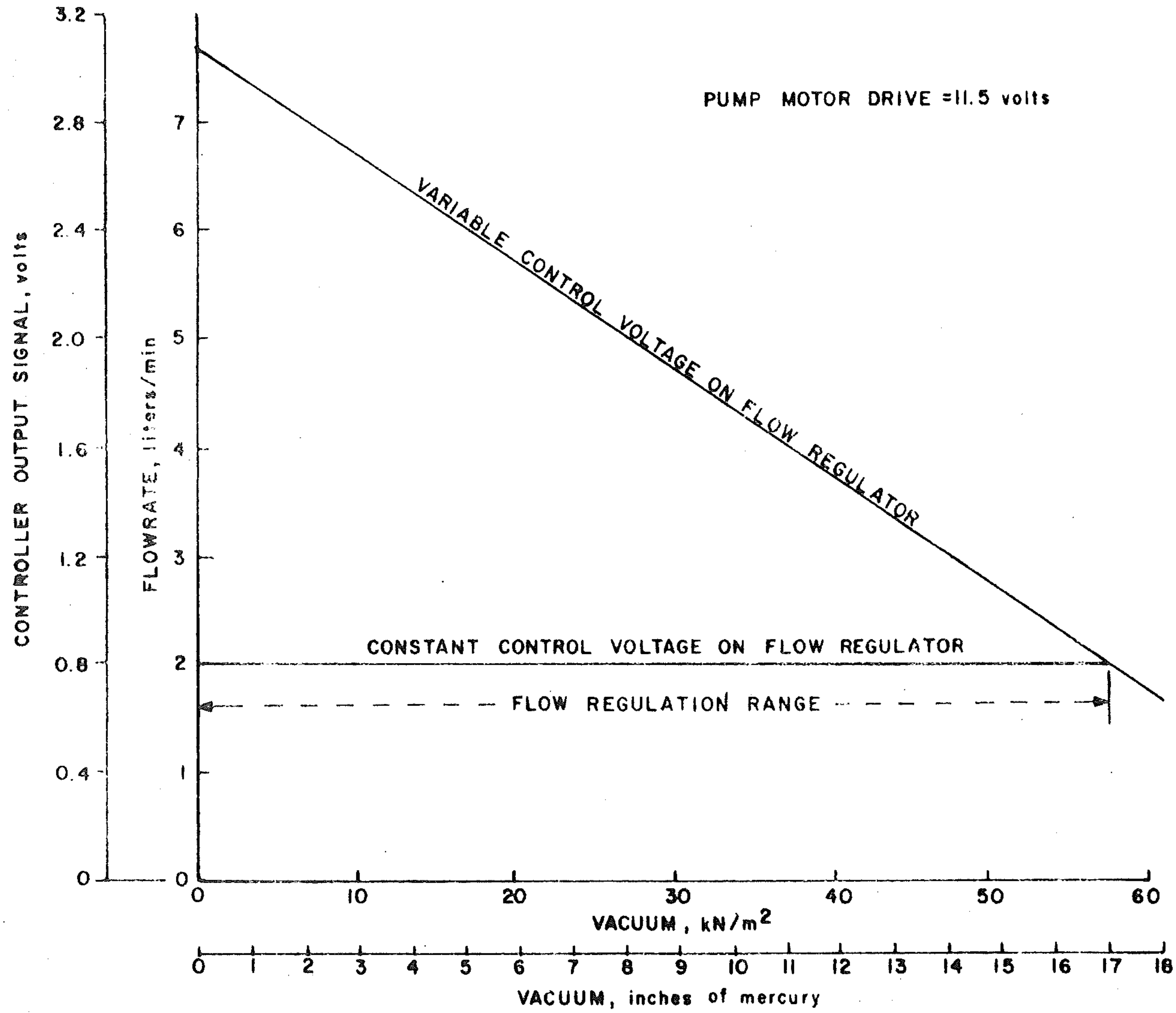


Figure 1. Flowrate Versus Pressure Drop Characteristics of Mass Flow Controlled-Pump Combinations.

Electronic System Design

The purpose of electronic subsystem of the M3X is to control the sequence of operations of the collection-detection head, process and condition the beta count signal, perform the computations of mass, concentration and time, and print out the results of the measurements.

The machine-mounted monitor preprototype utilizes the GCA RDM-301 Dust Monitor electronics with several modifications in the electrical hardware and the microprocessor software. Figure 2 is a block diagram of the system as designed for this prototype, and shows the following modules.

- CPU Board. This circuit board contains an Intel 4004 4-bit microprocessor and its associated circuitry. The control program is made up of 1536 instructions and is contained in 6 PROM (Programmable Read Only Memory) integrated circuit chips.
- I/O Board. The input/output circuit board accepts inputs from the control panel switches and the detected beta count pulses. It formats this information to make it readable by the CPU board. The I/O board also takes commands from the CPU board and outputs them to the proper actuation device such as the panel lights and the head solenoids.
- Mainframe. The mainframe holds the CPU and I/O boards, and connects them to sockets J1 through J6.
- Printer. The sample time, mass subtotals, and 1/2-hour average concentration are printed on a thermal printer paper tape. The final total mass and 8-hour average concentration are also printed.
- Actuator and High Voltage Board. This board contains the high voltage converter shown in Figure 3, and the relays and noise suppression networks shown in Figure 4. Figure 4 also traces the complete electrical path from the driving transistors on the I/O board, to the solenoids on the head.
- Control Panel. A new control panel has been developed for the machine-mounted monitor and is electrically depicted in Figure 5.
- Prototype Head. The prototype head has been separated from the electronics by a 5-foot cable for environmental testing. The cable plugs into connector J6 located on the top of the electronics package and wired as shown in Figure 6. Due to the increased capacitance of the 5-foot cable, the beta pulse detector comparator had to be moved to the head, and a cable driver added as shown in Figure 7. The head also contains the:

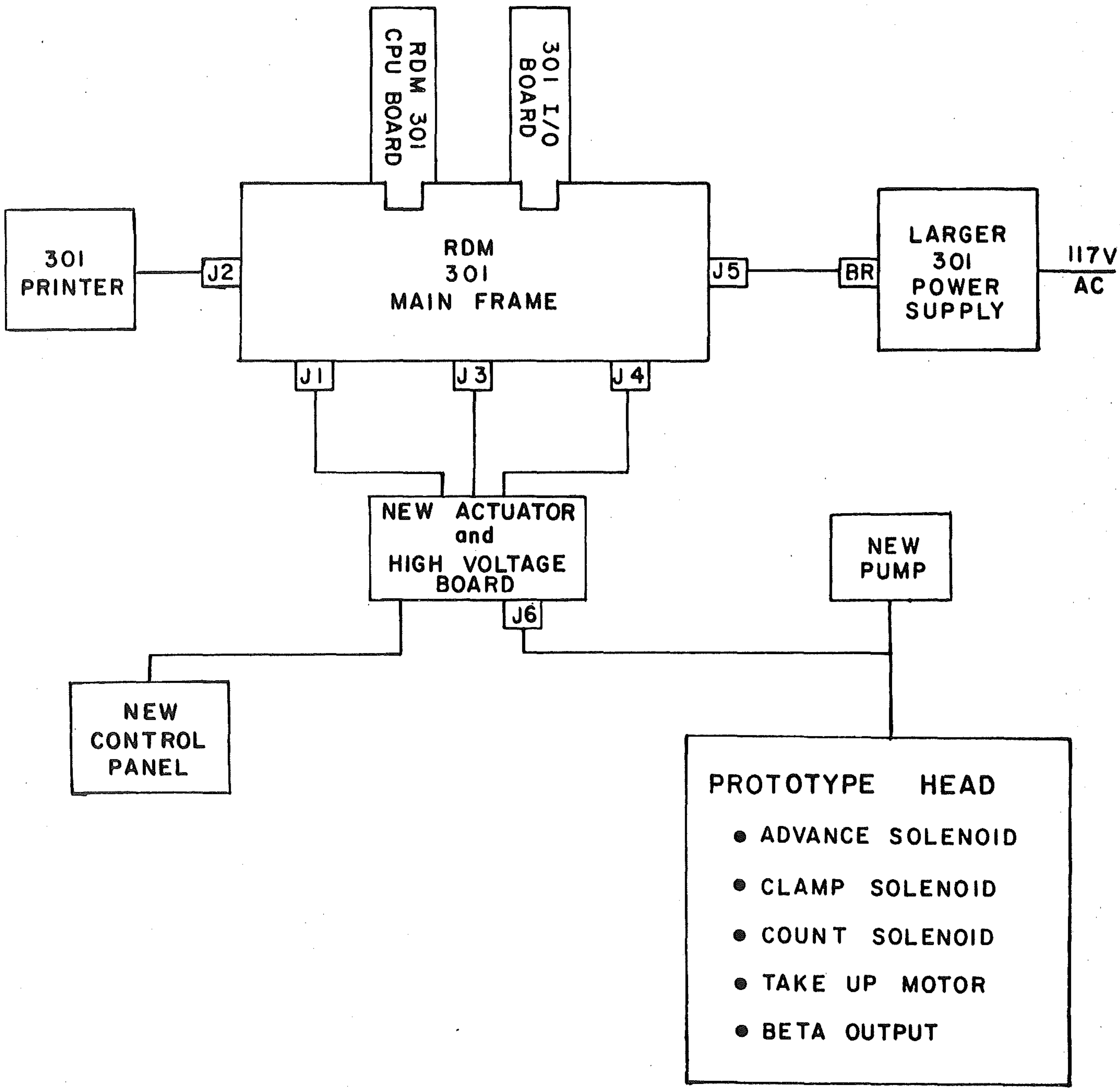


Figure 2. Machine-Mounted Monitor Prototype Electrical Block Diagram.

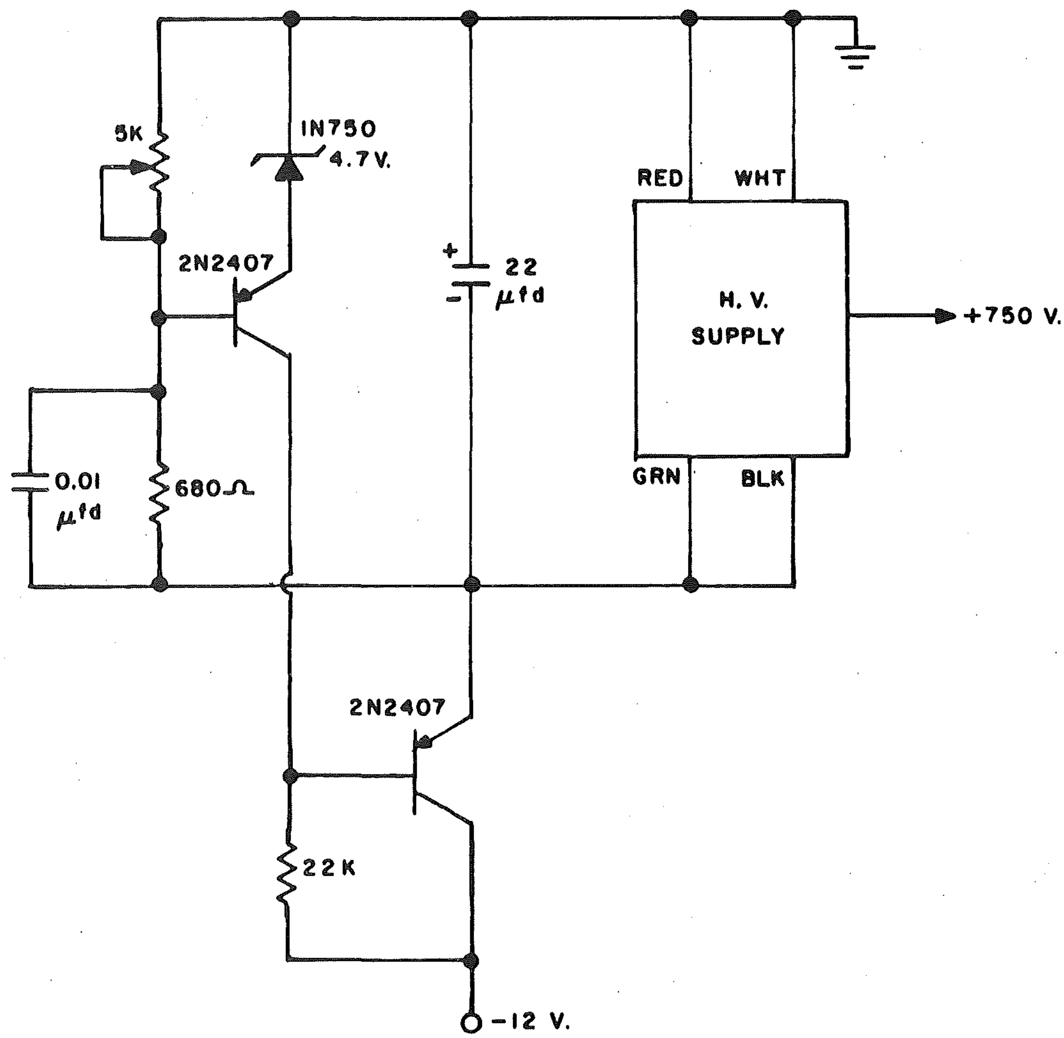


Figure 3. High Voltage Convertor Schematic.

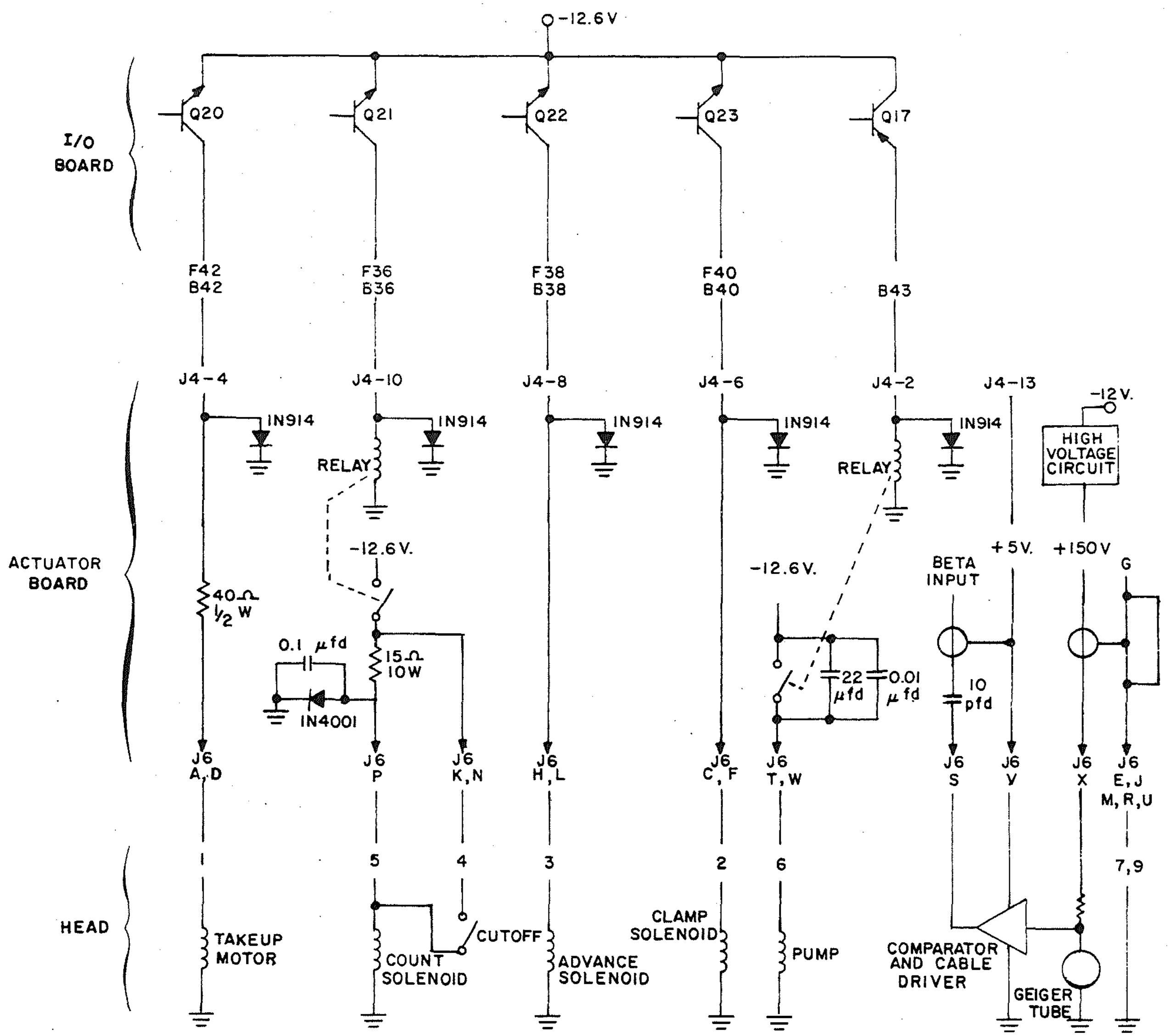


Figure 4. Actuator Board Schematic.

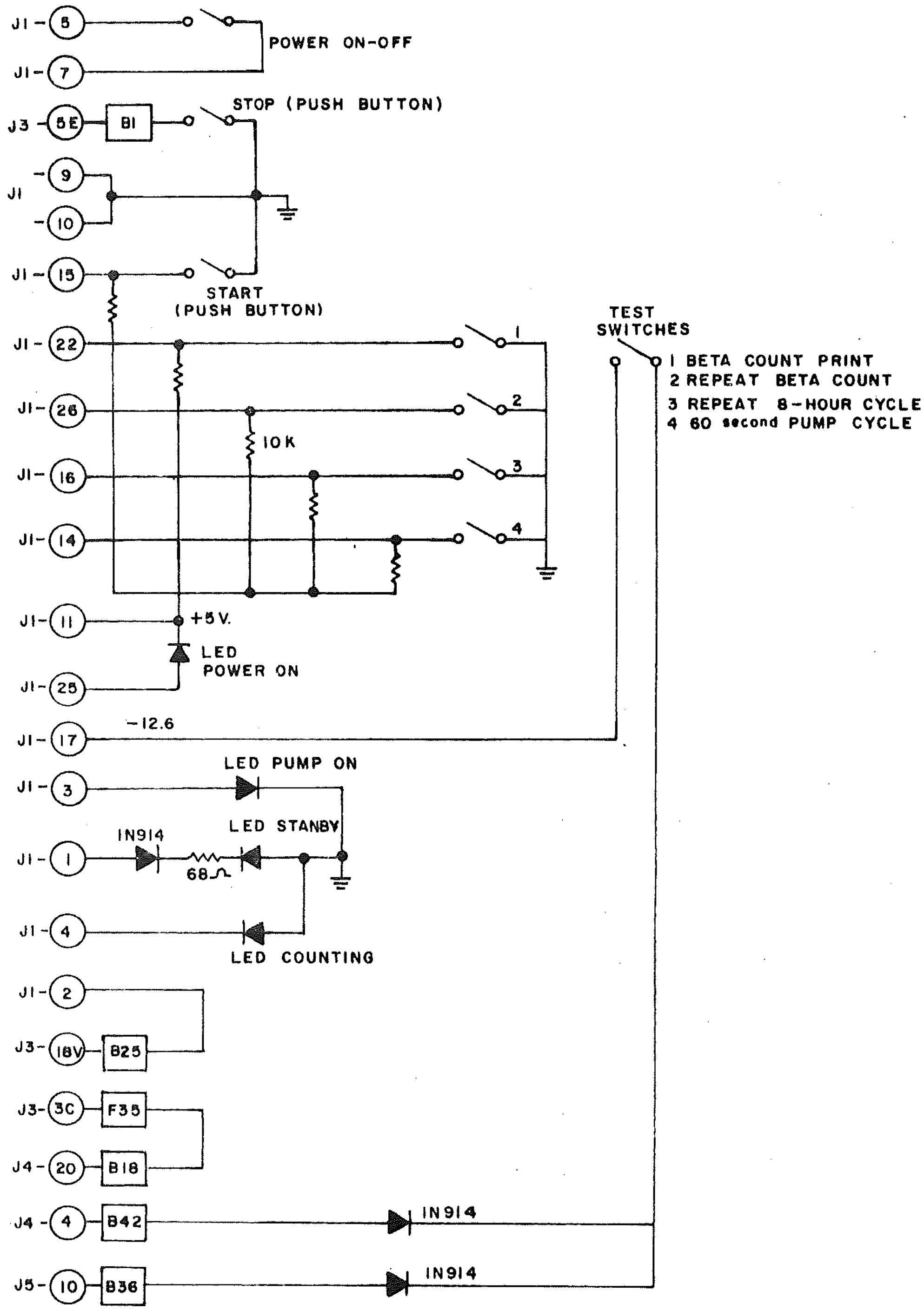


Figure 5. Control Panel Wiring Diagram.

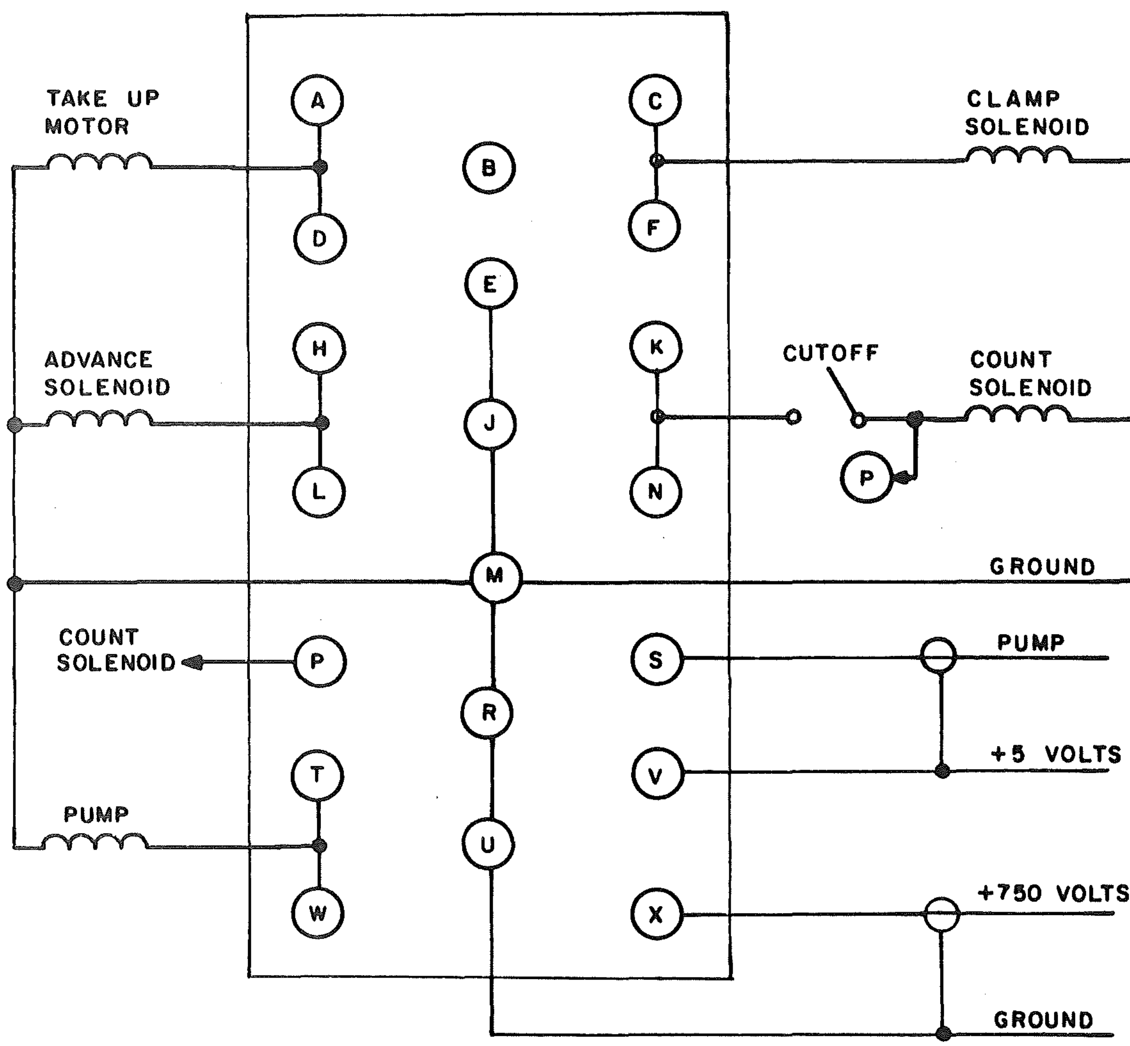


Figure 6. Output Connector J6 Wiring Diagram.

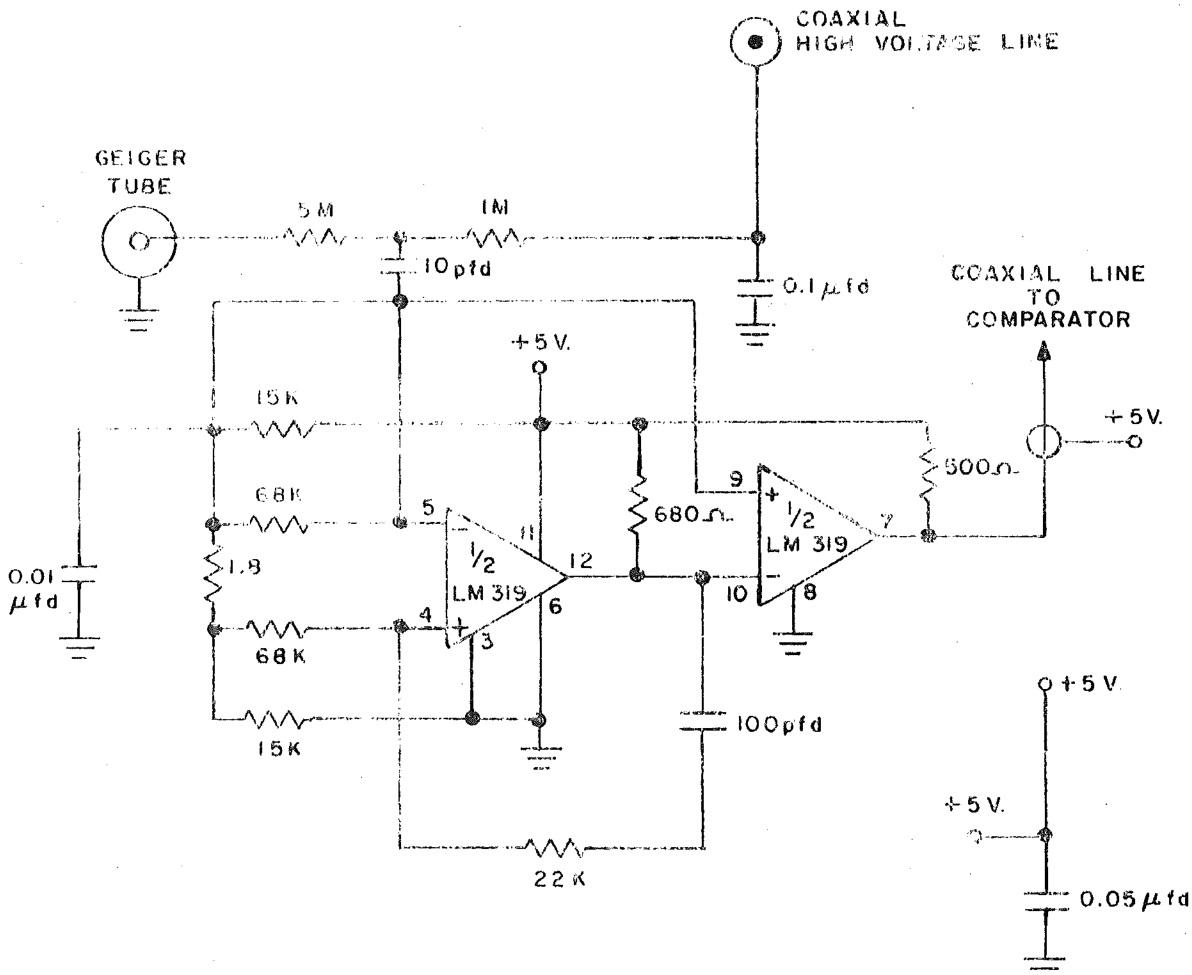


Figure 7. Comparator and Cable Driver Board Schematic.

–	count solenoid	12 volts 4 amps
–	advance solenoid	12 volts 6 amps
–	clamp solenoid	12 volts 2 amps
–	take-up reel motor	12 volts 1/4 amp
–	pump connection	12 volts 5 amps

Electronics System Operation

About one-half of the software subroutines of the RDM-301 have been preserved including the math subroutines, printer subroutines, and a few simple control subroutines. Figure 8 represents the flowchart followed by the new microprocessor software package.

The microprocessor program that determines the control sequence is initiated by turning the power on, or pushing the stop switch. All peripherals ncluding solenoids, lamps, and the detector high voltage power supply are issued a shut off reset command. The "power on" indicator and "ready" lamps are then lit, and the system waits for the "start" switch to be pushed.

When a "start" signal is received the "ready" lamp is turned off, and the take-up reel motor is turned on. The G.M. tube is allowed a 1-minute warm-up period to reach count-rate equilibrium. The print paper is then spaced so that the 8-hour readings will be clearly distinguished and the time register and total mass registers are automatically set to zero.

The paper advancing solenoid is then actuated for 1/10 of a second to rotate the filter paper supply reel 30 degrees. Since this solenoid draws 6 amps the other solenoids are left unenergized during this period. Next, the count solenoid is activated lifting the sealing tube from the filter tape and swinging the beta source - detector pair over the filter spot to be sensed. The count solenoid has a microswitch to limit the current from the initial 4 amps to a final 1 amp once the solenoid has pulled into its final position. A 1-second period is allowed for the sensing pair to swing into position. The de-clamping solenoid is then actuated for 1 second to allow the paper to be transported and to be pulled into the take up reel which is under constant tension from a stalled motor.

One second is allowed for the filter tape clamp to return to its clamped position. An advance flag is set in a one bit RAM register as a signal that the next beta count will be an initial one.

The beta counting process is then initiated by resetting the digital counter to zero, turning on the counter, and lighting a "count" indicator on the control panel. After 60 seconds the counter and lamp are turned off. A series of test switches have been added for convenience during the testing of the prototype. The first switch is examined and, if on, the beta count is then printed. The second test switch is examined and, if it is on, the count process is executed again, allowing statistical analysis of counts on the same spot, and counts during vibration and environmental testing of the sensor head.

The advance flag is then tested to determine whether the count is an initial one or not. If it is, then control is passed to the pumping routine. If not, then a sample time of 28.8 minutes is loaded into the sample time register. The mass is calculated by taking the difference of the natural logarithms of the last and the preceding beta counts and multiplying that difference by a system constant (approximately equal to 1.54 mg) which is read in

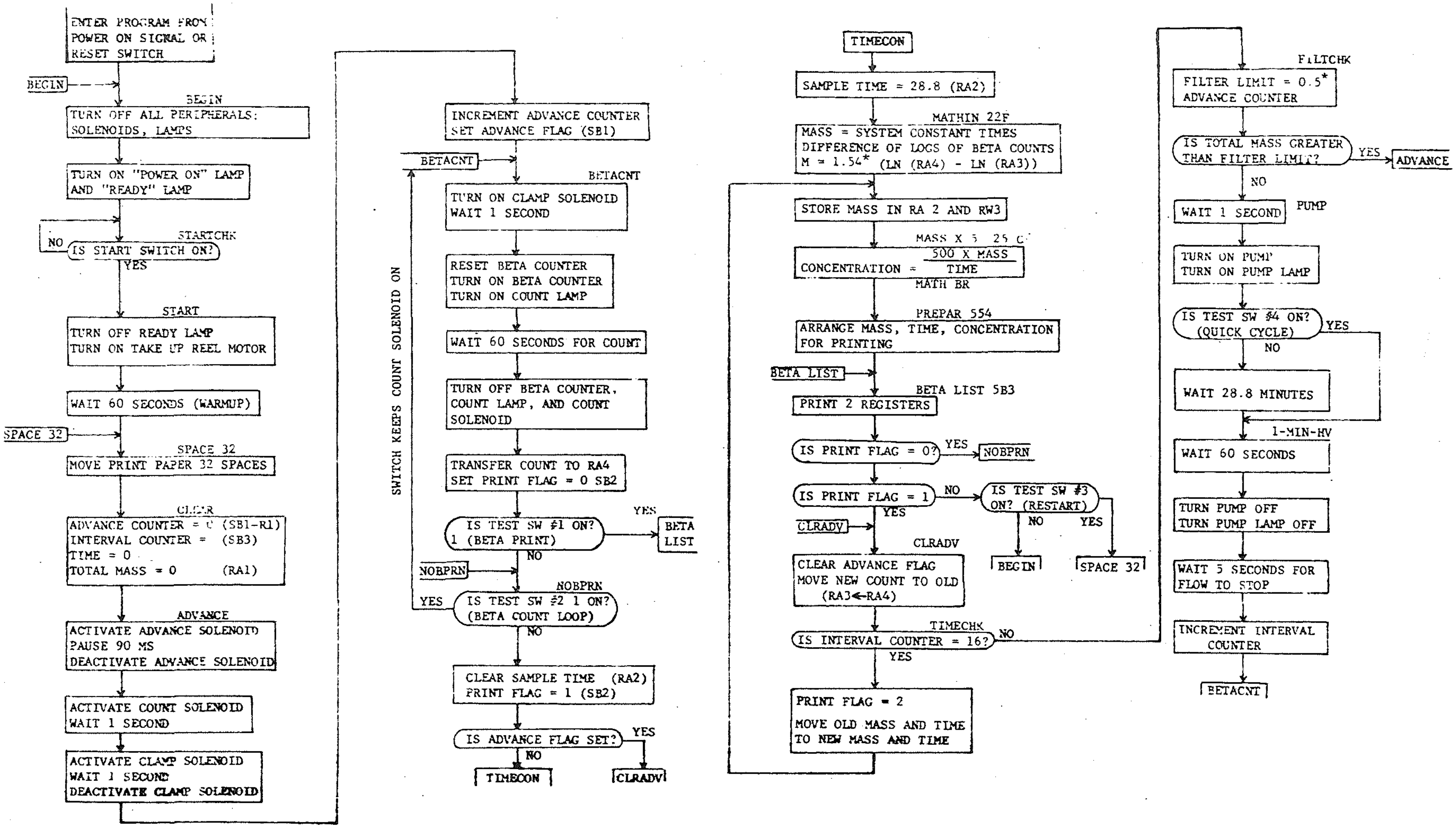


Figure 8. Machine-Mounted Monitor Control Sequence Flow Chart.

from preset switches. The concentration is then compared by multiplying the mass by 500 (minutes per cubic meter) and dividing by the sample time.

The print routine is then entered and the system prints out the accumulated time, mass, and last concentration. The print flag is checked after returning from the print routine to determine where control should be transferred. A flag of 0 transfers control back to the beta printing routine. A flag of 2 transfers control to end the sampling sequence. If test switch no. 3 is off, the sequence ends by going into the standby mode and waiting for the start switch. If the switch is on, the entire 8-hour sequence starts over as if the start switch were pushed. A print flag of one continues the control sequence. The advance flag is reset, the new beta count is moved to the old count register and the interval counter is checked to see if 16 half hour intervals are up. If they are up, then a print flag of 2 is set, the old accumulated mass and sample time moved to the new mass and time register, and the math routine is reentered to determine concentration. If 16 half hours are not over then the filter checking routine is entered.

The total mass is checked to insure that it is below the permitted maximum (0.5 mg) and that thus the tape does not have to be advanced. If the accumulated mass on a spot exceeds this maximum, the program loops back to the filter paper advance section. Otherwise the count solenoid is released, and 1 second allowed for the sealing tube to contact the filter tape before the pump and pump lamp are turned on. The entire count-pump cycle takes 1/2-hour and the pumping cycle lasts 28.8 minutes. Turning on test switch 4 shortens this pump cycle to 60 seconds for rapid testing purposes (without changing the time printout which remains as 1/2 hour cycles). The pump and pump lamp are turned off, and 5 seconds allowed for the flow to cease before the count solenoid is again actuated followed by a 1-minute pause. The time register is then incremented by 28.8 minutes and the beta counting section of the program reentered.

Printout Format and Data Presentation

The output information from the M3X is presented as a digital printout on a 0.6 cm (1/4-inch) wide paper take with thermal character impression. This printer was developed originally for the GCA RDM-301 dust monitor and the printout format used for the presently discussed instrument is similar to that of the RDM-301 but with several additions and modifications.

By panel switch selection several different data sequence formats can be chosen, in combination with different operational modes. The following printout-operational mode variations are available on the instrument.

a. When both central switches (labeled "Beta Count Print" and "Repeat Beta Count") are off; i.e., in the downward position, the printout consists of the elapsed dust sampling time in minutes, followed by the cumulative collected mass in milligrams, and finally the dust concentration level for the past period in milligrams per cubic meter. At the completion of the 8-hour cycle and after the printout of the last half-hour period the total elapsed sampling, the total cumulative mass and the <u>average</u> mass concentration over the 8-hour cycle are printed out. Should the average concentration over that cycle be "less than zero" (due to beta statistics) i.e., as could be obtained with an absolute filter at the inlet, the average concentration will read the arbitrary number of 506.94 mg/m^3.

b. When the switch labeled "Beta Count Print" is in its on position; i.e., upward or away from the operator, the printout format will be the same as for condition (a) except that preceding every data block the corresponding 1-minute beta count will also be printed out for diagnostic purposes. The initial beta count of a complete cycle; i.e., prior to any sampling, will also be printed out as any isolated number preceding the sequence described above.

c. When both central switches mentioned above are in their on or upwards position, the instrument is placed in a static checkout mode wherein the filter tape is not advanced and the pump is not turned on. In this condition sequential beta counts are the only information printed out every minute for diagnostic purposes; i.e., to determine the intrinsic stability of the beta counting system. If the "Beta Count Print" switch is off while the "Repeat Beta Count" switch is on the instrument will be in the counting mode without printing any information. The position of the "60-Second Pump Cycle" switch does not influence the printout or its timing for this general condition; i.e., the beta counts will be printed out every minute independently of the position of this latter switch.

If the second beta count of any given measurement period exceeds its corresponding initial count, the concentration reading for that period will be printed out as N. The same applies if the cumulative mass remains "negative." If, however a finite positive mass value preceded a "negative" measurement the corresponding mass "decrease" is subtracted and the resulting mass value is printed out.

Leading zeros are omitted from the printout, but if either the cumulative mass or the concentration exceed 0.9999 mg or 0.99 mg/m^3, respectively, higher order units are then printed out as required.

TESTING OF THE MACHINE-MOUNTED MONITOR PREPROTOTYPE

Laboratory Dust Testing Program

Methodology

Aerosol tests of the machine-mounted monitor were conducted by placing the collection detection head in a bench-top heating cabinet that had been enlarged for these tests by adding an external plywood box. The box had a large access opening to which an acrylic plate cover was fitted, and through which various tubing, hose, and electrical connections could be made. The machine-mounted monitor collection-detection head was subjected to tests with three different aerosols, namely, coal dust, limestone, and Arizona Road Dust, at three different temperatures, namely, freezing, room, and high temperature, at various humidity levels, and at various dust concentrations.

Although three instruments were fabricated within this program only one of them was subjected to the comprehensive dust, vibration and shock testing series. The other two units were only spot-checked to confirm their performance similarity.

A complete parametric test program; i.e., attempting to investigate the instrument performance as a result of all possible combinations of temperature, humidity, dust concentration, as well as vibration and shock was considered totally impractical as well as unnecessary and a test matrix was developed based upon the Latin square statistical design for multivariable experiments. The design of this test matrix assures that for any one variable held fixed, such as humidity, there is an equal number of cases for all the other conditions. Dust was always dispersed by means of a Wright dust feeder operated at different drive ratios for various concentration levels. A circulation fan within the heating cabinet assured that the aerosol was well mixed. Low temperature control was achieved by placing a block of dry ice in the cabinet and setting the heating cabinet thermostat to 32°F. The dry ice would then tend to lower the temperature of the cabinet air below freezing, but the heater than raised the temperature to the desired controlled level. Humidity was measured by wet bulb thermometry by circulating the test air through a 2-inch diameter acrylic duct that contained two identical thermometers, one of which was fitted with a wick the other end of the wick being placed in a reservoir of de-ionized water. A small blower, operated at less than line voltage by means of a variable voltage transformer (Variac), circulated the test air through the ducting to the humidity indicator, which allowed determination of the dry bulb and wet bulb temperatures, and back into the cabinet. Humidity was increased within the cabinet by means of a resistive heating element submerged in a beaker of water to generate steam. No provision was made for lowering humidity.

Sampling of the aerosol generated within the cabinet was accomplished by means of three 10 mm nylon cyclones mounted symmetrically within a common metal can with the cyclone inlets facing the axis of this cylindrical chamber. Sampling was performed in this manner to insure that each cyclone be exposed to the same dust concentration. Flowrate through the cyclones was 2.0 ℓpm. Gravimetric concentration was determined by means of 50 mm diameter membrane

(Gelman VM-1) filters, the flow through which was controlled by critical orifices. Loading on the filters was never large enough to perceptibly lower the gas density flowing through the critical orifices, thus flowrate was taken as constant through the cyclone/filter sampling train. Two cyclone/filter combinations were used to determine gravimetric concentration and the third cyclone was used to separate the nonrespirable aerosol fraction from the gas sampled by the machine-mounted monitor. Typical test durations were about 30, 60 and 90 minutes, depending on dust concentration levels. Weighing was performed on a Mettler H15 balance accurate to ± 0.1 mg.

Test Results

Table 1 presents data accumulated for this test series. For each test the gravimetrically determined concentration is compared with the concentration indicated by the machine-mounted monitor, and is presented in Table 1 as "GRAV/M3X." Tests 9, 10, 11 and 13 were excluded because of various electronic and/or mechanical component failures. After the eighth test, the calibration constant of the M3X was readjusted to the average values obtained with the gravimetric reference and thus all preceding values were renormalized to the new calibration constant (see eighth column of Table 1) of 1.54 mg.

Figure 9 summarizes the data of Table 1 and depicts the error bars associated with the gravimetric reference determinations assuming a weighing error of twice ± 0.1 mg. The horizontal error bars associated with the M3X statistics are negligible in comparison; the calculated 2-sigma beta sensing errors are equal to ± 0.26 mg/m^3 for the 29-minute tests and about 0.15 mg/m^3 for the 89 minute tests. It should be noted that of the 24 data points only three fall outside the theoretically predicted error band and that the correlation coefficient of the gravimetrical versus M3X data is 0.979. The least squares regression line has the equation $y = 1.052 + 0.92x$, where y represents the gravimetric values, and x the results obtained with the prototype instrument under scrutiny. The standard error of the estimate for the data set of Table 1 is 1.223 mg/m^3. Since the error band for most gravimetric reference determinations was about ± 3.4 mg/m^3 (based on a weighing accuracy of twice ± 0.1 mg for a typical sampling time of 30 minutes), whereas as mentioned before the 2-sigma error band for the M3X was only ± 0.26 mg/m^3, most of the error of the estimate must be attributed to the gravimetric determinations.

In addition, a Latin Square analysis was performed of the data of Table 1. The data were aggregated by dust type, temperature and humidity. The analysis of variance was performed to determine whether the instrument was sensitive to any of these variables. Table 2 summarizes the results of this calculation. The F-statistic values shown are for a 2.5 percent and for a 25 percent confidence level; i.e., if the calculated F-ratio exceeds the $F_{0.25}$ there is a one chance in four that the variable under scrutiny has some significance. Table 2, however, indicates that no variable appears to be significant even at that level. It should be considered that the usual test of significance is performed at either the 5 percent or 1 percent level, which in this case would indicate even less significance.

Table 1. M3X Test Data.

No.	Dust	Temperature (°C)	Relative humidity (%)	Average gravimetric concentration (mg/m^3)	M3X concentration (mg/m^3)	M3X initial concentration (mg/m^3)	Normalized gravimetric/ M3X ratio	Test duration (minutes)
1	ARD	22	30	17.65	18.58	17.00	0.95	29
2	Coal	0	100	15.97	15.50	14.30	1.03	29
3	Coal	22	25	5.79	5.12	4.73	1.13	29
4	Coal	22	25	12.61	10.51	9.61	1.20	29
5	Coal	22	70	18.52	21.79	19.98	0.85	29
6	Coal	22	62	15.15	16.12	14.72	0.94	29
7	ARD	48	13	7.85	7.27	6.67	1.08	59
8	Limestone	48	13	29.44	29.15	26.76	1.01	29
12	ARD	22	48	18.51	22.30		0.83	29
14	ARD	48	> 50	13.47	12.62		1.07	29
15	ARD	22	50	15.15	16.55		0.92	29
16	ARD	22	40	14.29	13.75		1.04	29
17	ARD	22	40	17.69	17.35		1.02	29
18	Limestone	22	92	20.20	23.31		0.87	29
19	Limestone	22	95	24.38	24.21		1.01	29
20	Coal	48	55	11.78	12.03		0.98	29
21	Coal	48	52	15.15	15.25		0.99	29
22	Coal	48	24	6.30	6.76		0.93	89
23	Coal	48	18	6.03	6.87		0.88	89
24	ARD	22	95	9.93	8.77		1.13	59
25	ARD	22	95	10.75	11.56		0.93	59
26	ARD	0	Saturated	12.60	12.66		0.99	29
27	ARD	0	Saturated	13.47	11.90		1.13	29
28	Limestone	0	Saturated	5.63	5.30		1.06	56

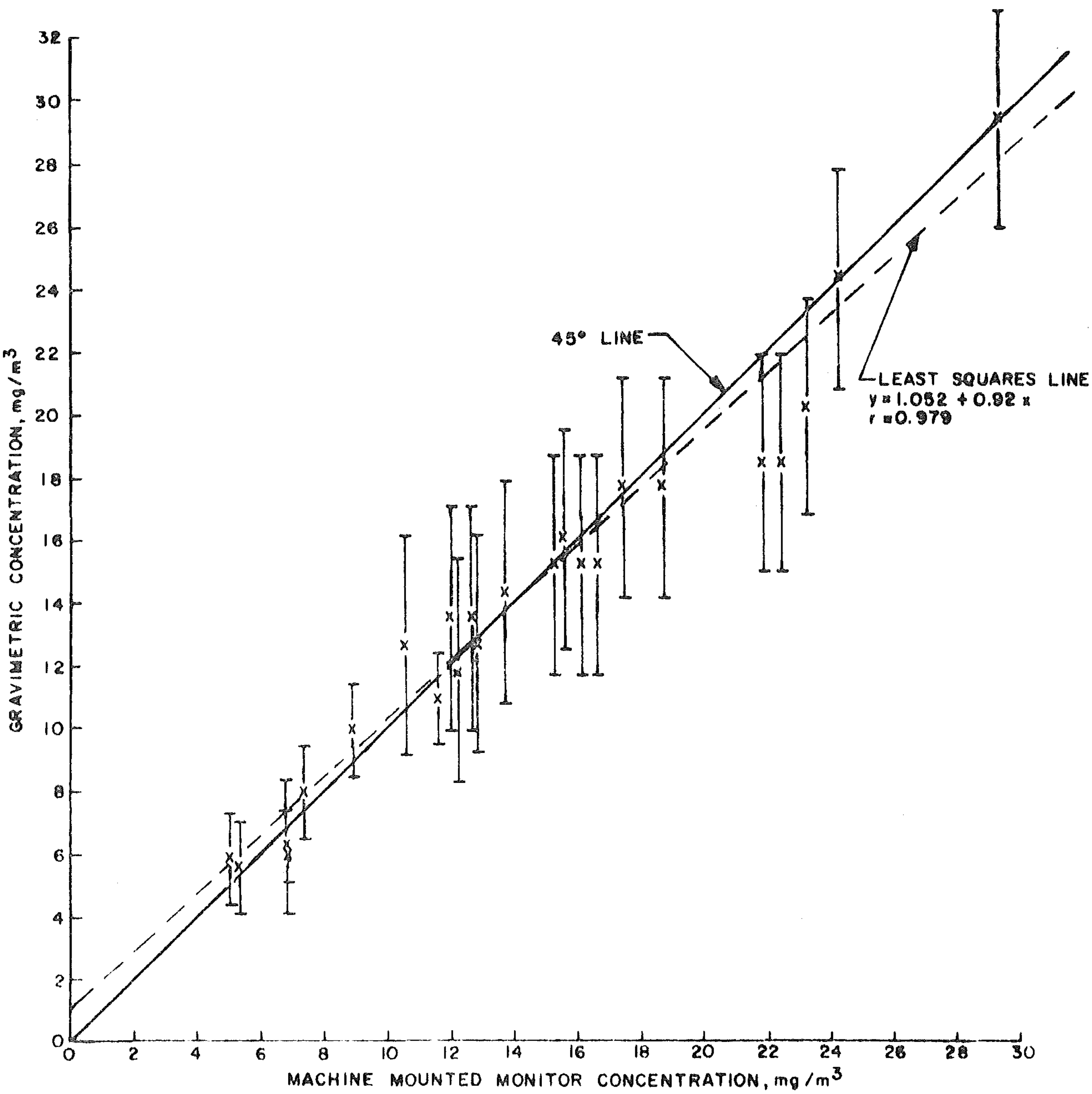


Figure 9. Plot of Experimental Dust Concentration Measurement Runs of the M3X (Table 1)

Table 2. Latin Square Data Analysis Results.

Variable	Degrees of freedom	Mean square	F-ratio	$F_{0.25}$	$F_{0.025}$
Temperature	2	0.00293	0.716	1.70	6.54
Dust type	1	0.00013	0.003	1.57	8.07
Humidity	1	0.00053	0.013	1.57	8.07
Error	7	0.04094			

Thus it can be stated that performance of the instrument is essentially independent of temperature, humidity, concentration and type of dust over the ranges and conditions tested within this laboratory program.

A series of low concentration and long duration tests was performed using coal dust to determine the behavior of the M3X at dust levels around and below about 2 mg/m^3. Table 3 lists the results of these tests and Figure 10 is a plot of the corresponding points. The error bars of both gravimetric and the average of the M3X values are shown in this case because for these low concentrations these latter errors can no longer be neglected. Again, most points fall within the expected error band and the correlation coefficient for these data is 0.978; the least squares regression line is $y = -0.066 + 1.08\chi$, and the standard error of the estimate for this data set is 0.16 mg/m^3.

Table 3. M3X Low Concentration Test Data.

No.	Test duration (hours)	M3X concentration (mg/m^3)	Gravimetric concentration (mg/m^3)
29	16	0.16	0.21
30	5.5	1.91	2.03
31	8	0.16	0.26
32	8	0.93	0.84
33	8	1.47	1.36
34	8	1.73	1.40
35	24	0.69	0.79
36	19	0.28	0.38

In addition, several 8-hour long zero-concentration tests were run using an absolute filter at the inlet to confirm the absence of any significant zero bias. All three units were subjected to this test and the results are shown in Table 4. These data indicate that the standard deviation of the zero-concentration runs falls in all cases within the predicted value of 0.13 mg/m^3 (2σ = 0.26 mg/m^3) and that the total drift is usually less than the two-sigma band. Particle size distribution determinations were performed for the three

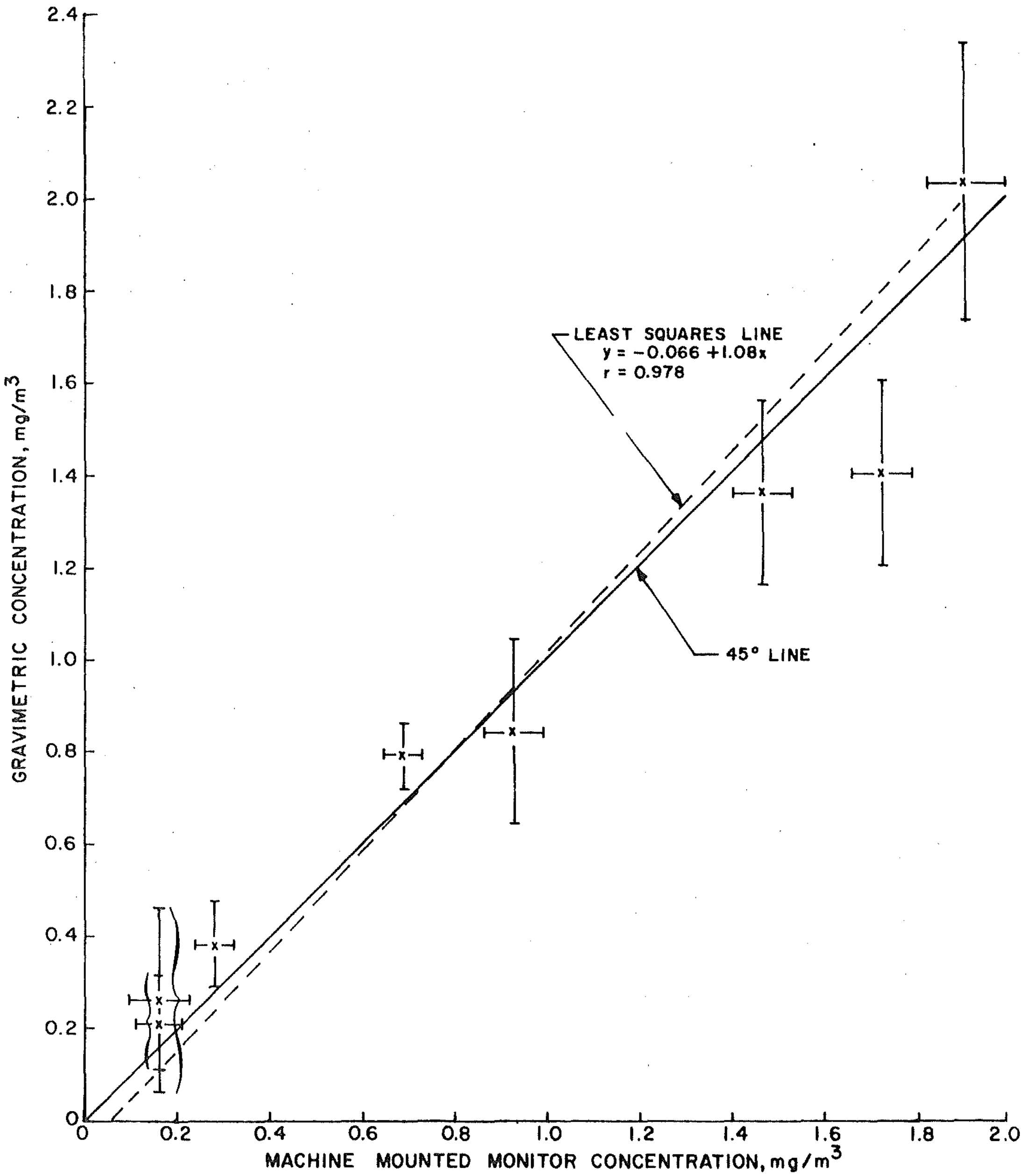


Figure 10. Low dust concentration test results (Table 3).

types of dust generated for the tests of Table 1. These size measurements were obtained by means of an in-stack type Andersen 2000 cascade impactor with eight impaction stages followed by a back-up filter. The impactor was operated at 14.1 ℓpm (0.5 cfm) and the dust was collected on glass fiber substrates at each stage. A high precision balance with a resolution of 0.01 mg was used to determine the weight increments. Replication of size distribution measurements was effected to determine the stability of the test aerosol as well as to establish the reliability of the experimental procedures. The range of results are shown as error bars of the size distribution points for coal dust depicted on Figure 11. The magnitude of these variations is typical of those observed for the three types of dust; i.e., coal, Arizona road and limestone, used on these tests. It is interesting to note that both the particle size as well as the shape of these three distributions do not differ too markedly; i.e., the mass median diameter varies only from about 2 μm for limestone to 4.5 μm for Arizona road dust.

Table 4. Zero-Concentration Test Data.

No.	Unit no.	Standard deviation (mg/m^3)	Total drift (mg/m^3)
37	1	0.12	-0.28
38	1	0.09	0.19
39	1	0.06	-0.04
40	2	0.10	0.09
41	3	0.10	-0.07
42	3	0.09	-0.21
43	3	0.09	-0.03

Electrical noise tests, although originally intended, were not performed because the prototype was not designed as an integral unitary package with complete electrical shielding, but as a modular cable-interconnected instrument compatible only with laboratory testing. Since the objective of this program was to develop a collection mass detection system and subjected it to intensive testing, no effort was made to harden any of peripheral elements such as the electronic control subsystem. For a follow-up field operational prototype proper electrical shielding and filtering are considered routine design procedures.

Shock and Vibration Tests

One of the machine-mounted monitor preprototypes (serial no. 3), was tested for shock and vibration testing at the Acton Environmental Testing Corporation.

Shock tests were performed as defined by Mil standards 810-c, test method 516.2, Procedure I, shock parameters a and c (peak value = 20 g's, nominal duration = 11 ms (10 March 1975). Figure 12 shows the electromagnetically controlled table used to perform both the shock and vibration tests. The M3X monitor head can be seen mounted on the table for a test in what was arbitrarily

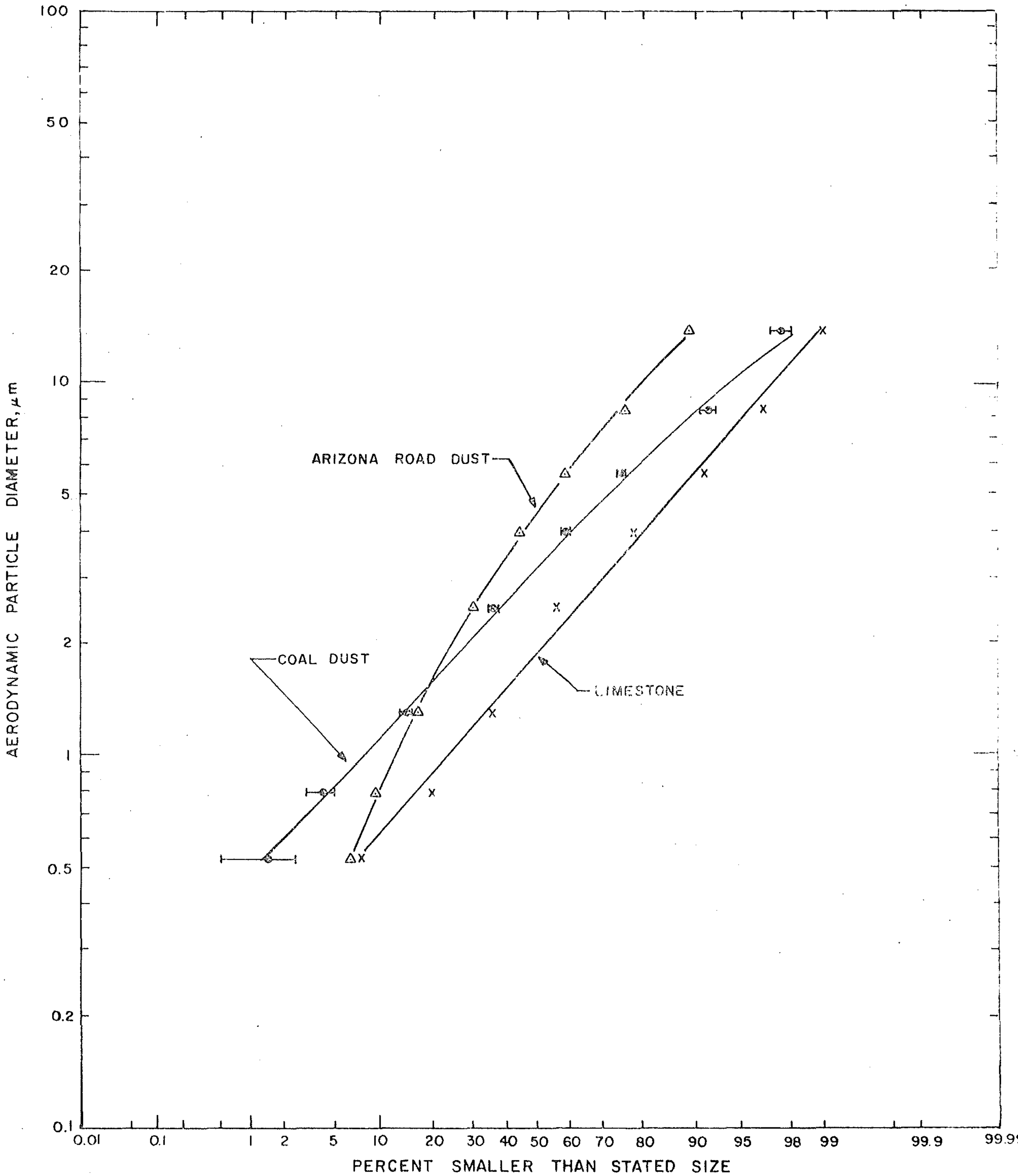


Figure 11. Particle size distributions for the test dusts used to evaluate the performance of the M3X.

assigned the vertical direction. Arrows on the border of Figure 12 indicate the direction of motion of the table. For tests in the other two orthogonal directions, called the latitudinal and longitudinal directions, the test table was swiveled 90° and attached to the plate seen in the foreground of Figure 12. This plate rested on an oiled flat-plate table and was therefore free to slide back and forth. Figure 13 is a close-up view of the prototype under test mounted for vertical testing. Figure 14 shows the M3X head mounted for longitudinal testing, and Figure 15 shows the instrument mounted for latitudinal testing.

The shock tests were performed such that an accelerometer attached to the 1-inch thick aluminum mounting plate machined by GCA, sensed an acceleration of about 20 g's in about 11 msec; that is the rise and fall times to the maximum acceleration are on the order of 5-1/2 msec. In order to accomplish this, the shock table was controlled by a mini-computer (PDP 11) which calculates the input voltage and current to the electro-magnet necessary to achieve this acceleration with the instrument being tested loaded on the shock table. Input data for the computer consists of shock tests performed at lower acceleration, which are analyzed so that the pulse at the maximum acceleration will be correct. Three shocks at 20 g's were applied to the M3X in both the plus and minus direction for each of the three orthogonal directions so that 18 shocks in total were applied to the instrument. The accelerometer waveform after each test was displayed on a CRT which constituted the output terminal for the computer. Hard copy records were made for selected tests. Figures 16 and 17 show acceleration versus time for shocks in the latitudinal direction; Figure 16 for the positive direction and Figure 17 for the negative direction. Proper operation of the M3X under test was verified after the first shock and after the sixth shock (the last shock in the latitudinal direction). Some vibration of the 3M3 was evidenced by the spikes on the trailing edge of the shock pulse which are more pronounced in Figure 17, which was performed after the test shown in Figure 16. Figure 18 shows the accelerator output for one of the three shocks in the plus longitudinal direction. For this condition the vibration or rattling of the instrument increased. On closer inspection of the M3X after the minus longitudinal shock shown in Figure 19, which indicates major rattling after the shock, it was observed that the standoffs had worked loose from the 1-inch thick mounting plate. After retightening the instrument to its mounting plate, a minus longitudinal shock, shown in Figure 20, did not display any vibration or rattling upon recovery from the 20 g acceleration. Figures 21 and 22, showing the accelerometer output for a plus and minus shock in the vertical direction, likewise display little vibration or rattle. Figures 23 and 24 show plus and minus shocks, respectively, in the vertical direction, on a much expanded time scale (from 50 msec/division to 3 msec/division). The M3X operated properly after all shock testing was completed and had demonstrated an ability to withstand shock without excessive induced vibration or rattle.

The vibration tests were conducted with the instrument mounted to the test table in the same way as for the shock tests. The input acceleration at the mounting plate, as monitored by an accelerometer was constant and the motion of the plate was sinusoidal to the frequency being varied from 10 to 500 Hz. The vibration test is considered more rigorous because the device under test is likely to resonate at some characteristic frequency or frequencies thus

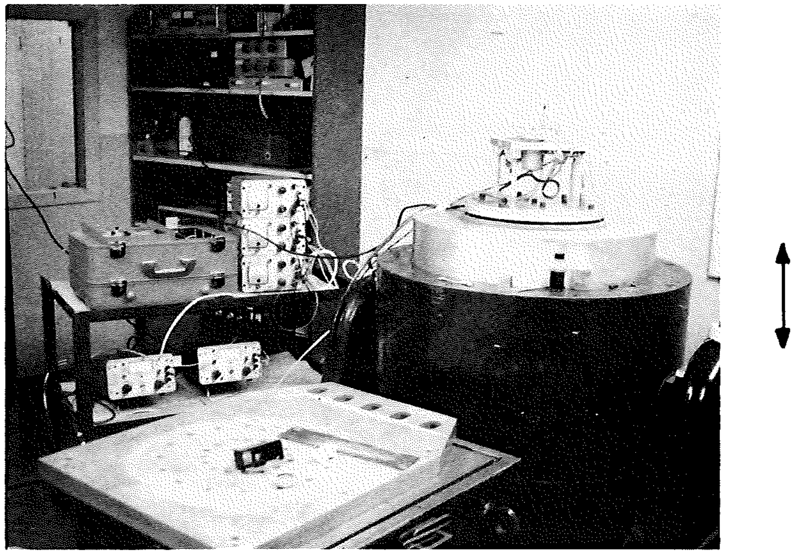


Figure 12. Vertical Motion.

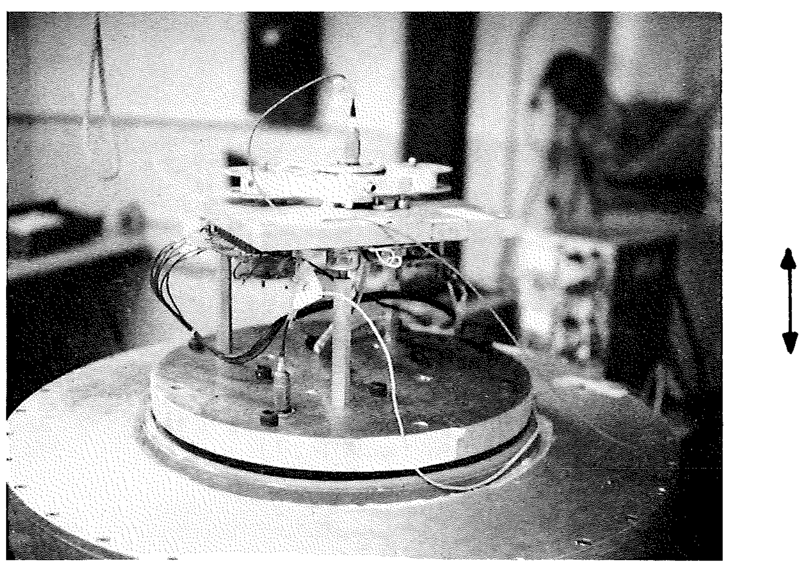


Figure 13. Vertical Motion.

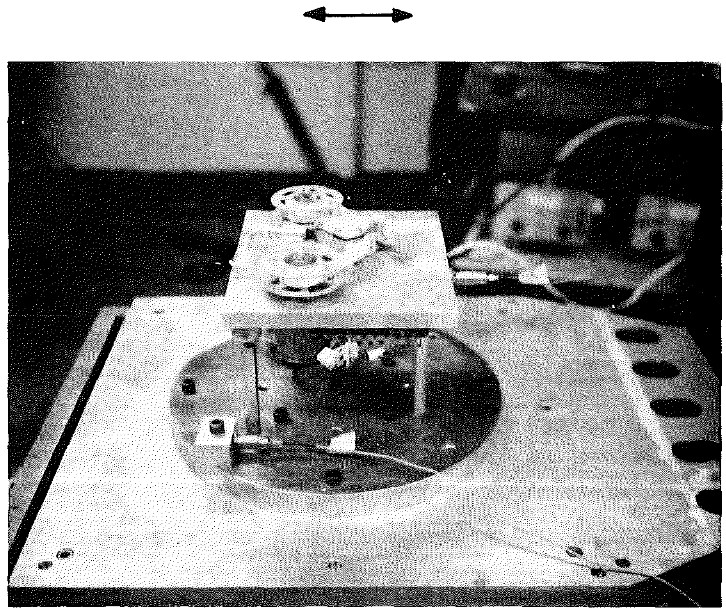


Figure 14. Longitudinal Motion.

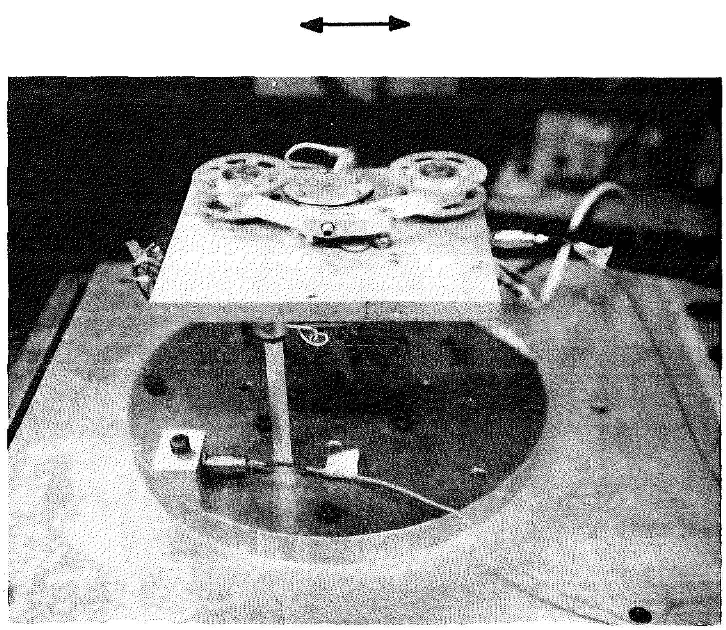


Figure 15. Lateral Motion.

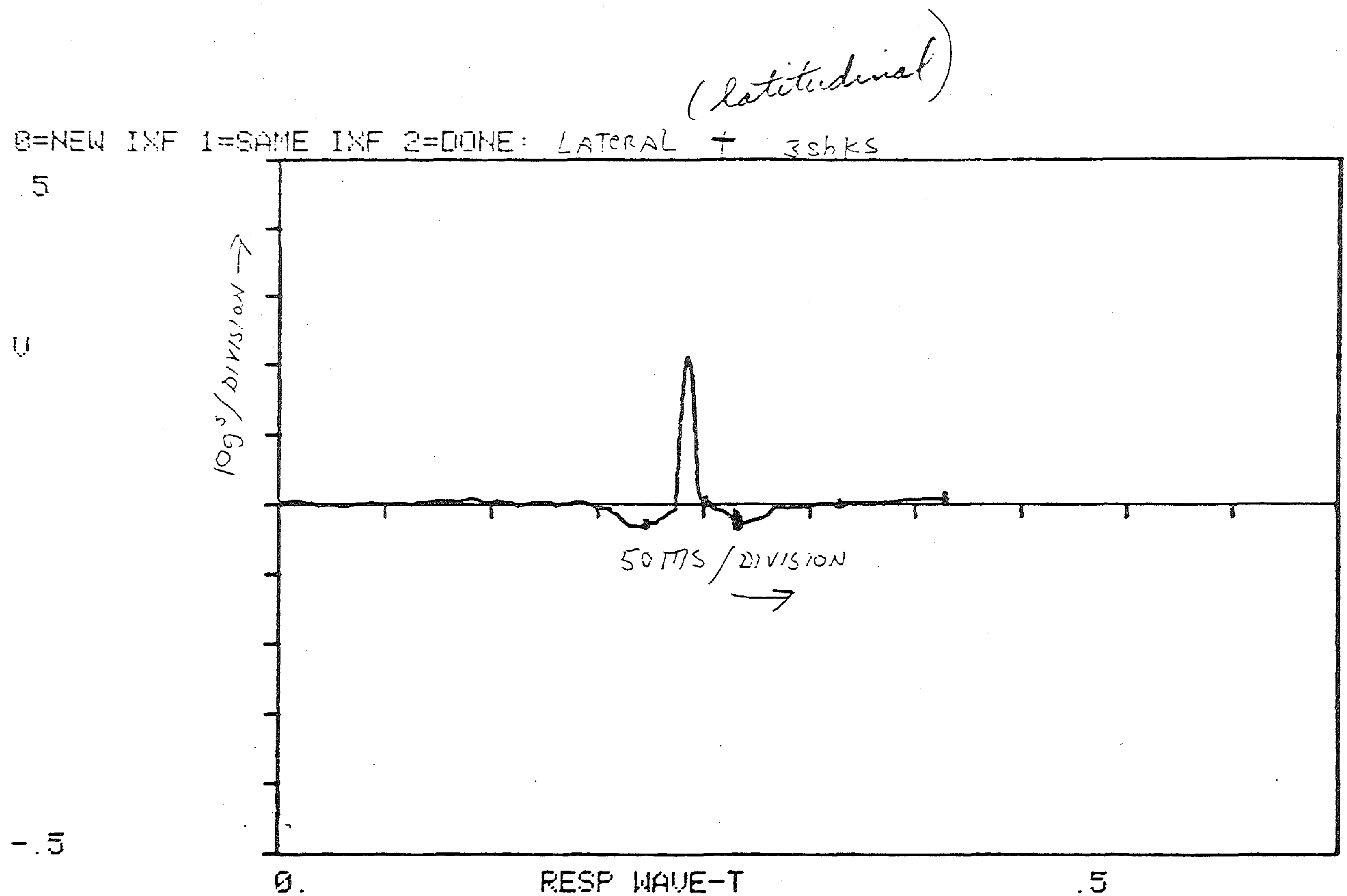


Figure 16. Acceleration Waveform for Latitudinal Positive Direction Shock.

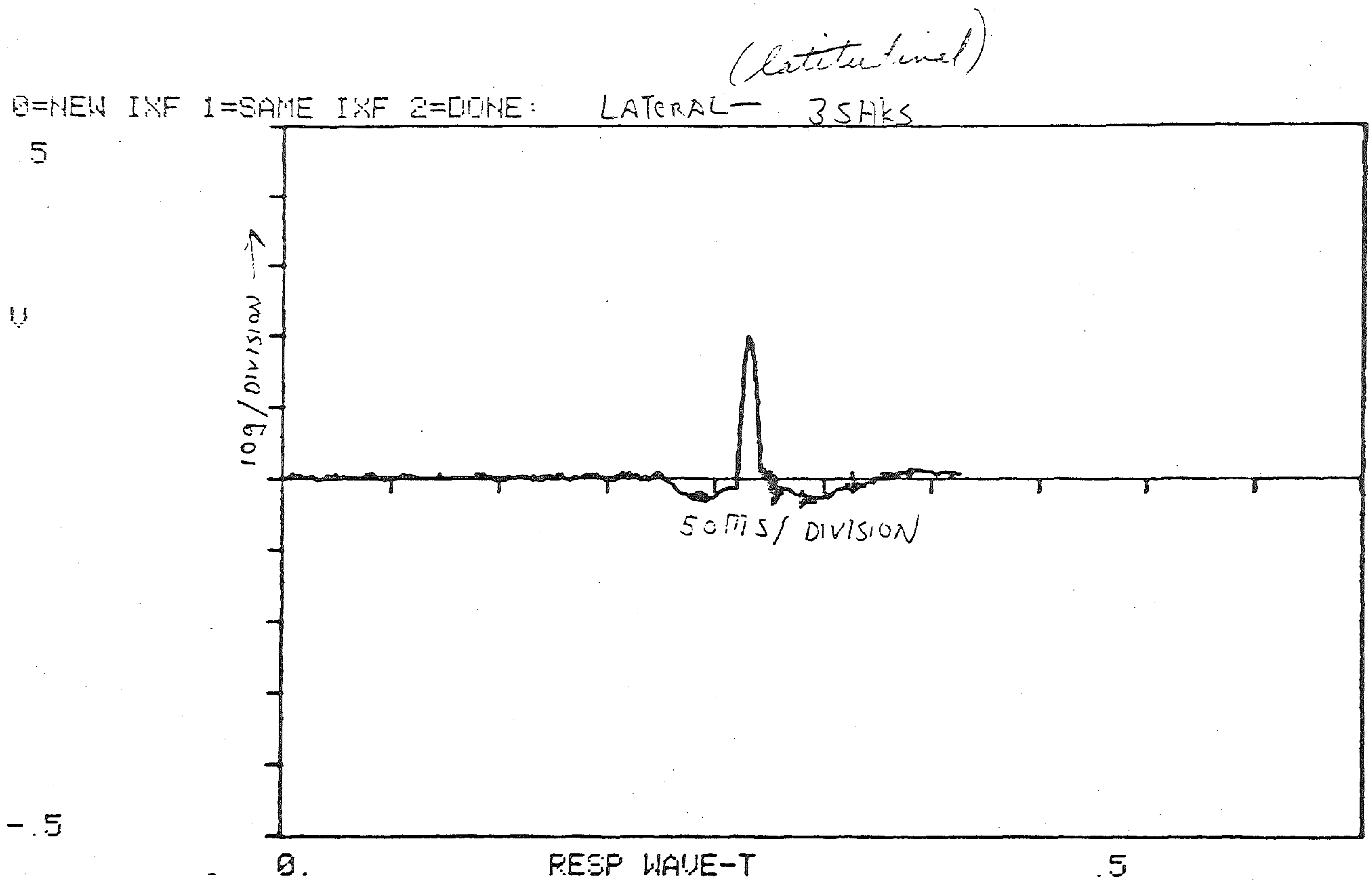


Figure 17. Acceleration Waveform for Latitudinal Negative Direction Shock.

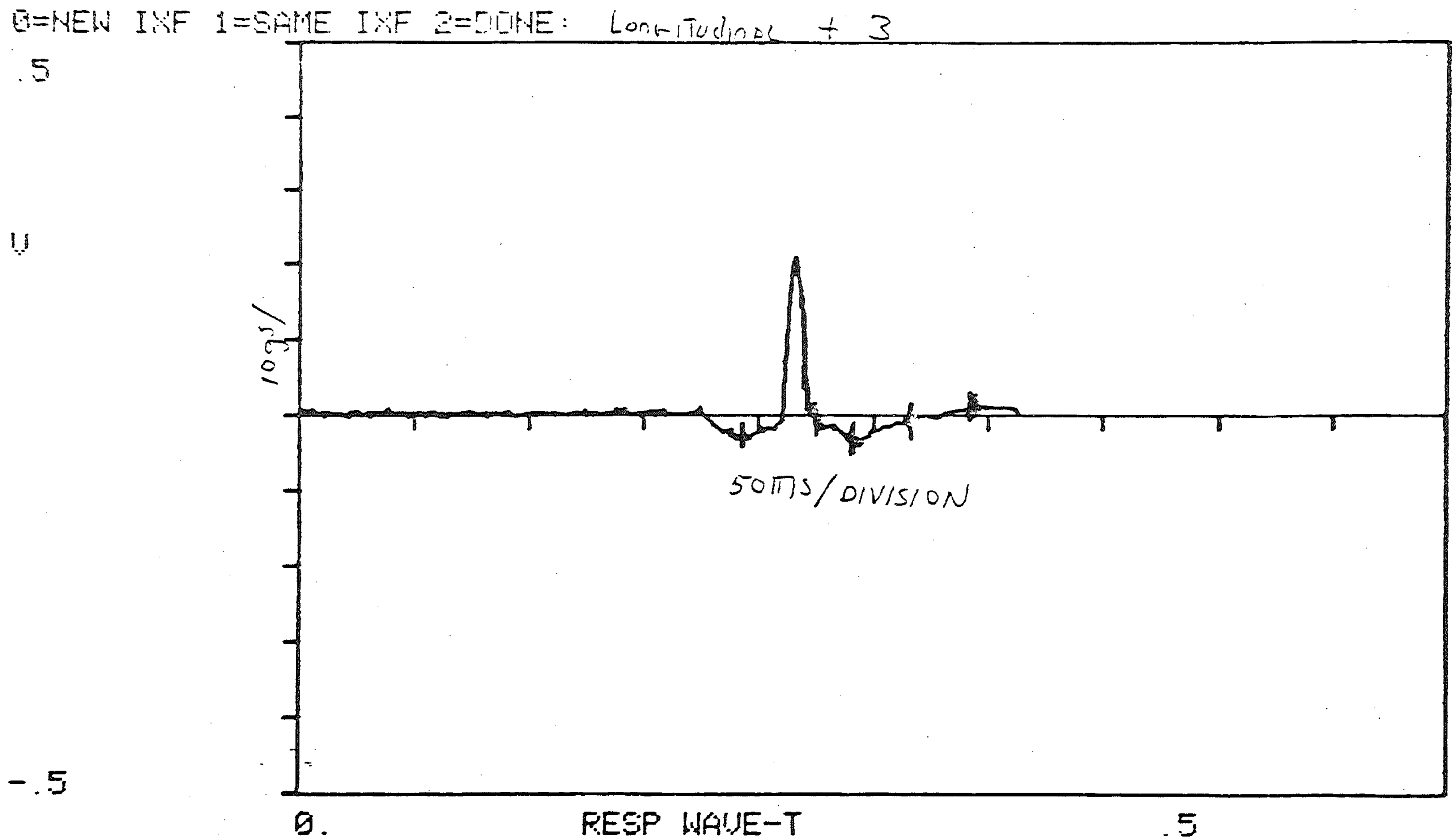


Figure 18. Acceleration Waveform for Longitudinal Positive Direction Shock.

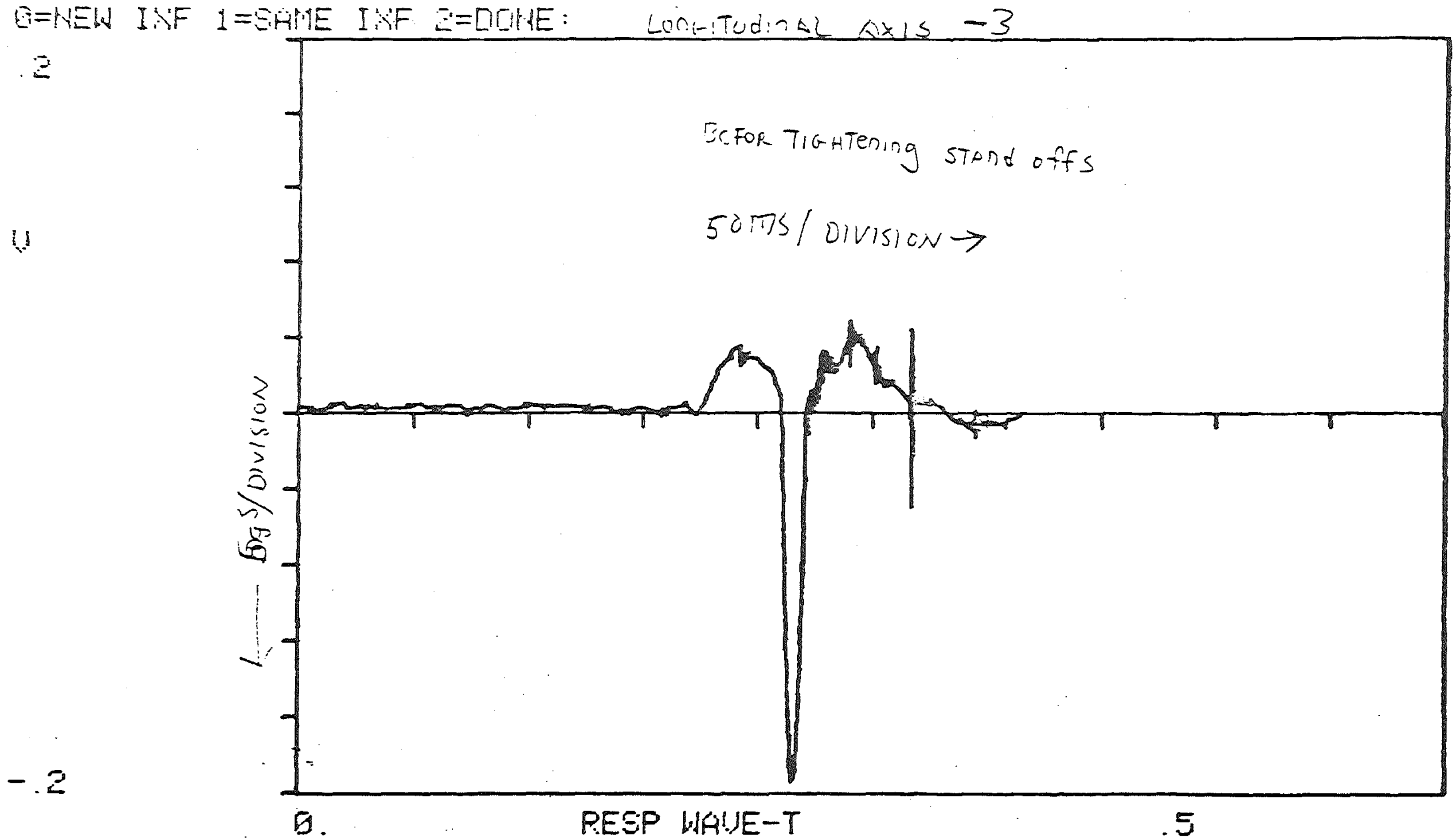


Figure 19. Initial Acceleration Waveform for Longitudinal Negative Direction Shock.

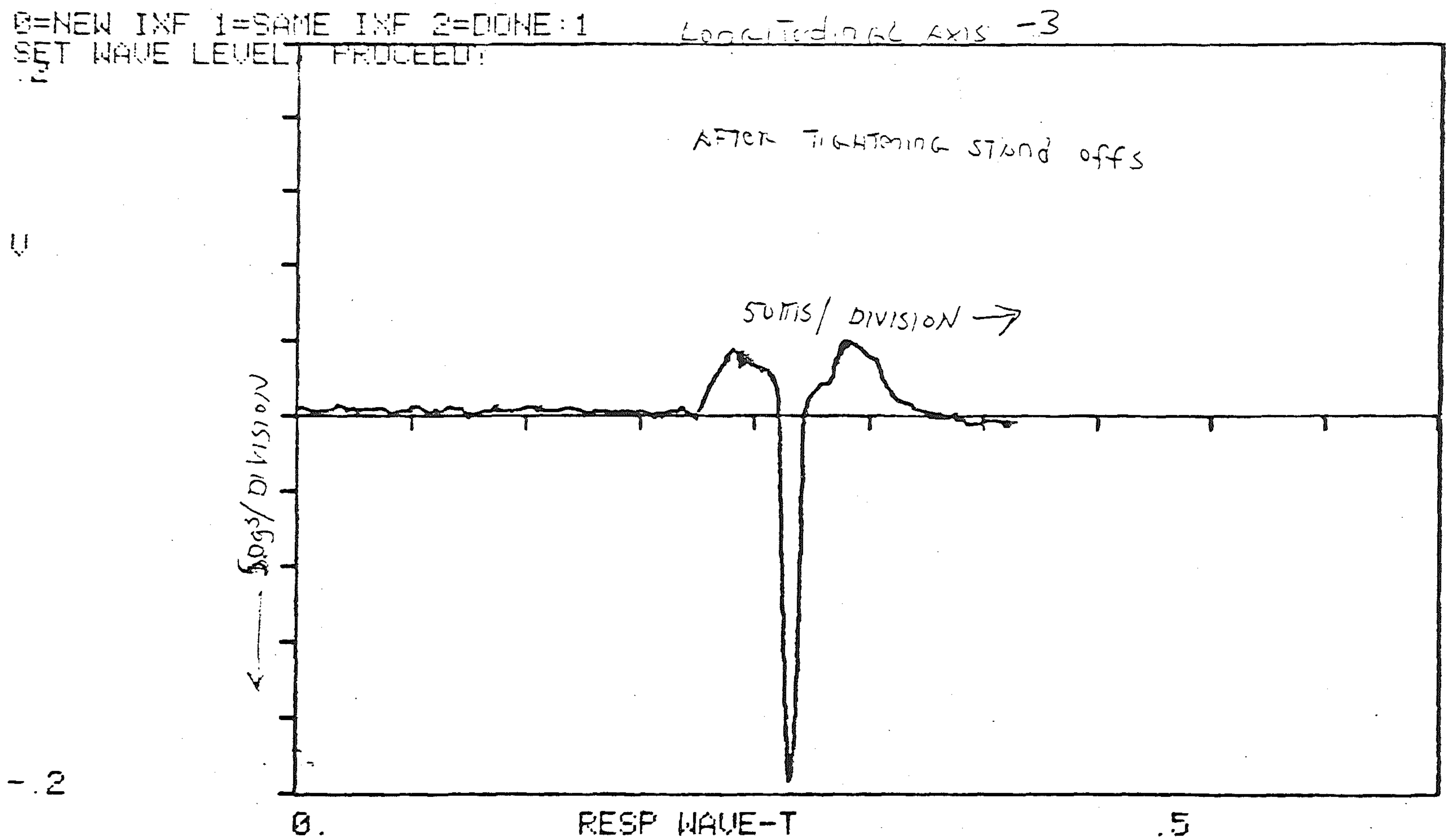


Figure 20. Final Acceleration Waveform for Longitudinal Negative Direction Shock.

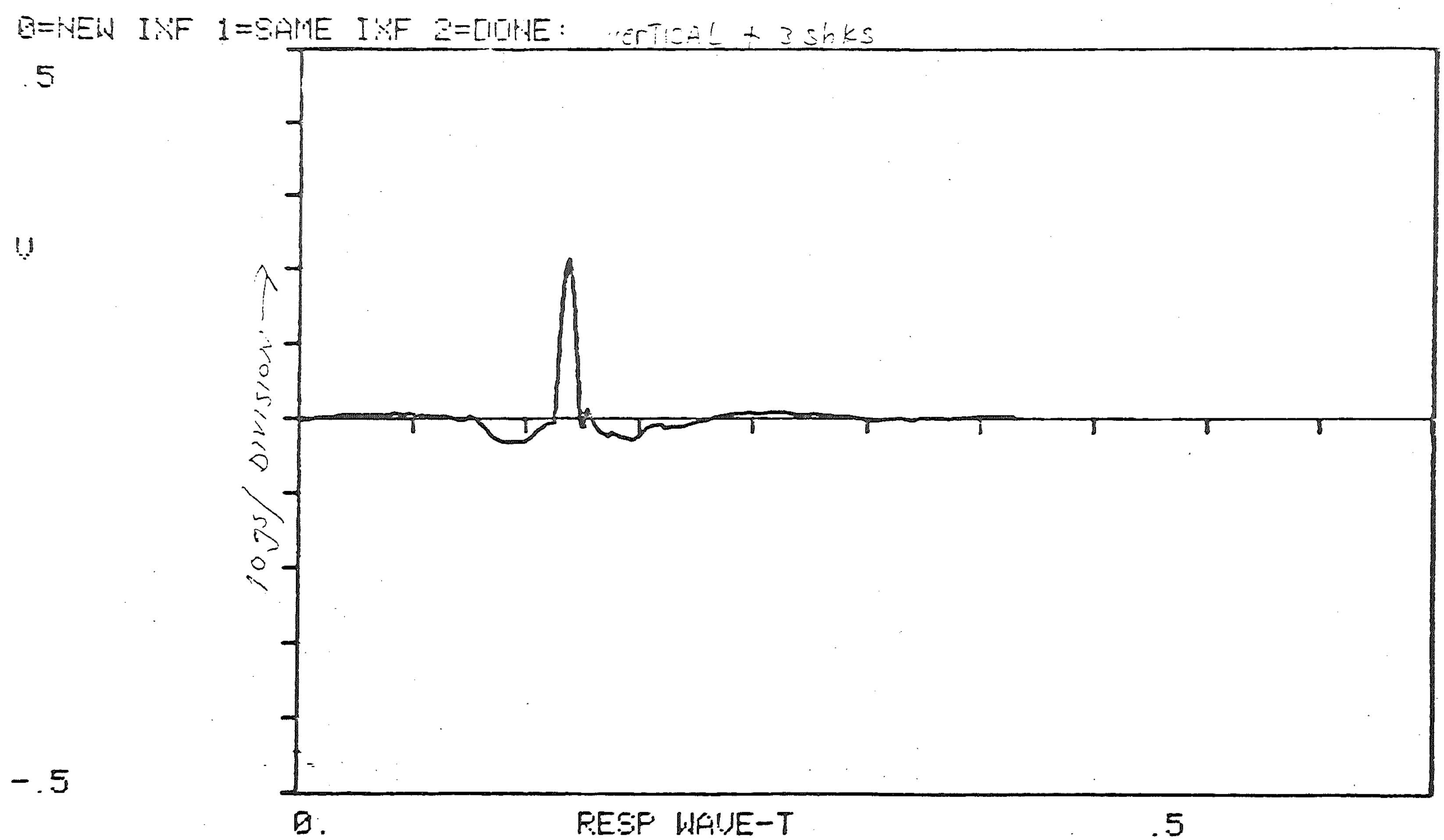


Figure 21. Acceleration Waveform for Vertical Positive Direction Shock.

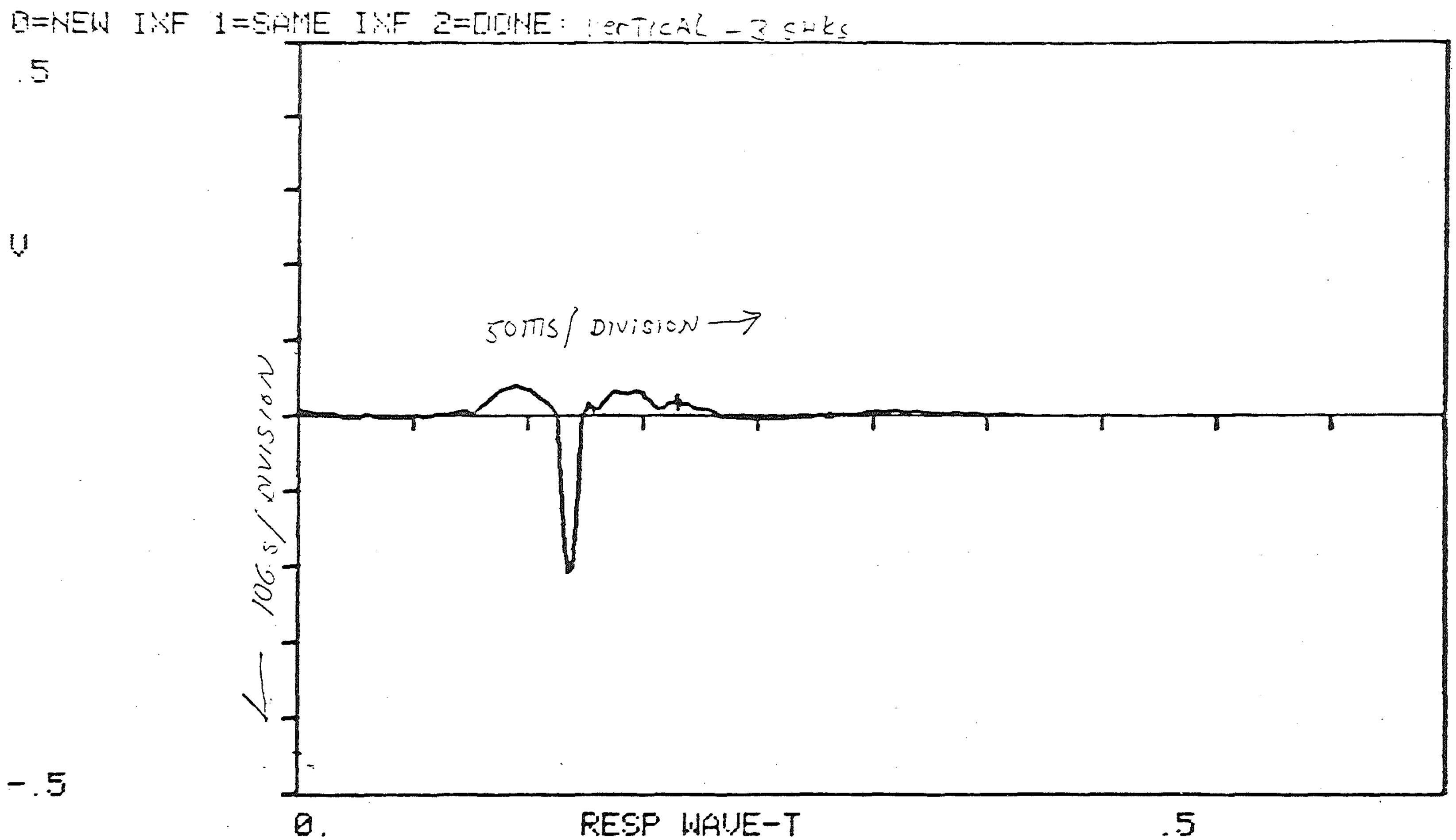


Figure 22. Acceleration Waveform for Vertical Negative Direction Shock.

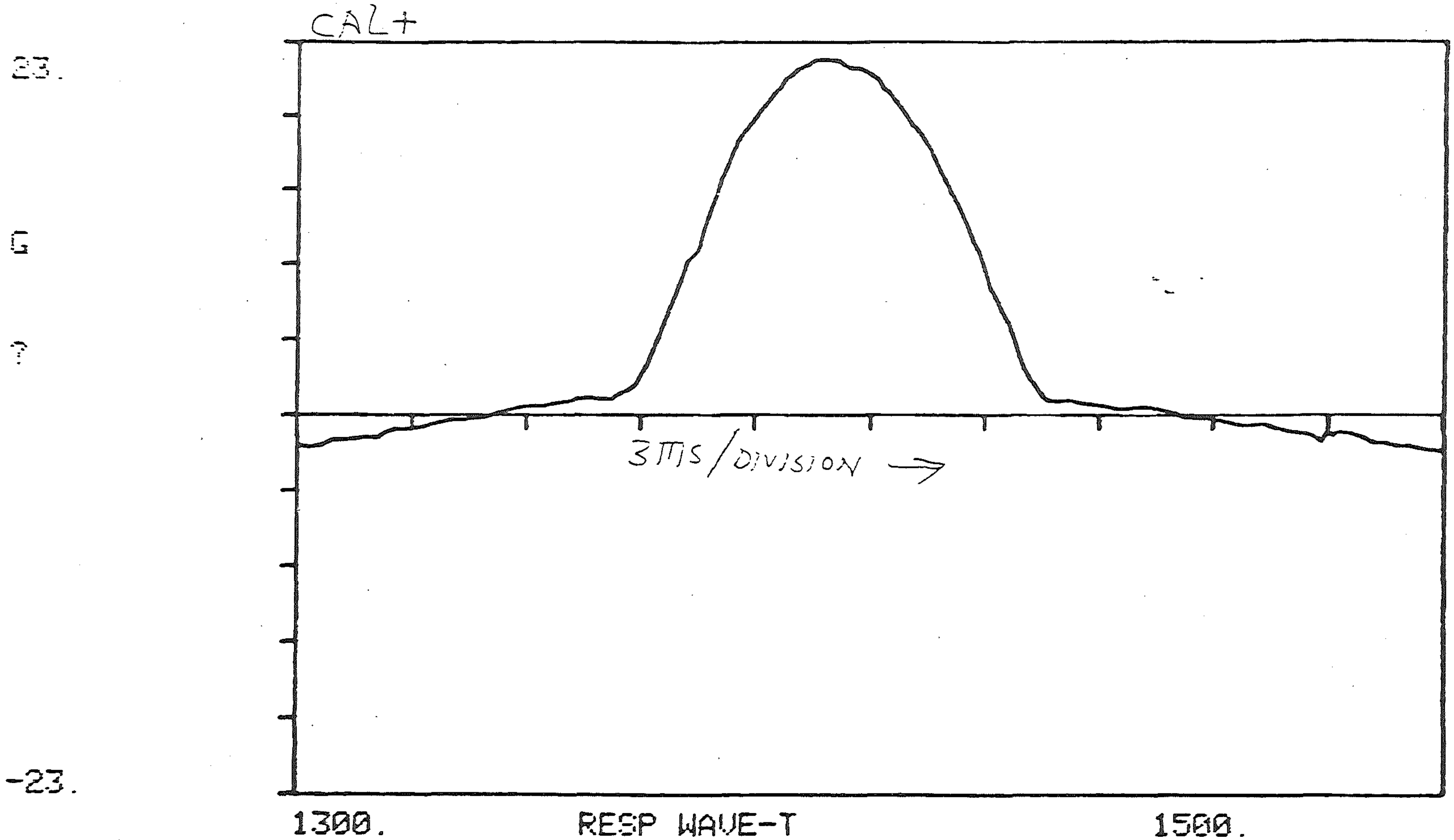


Figure 23. Acceleration Waveform for Vertical Positive Direction Shock, Expanded Scale.

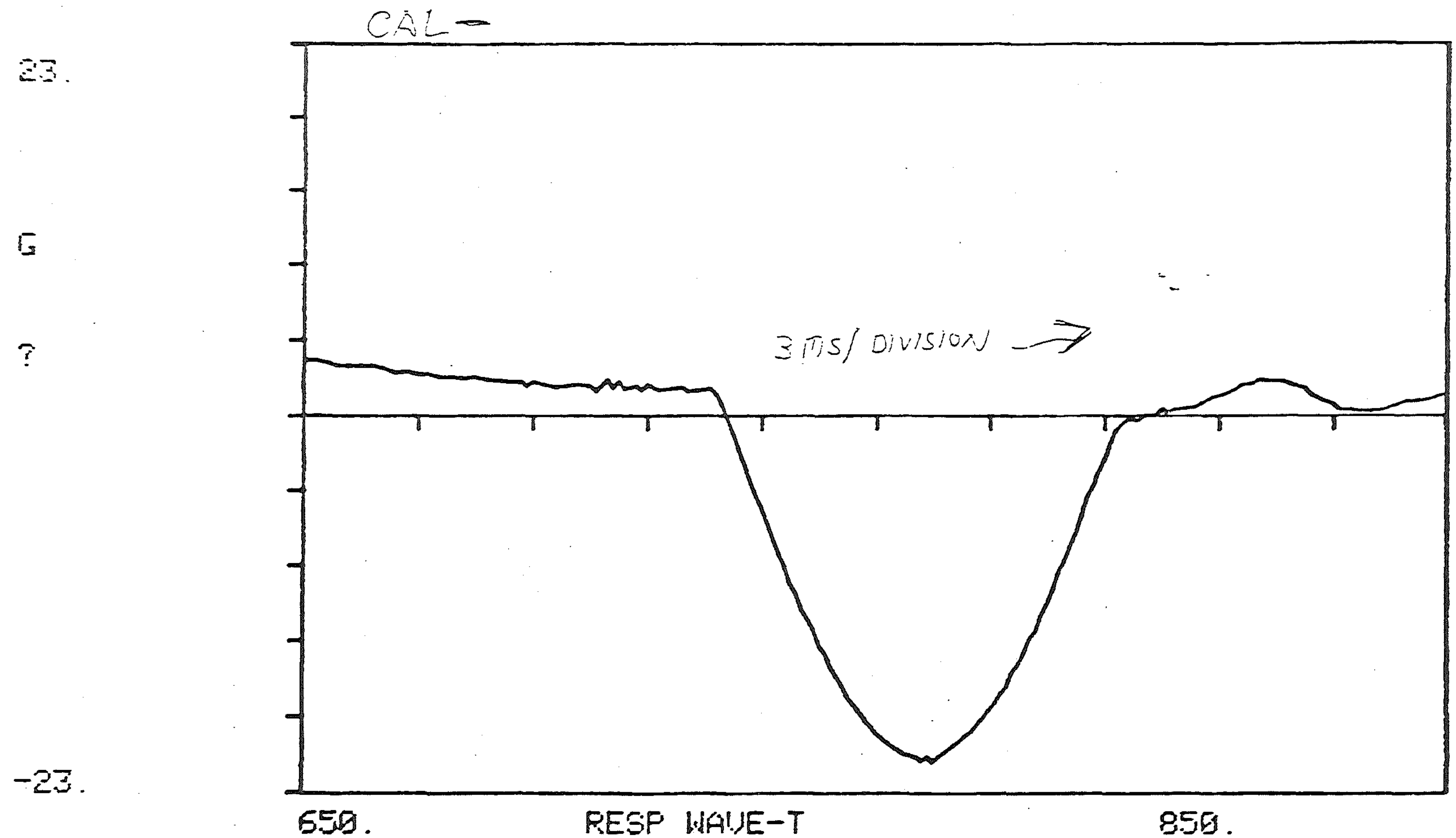


Figure 24. Acceleration Waveform for Vertical Negative Direction Shock, Expanded Scale.

developing larger accelerations (a second accelerometer is placed on the instrument under test) on the body of the instrument. A vibration level of 1g was chosen to test the instrument. A survey test, however, at an input of 2.5 g, up to a frequency of about 50 Hz was performed with the M3X in the vertical orientation, with the result shown in Figure 25. Figure 26 shows the input acceleration on the instrument mounting plate. This test shows that the M3X resonates to about 6 g's at about 28 Hz.

Figure 27 shows the input acceleration on the mounting plate for the 1g vibration test which was perfomed in three orthogonal directions. Figure 28 shows the accelerometer output on the M3X body for the vertical orientation vibration test. The spike at about 72 Hz is attributed to one of the tape reels shaking.

Figure 29 shows the accelerometer output for the longitudinal vibration test. The noise spikes are due to the switching of the M3X from the pump mode to the count mode. The instrument was running during this test. Before initiation of the vibration test a small cloud of airborne Arizona road dust was generated, near the inlet of the monitor with a hand-held squeeze bulb. The mass of collected dust on the collection spot was determined by the M3X after which the vibration was initiated. At the completion of the test, the final mass (to which no dust was added during the vibration test) was compared with the initially determined mass. The mass loss reading from the instrument were: 0.0155 mg for the longitudinal vibration test and 0.0116 mg for the latitudinal test. Both of these values fall approximately within the predicted 2-sigma beta counting statistics error band of ± 0.015 mg. Thus no significant error due to dust loss count could be detected during these vibration tests.

Comparison of Figures 28, 29 and 30 show that a resonant frequency is reached at some characteristic low frequency, but this frequency varies for the different vibration directions. As vibration frequency increases it may be observed that the shock mounts used become more efficient at decoupling the instrument from the accelerations applied to the mounting plate. These shock mounts, however, are not particularly effective at these low frequency. It must be emphasized, however, that the M3X remained unaffected by both the shock and vibration tests without detriment to its operation, and that the use of even more effective shock mounts for a field testable unit should make its operation essentially impervious to the shock and vibration environment associated with a mining machine.

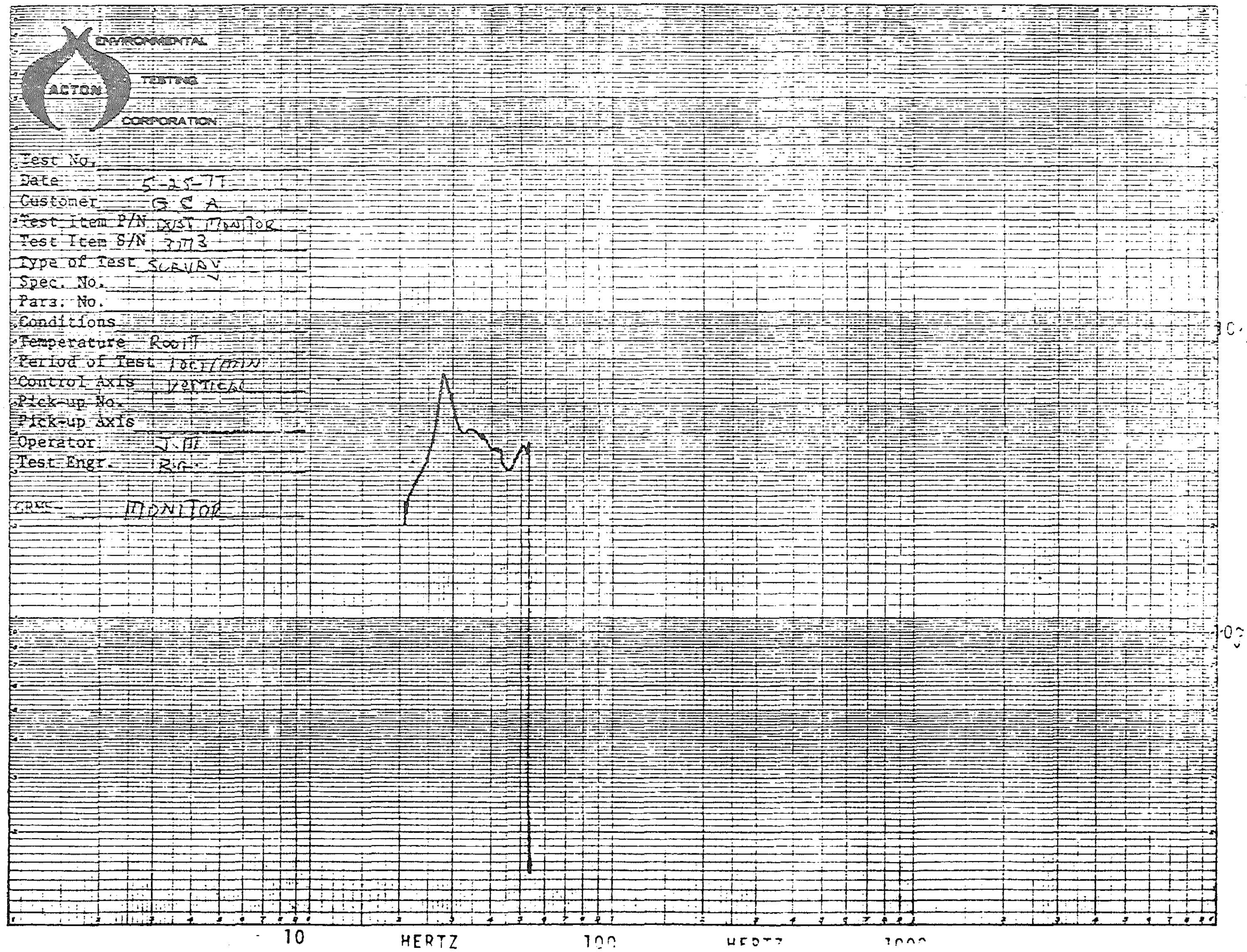


Figure 25. Acceleration Waveform for Vertical Orientation Vibration at 2.5 g Input.

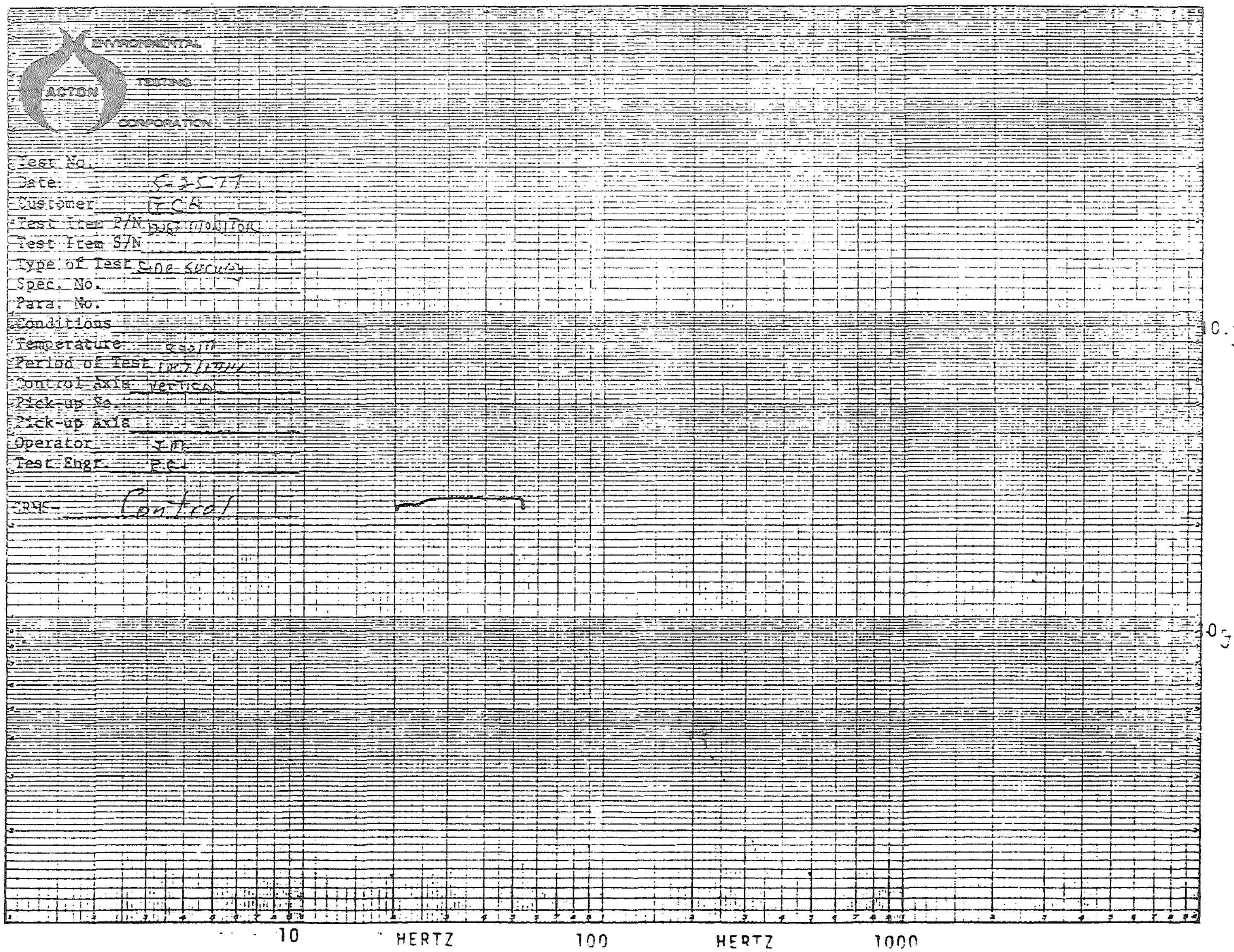


Figure 26. Input Acceleration of Mounting Plate for 2.5 g Vibration Test.

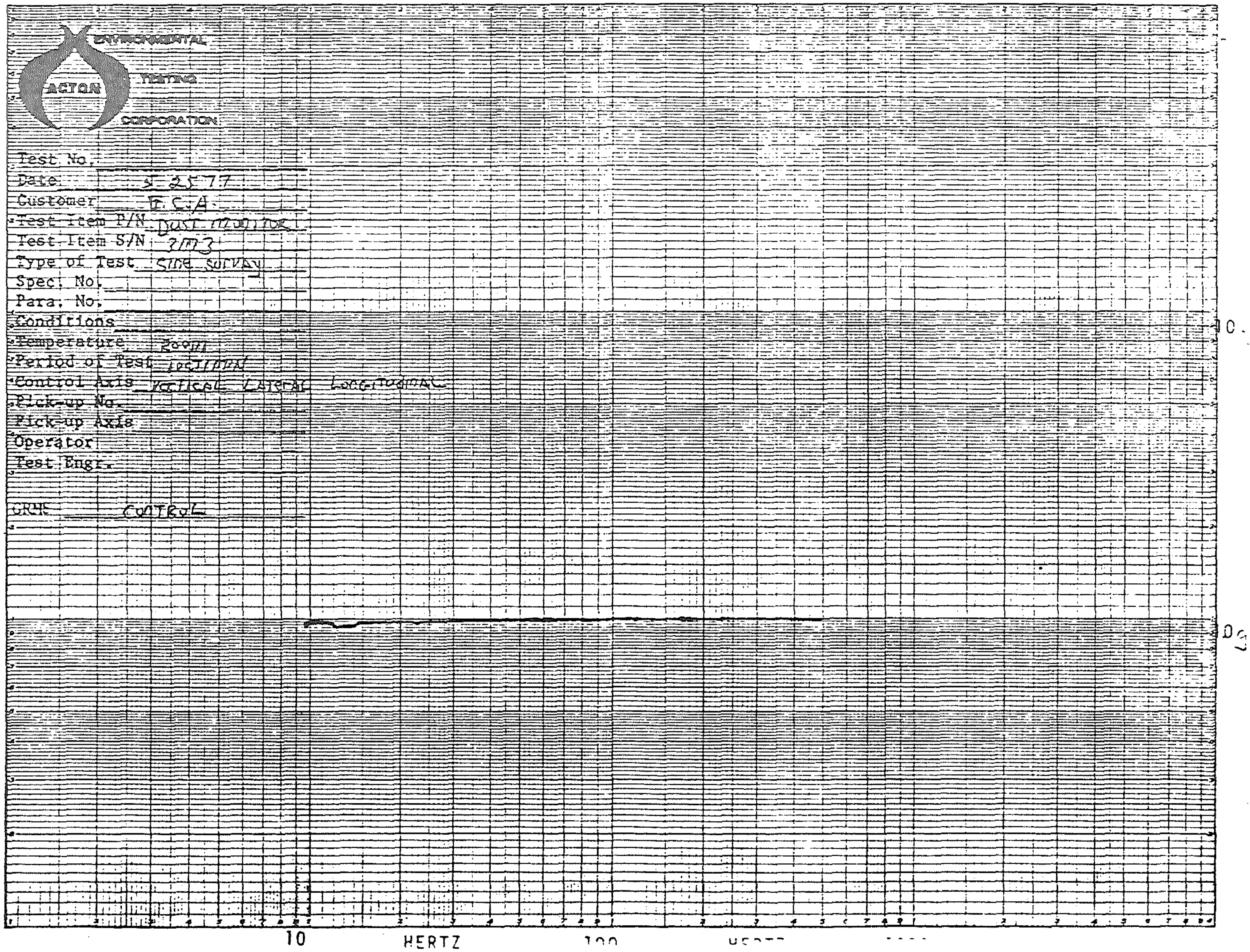


Figure 27. Input Acceleration of Mounting Plate for 1 g Vibration Test.

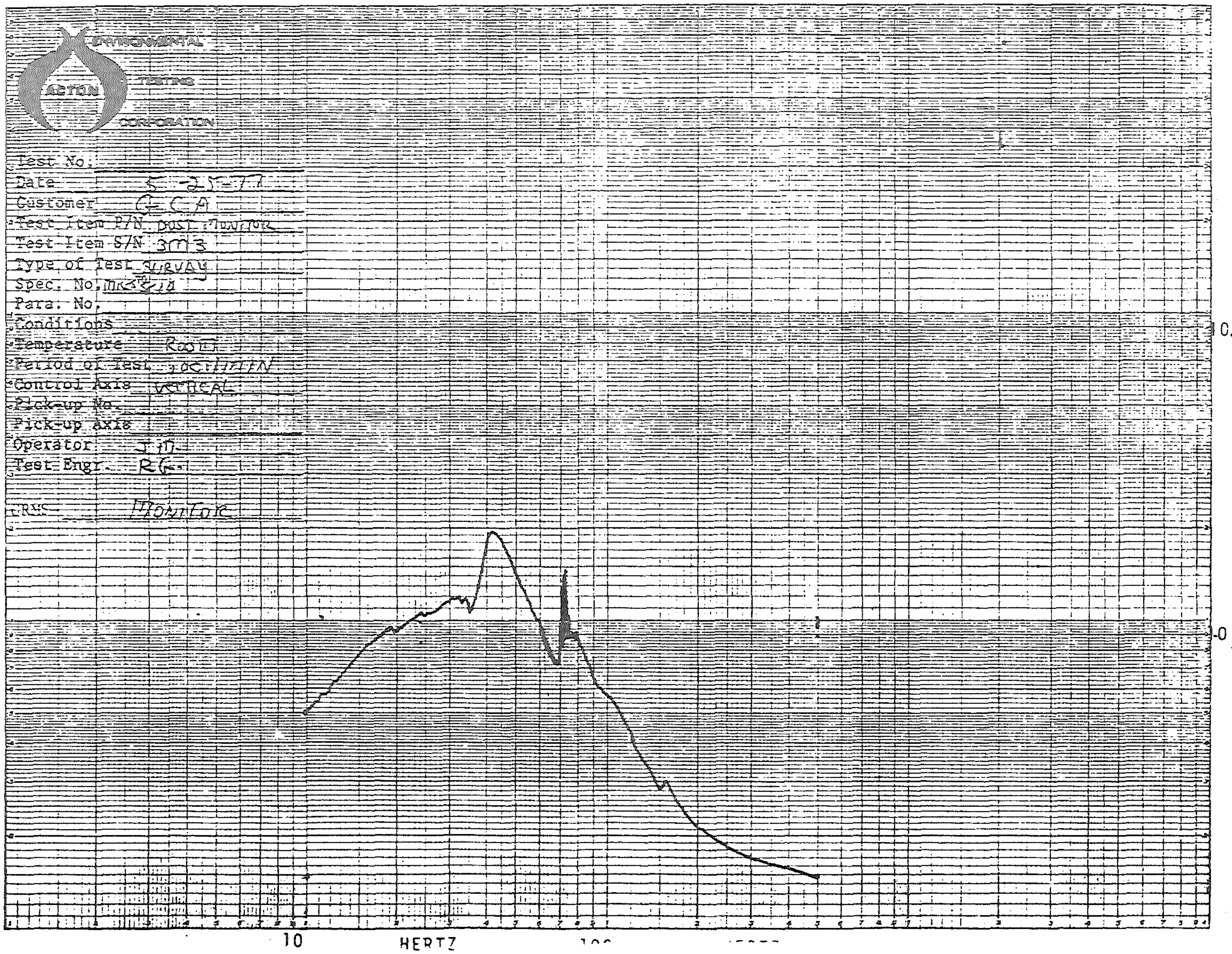


Figure 28. Accelerometer Waveform for Vertical Vibration Test at 1 g.

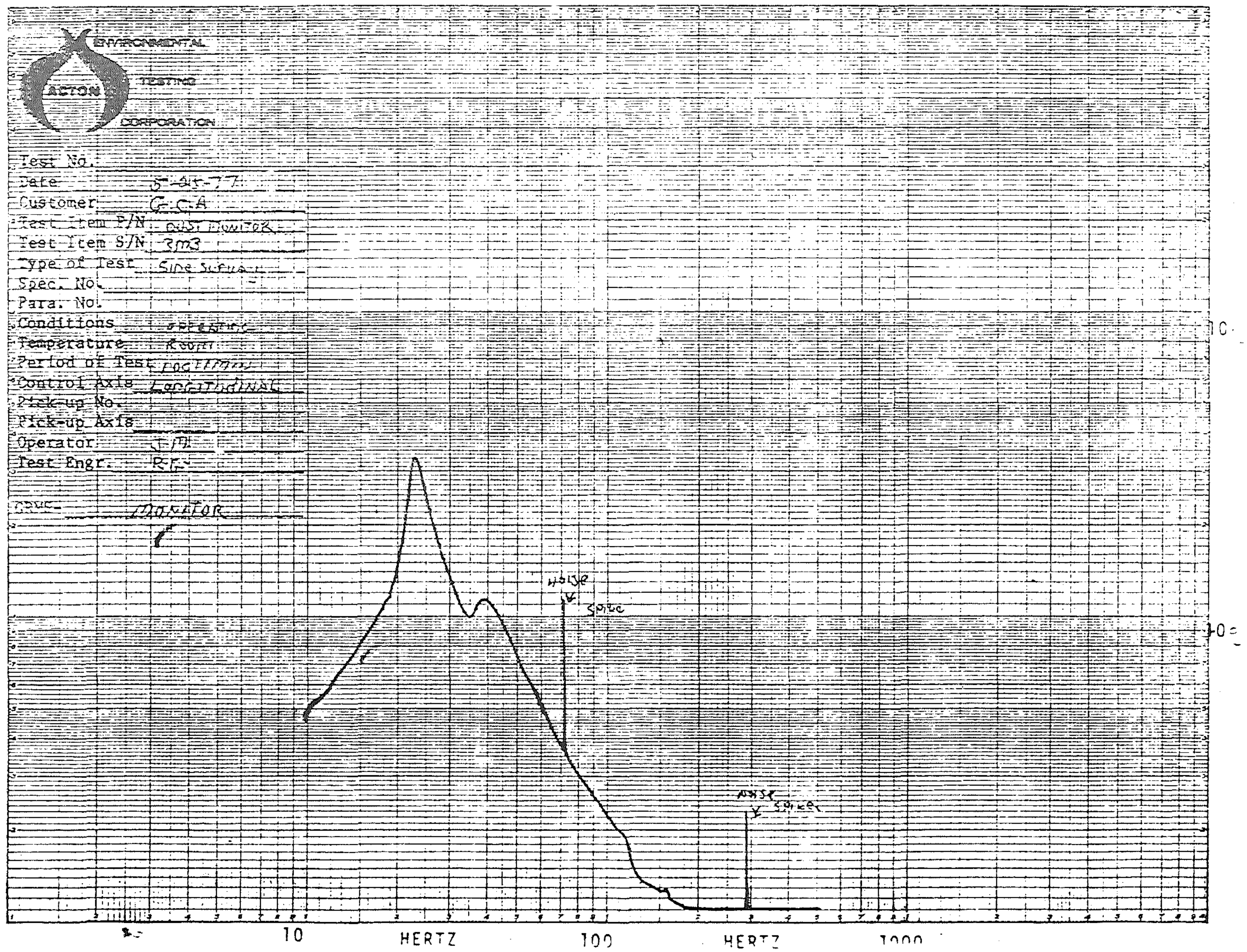


Figure 29. Accelerometer Waveform for Longitudinal Vibration Test at 1 g.

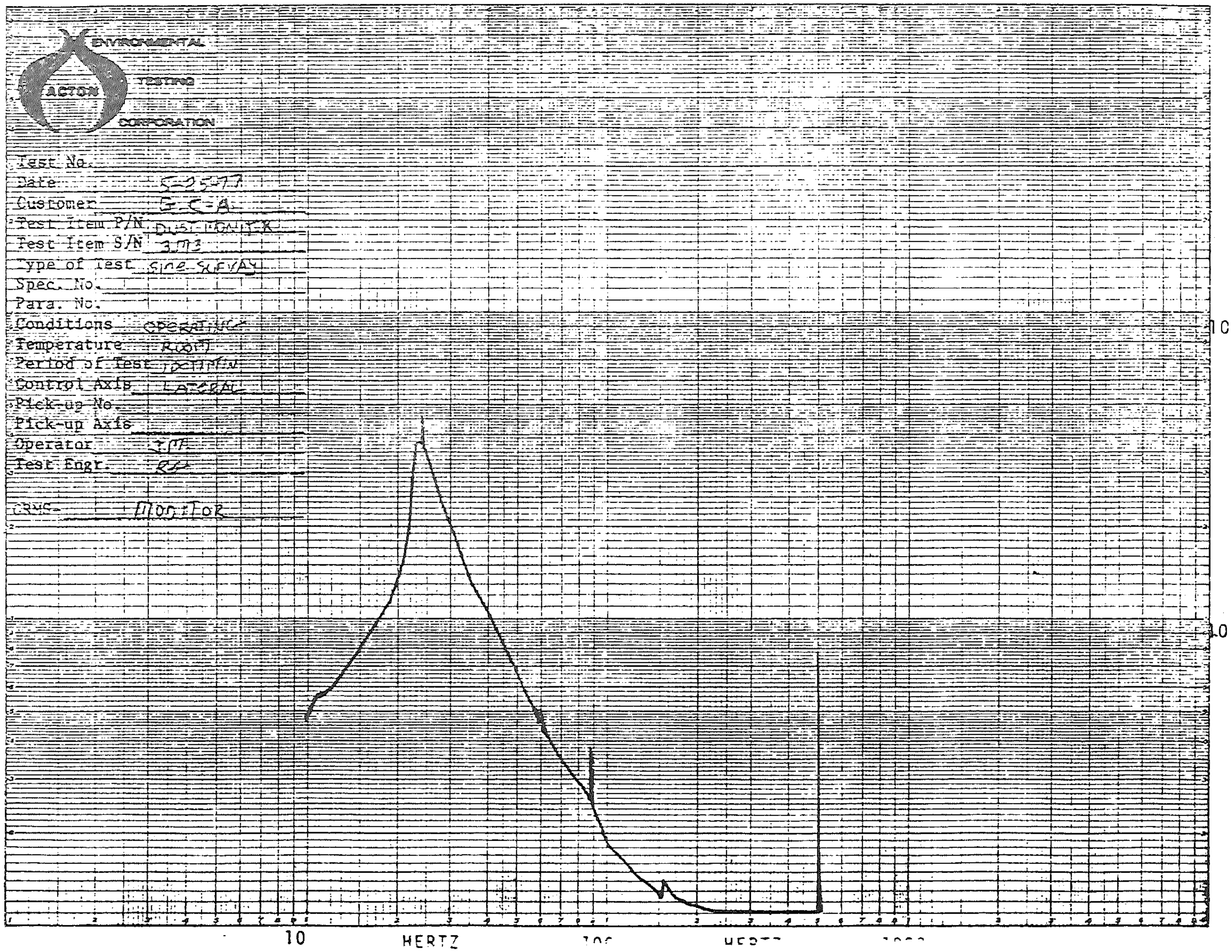


Figure 30. Accelerometer Waveform for Lateral Vibration Test at 1 g.

Instrument Specifications

- Short-term sampling period: 28.8 minutes
- Short-term measurement cycle: 30 minutes
- Short-term mass concentration range: 1 to 10 mg/m^3
- Short-term mass concentration measurement accuracy: ± 25 percent or better (2-sigma)
- Beta counting time: 1 minute
- Long-term sampling duration: 8 hours
- Long-term mass concentration range: 0.25 to 10 mg/m^3
- Readout resolution: 0.0001 mg for mass
  0.01 mg/m^3 for concentration
  0.1 minutes for time
  1 count for beta count.
- Sampling flowrate: 2 liters/minute
- Pressure drop of clean filter: 1 in. Hg (typical)
- Maximum filter pressure drop: 15 in. Hg
- Face velocity at collection area: 75 cm/sec
- Maximum mass per spot: 0.5 mg
- Collection spots per filter tape roll: 1000 approximately

Instrument Set-Up and Preparation

- Power Supply Requirements: Due to the higher current demands of the M3X a power supply larger than the RDM-301 supply must be used. Figure 31 shows the manner in which the power supplies should be wired. A small (24 Vac) transformer should supply voltage to turn on a main power supply relay when the "power on" switch is thrown. This relay should supply 117 Vac to the power supplies. Three power supplies are recommended. A + 5 V at 5A regulated with over voltage protection, a -12 V at 2A regulated, and a -15 V at 8A unregulated. In future units where the collection-detection head would be nearer the electronics, shorter lengths of larger diameter wire will allow the use of a dual voltage +5, -12 V supply.

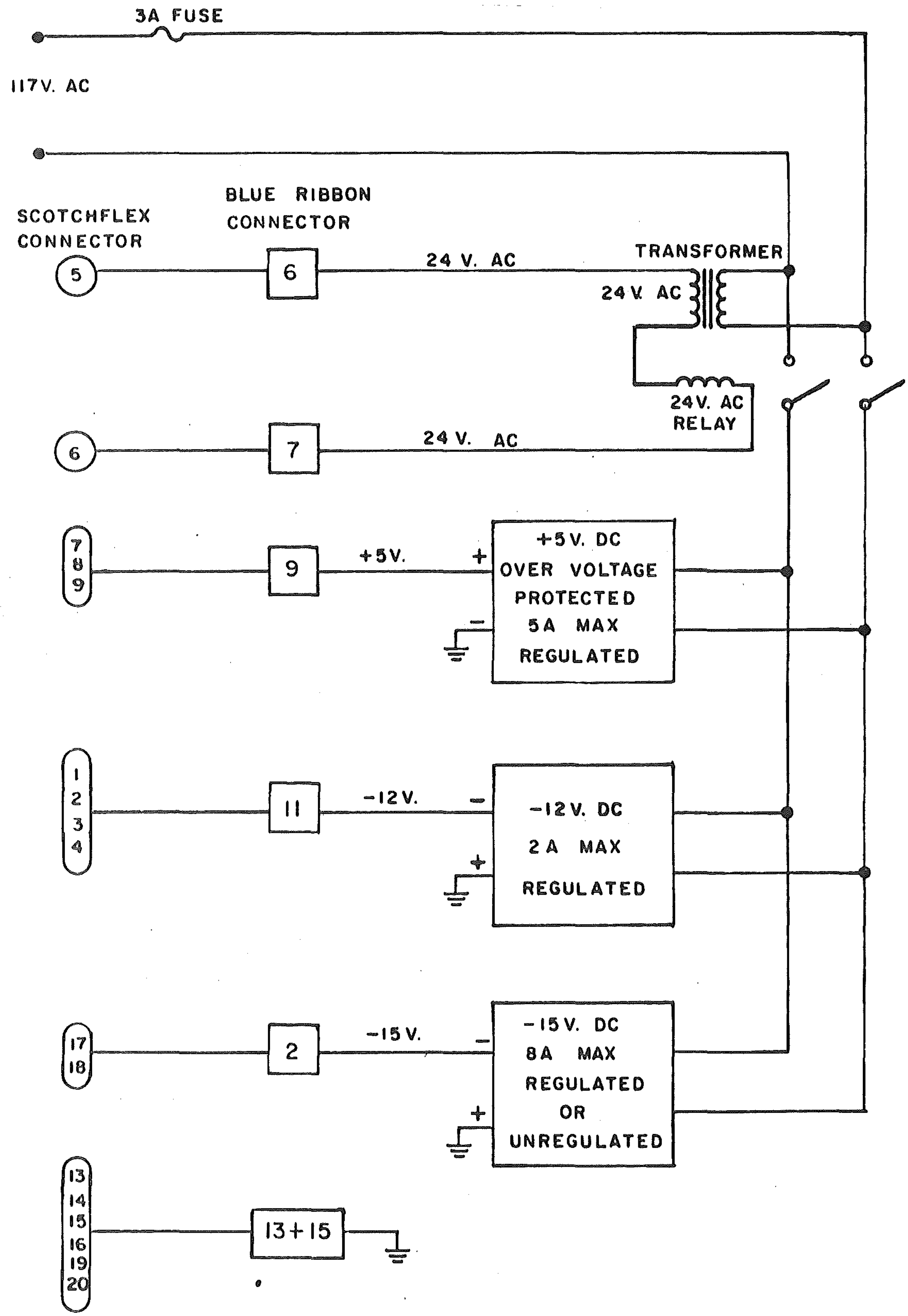


Figure 31. Power Supply Wiring Diagram.

In addition, for the operation of the mass flow controller a ± 15 volt power supply (4 watts) is required. The + 15 volt section of this supply can be used (by adjustable voltage division) to provide the adjustable 0.1 to 5 volts required to establish the desired flowrate of 2 liters/minute.

- System Interwiring and Flow Interconnections. Reference will be made to the photographs of Figures 32 through 37. Figure 32 shows the four components of the prototype: the collection-detection head, the electronic control unit, the mass flow controller and the pump. Two cables are available for connection to the power supplies mentioned previously: the colored ribbon cable from the electronic control unit and the cable from the flow controller. A black cable with its connector, from the collection-detection head, must be plugged into the top receptacle of the electronic control unit.

  Referring to Figure 33 the two pump leads (unpolarized) must be connected to the "T" and "GNO" labeled terminals of the terminal strip at the rear of the collection-detection head.

  The flow ducts are to be interconnected as shown in Figures 32 and 33. The flow controller cable includes an output signal lead which can be connected to a d.c. voltmeter to indicate a signal proportional to the flowrate. This signal is of the order of 0.8 volts for a 2 liter/min flowrate.

- Filter Tape and Digital Printout Tape Loading. In order to insert or remove the filter tape from the collection-detection head the following procedure should be applied. Place the instrument in the POWER ON position (Figure 34) (with all external power supply voltages applied), and switch the REPEAT BETA COUNT selector to the upward (or enabled) position. Manually push tape release level (Figure 33) towards its small solenoid compressing the return spring. The filter tape can now be pulled out towards the front from under the beta source holder (Figure 35). The same operation applies for insertion of a new roll. Caution should be exercised in placing the new tape within the curved groove or track provided on the detector enclosure. The printed tape cartridge can be removed by sliding it away from the printout head. When inserting a new printing cartridge, care should be taken in sliding it parallel within the side tracks to the end of its travel to ensure proper head contact and capstan engagement. The take-up reel can be removed by lifting the shaft lock, which should be placed again in the locked position after reel replacement.

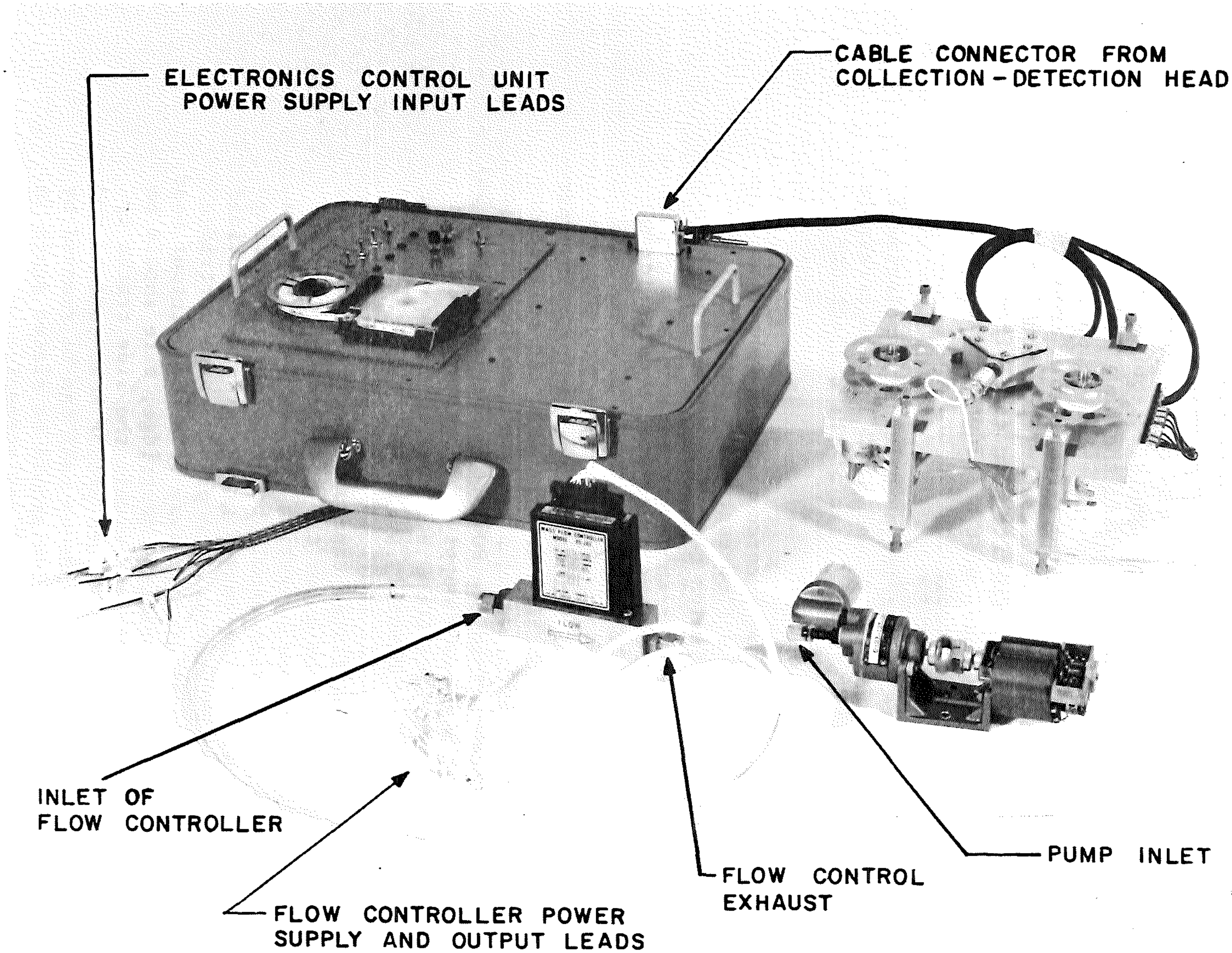


Figure 32. Overall System and Interconnection View.

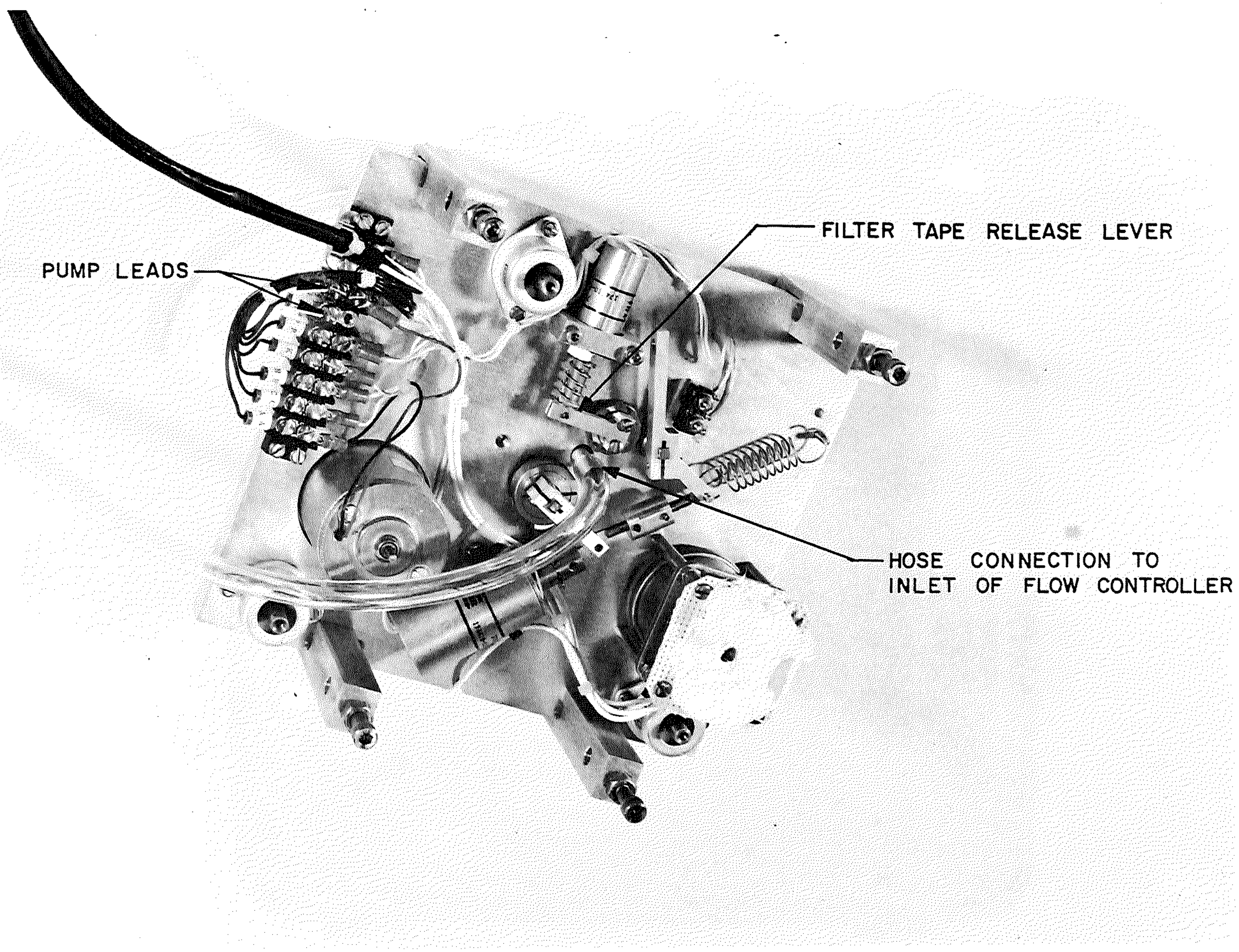


Figure 33. Rear View of Collection-Detection Head.

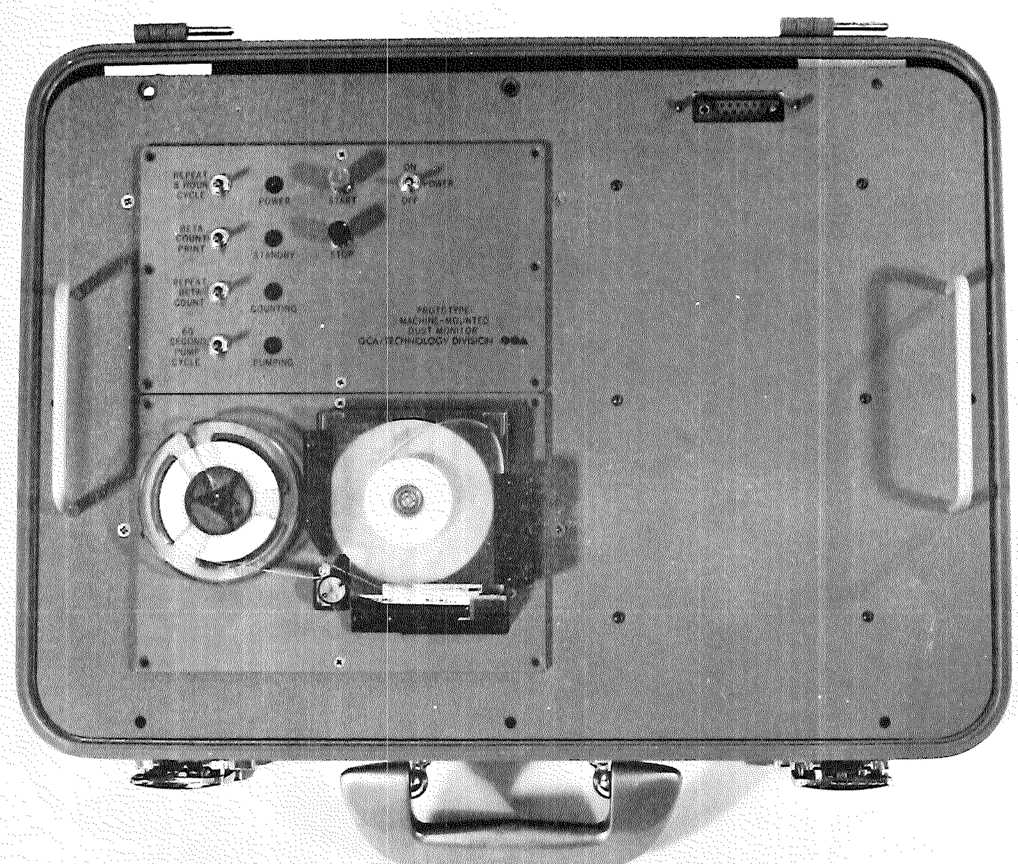


Figure 34. Top View of Control Unit.

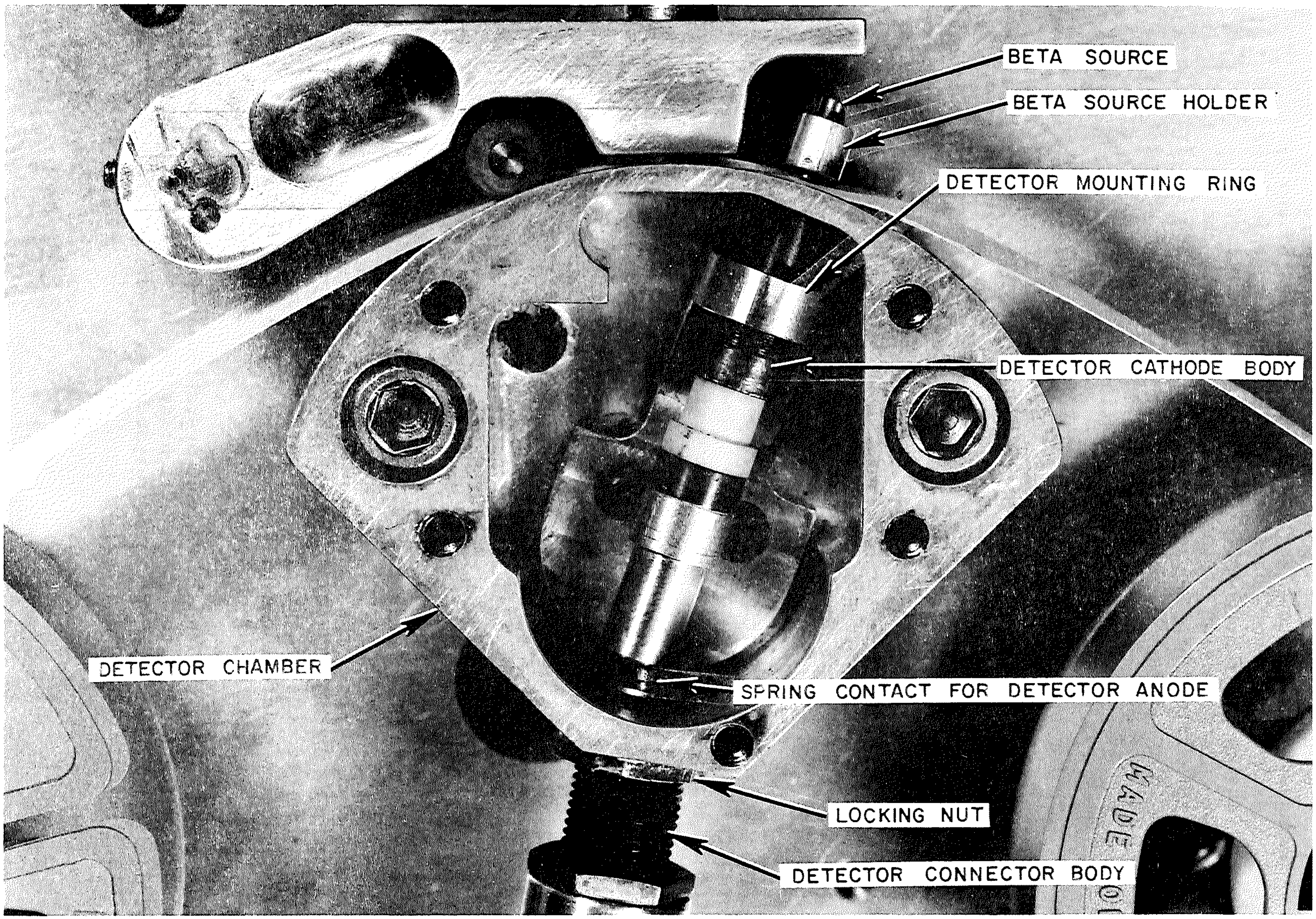


Figure 35. Detailed View of Open Detector Chamber.

- Inlet Connection. The sampling inlet is attached to the swing-away filter tape seal as shown in Figures 35 and 36. A flexible length of tubing can be connected to this inlet for dust testing purposes. Care should be exercised in allowing free motion of the pivoting seal; i.e., the use of an inflexible tubing would restrict this motion and impair the filter seal.

Instrument Operation

To initiate the operation of the instrument (after the various power supply voltages have been provided), place the POWER switch in the ON position, the POWER light should then be on, as well as the STANDBY light. For operation in the normal 8-hour, 30 minute cycle condition place the switch 60 SECOND PUMP CYCLE in the downward position as well as the REPEAT BETA COUNT switch. The BETA COUNT PRINT switch can be left in either position (upward for beta count print and downward to disable that function). The REPEAT 8 HOUR CYCLE switch determines whether the instrument will repeat these 8-hour cycle indefinitely or stop after the completion of one 8-hour cycle (the downward position always means that this function is disabled; i.e., no repetitions of the cycle).

After appropriate selection of the various control positions (also refer to the report section on printout format) the actual measurement cycle is initiated by depressing the START button momentarily, as a result of which the instrument goes into a 1-minute automatic warm-up period during which the STANDBY light goes out. At the completion of this static 1-minute period the filter tape is advanced automatically to a new position, as well as the printout tape (without printing any information). The beta source-detector pair swings into the sensing position and the COUNTING light goes on. At the completion of an initial 1-minute beta counting period the printer prints out the initial beta count (if so selected with the BETA COUNT PRINT switch), the tape seal arm swings back into position and the pump is activated as indicated by the PUMPING light. After the completion of the first 28.8-minute pumping period the instrument performs its second beta count as above after which the first complete measurement printout is executed; i.e., time, mass and concentration (and beta count if so selected).

For checkout purposes the instrument can be placed in a rapid cycle mode by placing the 60 SECOND PUMP CYCLE switch in the upward position (enabling position), which reduces the pumping period from its normal 28.8 minutes to 1 minute (the time printout, however remains based on the 28.8 minute period, as well as the computation of concentration).

In order to interrupt the instrument operation at any time within its cycle, depress the STOP switch which will place the instrument back into its STANDBY condition from which it can be restarted as described above (including the initial 1-minute warm-up period).

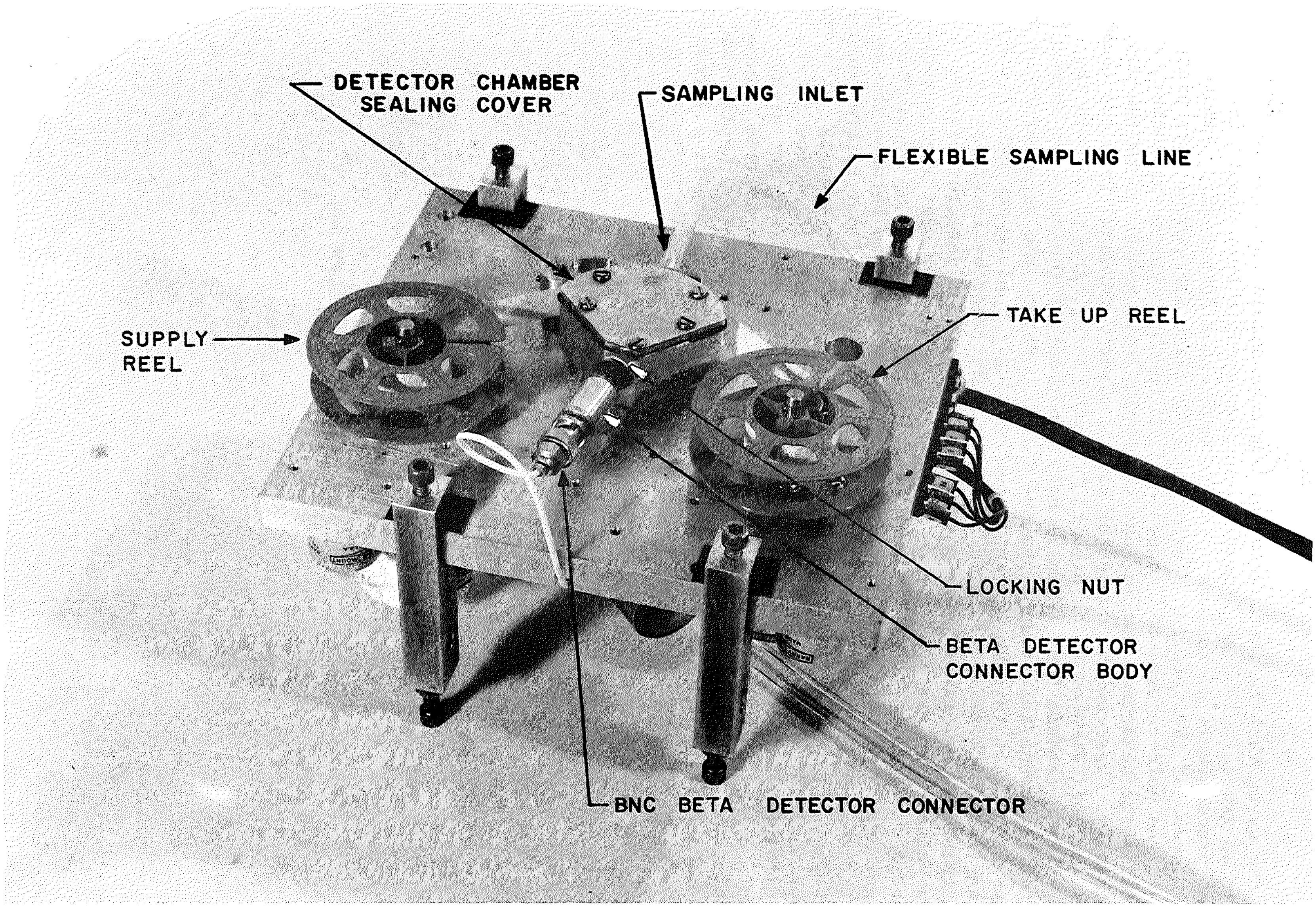


Figure 36. Front View of Collection-Detection Head.

Beta Detector Replacement

In the event that the beta detector G-M tube should fail (as indicated by either an excessively high, insufficient, or erratic beta count) its replacement procedure is as follows. (Refer to Figures 35 and 36.) Remove the five screws of the detector chamber sealing plate and remove this plate. Disconnect the gold-colored BNC connector from the beta connector socket, and loosen the large hexagonal locking nut that holds this connector to the detector chamber. Unscrew the connector (black plastic threads) from the chamber, then unscrew the detector using a pair of pliers being careful to hold the detector at the cathode body (this is only important if the detector should be kept intact and when inserting a new one later). Rotate the detector first to allow its extraction through the connector opening. Replace new detector by inserting it through this opening. Replace new detector by inserting it through this opening, taking care not to touch the front detector window. Screw in detector in its mounting until (in its swing away position as shown in Figure 35) it just touches the metal housing and then back up about one-half turn. Apply Glyptol or any equivalent locking compound between the detector threads and its mounting ring to ensure that it will not rotate during its operation. Thread detector connector body back into its opening until the small spring loaded contact is slightly compressed (about 1/3 of its total travel distance) in either of the two end positions of the detector pivot rotation. Apply silicone-rubber sealing compound to the threads and tighten the locking nut to preserve the position of the connector body. Replace BNC connector, and the sealing plate with its gasket tightening the five screws on the detector chamber body.

CONCLUSIONS AND FOLLOW-ON FIELD PROTOTYPE CONSIDERATIONS

This development program has resulted in three units of a prototype instrument designed to be operated under laboratory conditions as far as the overall system is concerned. Only the collection-detection head has been designed for exposure to the environmental test conditions contractually stipulated, because the objective of this first development stage did not envision field testing of the complete instrument. For this same reason, several of the elements of the system were left as separate unenclosed entities to facilitate any further laboratory testing and/or possible modification or adaptation.

The collection-detection head incorporates a new design concept with respect to the configuration of the dust collection and mass detection combination, using a pivoting beta source-detector combination with the latter enclosed within an evacuated chamber. This configuration eliminates any flow obstruction in the path of the dust particles arriving at the filter collection area, while at the same time ensuring that the collection area remains exactly in the same position throughout the measurement cycle consisting of an initial beta count, dust collection and final beta count. Furthermore, this design prevents any significant build-up of dust contamination on either the beta source or the detector since these elements do not come in contact with the dust flow at any time during the normal operation of the instrument. The electronic control system of the M3X incorporates a microprocessor programmed to provide the required control sequence and data processing functions of the instrument. The use of this type of programmable system permitted the inclusion of an adaptive operation sequence which controls the filter tape advance on the basis of its mass loading. This method of control results in an optimal use of the collection medium, minimizing the collection spots over a given shift period, at the same time preventing the possibility of excess dust collection on a given filter area. The microprocessor used on the M3X is completely reprogrammable permitting the incorporation of future modifications to the present operation sequence or of their specific operational criteria, such as maximum spot mass loading, cycle period duration, etc.

The results of the testing sequence were entirely successful and fully justify pursuing this concept with minor basic design modifications with the objective of developing a practical field-worthy version capable of continuous, trouble-free operation as a mining-machine mounted respirable dust monitor. Obviously, the design of this follow-on version will be facilitated to a significant extent as a result of the experience obtained from this initial prototype development program, ensuring a successful implementation of this new monitoring approach to the routine surveillance of the mining environment.

Some of the overall design considerations for the follow-on field prototype of the mining machine-mounted monitor will now be discussed. A more specific treatment of this subject, however, will be deferred until a complete definition of the detailed requirements is established and a comprehensive proposal can be evolved.

The basic building blocks of a machine-mounted monitor would be the following: source of power, back-up battery, power supply, electronic control and data processing unit, a digital printer or recorder, the collection-detection head, a pump-flow control system, and the sampling inlet-cyclone combination. The primary source of power is expected to be derived from the power available at the mining-machine itself. A back-up battery must, however, be available to permit continuous monitor operation during main power interruptions lasting up to several hours. A power supply unit is required to furnish the various voltages for the operation of the monitor. The electronic subsystem would be constituted by the microprocessor and peripheral circuitry required for the sequential control, signal processing, computation and printout drive functions of the instrument. A printer or recorder would provide the output information and nonvolatile data memory. The collection-detection head, in combination with the particle size selective inlet separator and a flow subsystem are designed to collect the respirable fraction of the dust and sense its mass as retained on a filter medium.

The various elements enumerated above are not expected to all be discrete and separate physical entities but to be, in most cases, combined into a minimum of such separate elements in order to facilitate mounting to and incorporation with the mining machines. It is contemplated, at this time, that the projected monitoring system will be constituted by two main assemblies: one containing the back-up battery and charger as well as all the power supplies for the monitor, and the other containing all the other elements enumerated above. The battery-supply assembly would be attached at some convenient unobtrusive location on the mining-machine with an umbilical cable connecting to the main unit of the monitor. This latter assembly would be housed in an explosion-proof heavy-duty enclosure whose interior would be accessible only to authorized personnel. Operational and alarm indicators would be clearly visible from the outside of the unit and the inlet would be integrated with this assembly such that a representative sample of the air inhaled by the machine operator is introduced into the collection-detection elements of the monitor.

Certain specific additional aspects of the monitor under consideration worth mentioning are maintenance minimization and real-time data keep alive capabilities. It is expected that the design of the instrument will be such that filter tape replacement will be required only once every 6 months as a results of the adaptive tape advance system based on a maximum filter spot loading as developed for the preprototype system. The only other routine maintenance would be cleaning and/or cyclone replacement after periods of time similar to those presently required for personal samplers. A continuous real-time and date operation over a full year without externally applied power would be incorporated using state-of-the-art digital watch technology such as C-MOS circuitry, powered by a small rechargeable battery. Thus the setting of time and date would normally be performed when the monitor is fabricated, and subsequent corrections to compensate for any long-term drifts could be performed in the field, although accuracies of the order of 1 minute per year may make such adjustment unnecessary. The main back-up battery would be designed to provide up to about 6 hours of monitor operation in the absence of mining machine power. The estimated cost of development and production for these field-worthy prototype machine-mounted monitors including installation on and interfacing with the mining machines and the required field support is $225,000 including all options, and about $185,000 excluding option 1.5.11 of the pertinent contract (the latter estimate also applies if options 1.5.9 and

1.5.10 and 1.5.11 are excluded). The estimated end-user cost for a final production version of the machine-mounted monitor, assuming a production quantity of 500 units per year is about $14,000 for the version containing all options and about $13,000 for the version without either option 1.5.11 or all three above cited options.

REFERENCES

1. Jacobson, M. and P.S. Parobeck. Respirable Mine Dust Sample Processing Laboratory. U.S. Bureau of Mines Information Circular 8520.

2. Goldberg, S.A., L.D. Raymond, and D.C. Taylor. Bureau of Mines Procedure for Analysis of Respirable Dust From Coal Mines. J AIHA. 34:200, 1973.

3. Lilienfeld, P. A New Ambient Particulate Mass Monitor Using Beta Attenuation. Paper No. 75-65-2, Annual Air Pollution Control Association Meeting, Boston, Mass., June 1975.

4. Benarie, M. and A. Loverdo. Pesee Automatique des Polluants Atmospheriques par Jaugue Beta. Mesures, Regulation et Automatisme, 32:90, 1967.

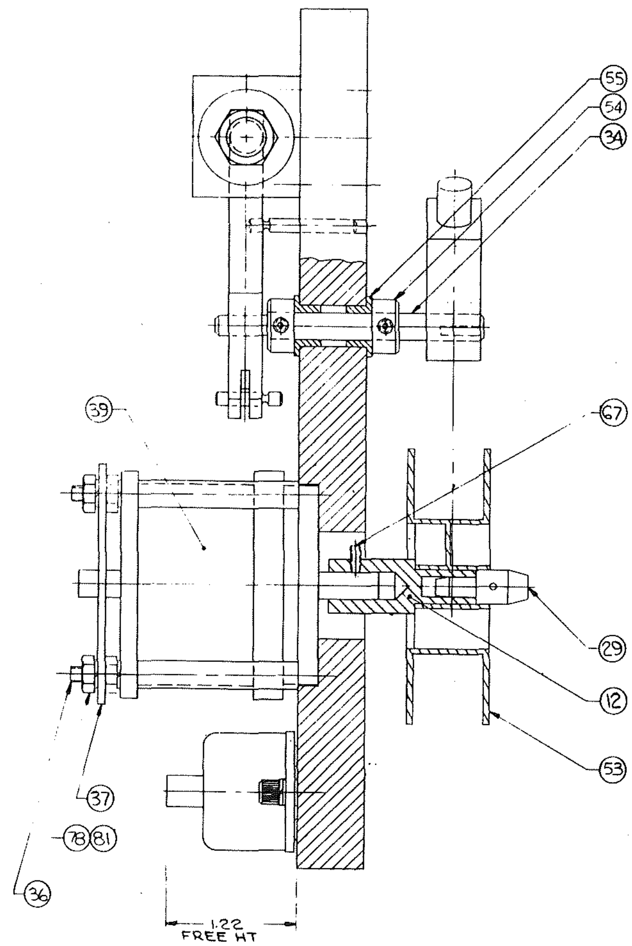
5. Lilienfeld, P. Beta Absorption Mass Monitoring of Particulates - A Review. Joint Conference on Sensing of Environmental Pollutants, Palo Alto, California. AIAA Paper No. 71, p. 1031, November 1971.

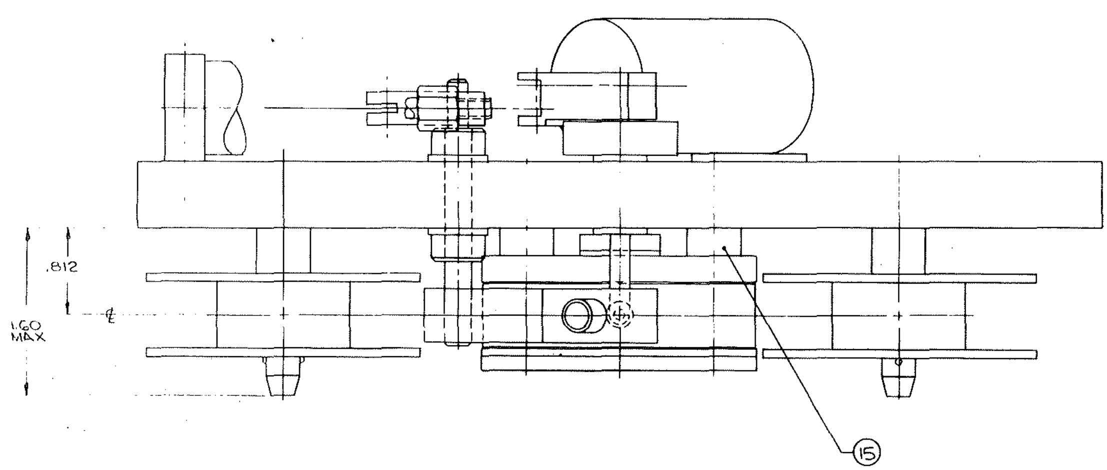
6. Lilienfeld P. Design and Operation of Dust Measuring Instrumentation Based on the Beta-Radiation Method. Staub, 35(12):458, 1975.

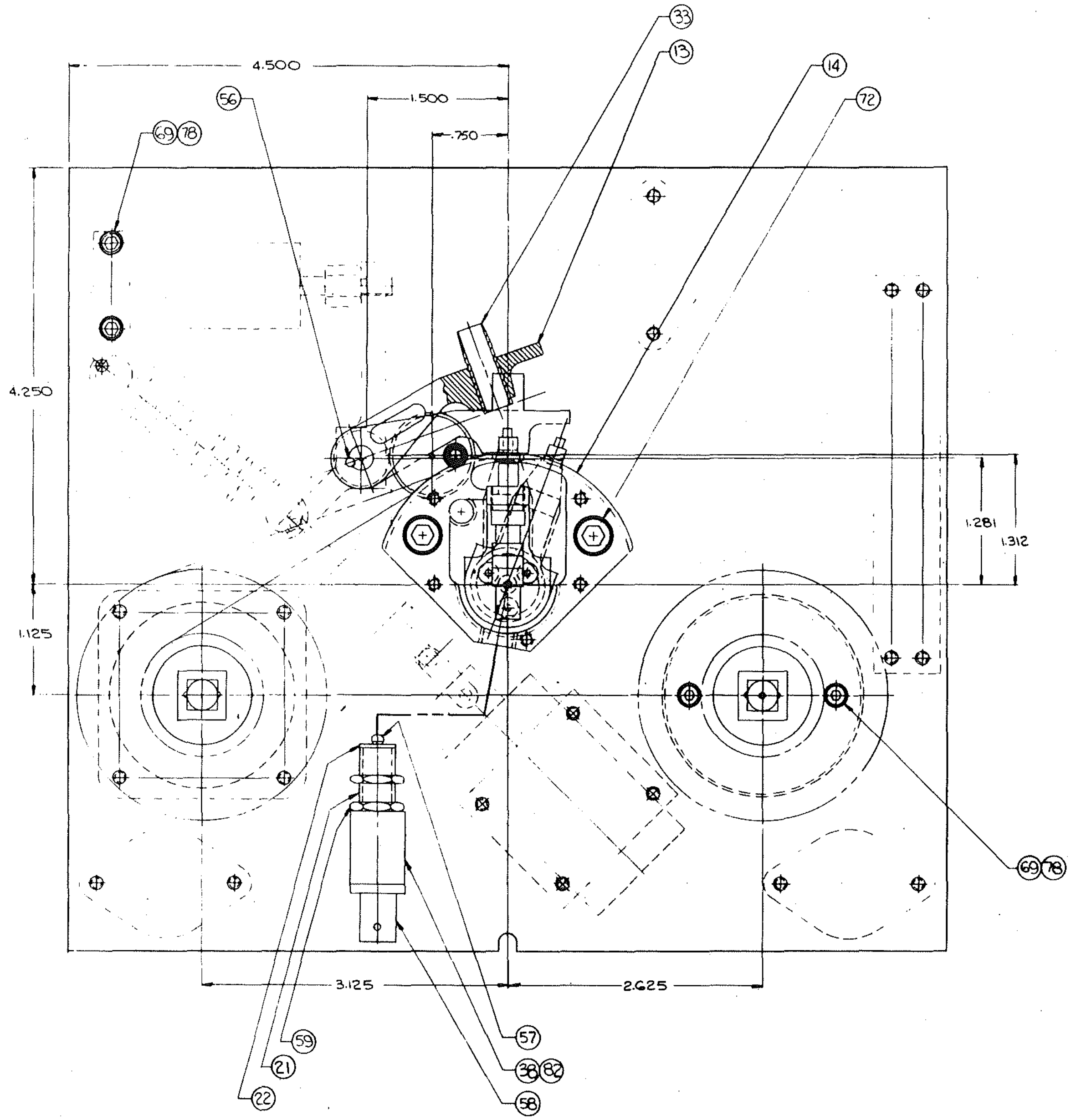
7. Lilienfeld, P. Design, Development, Fabrication and Testing of a Portable Self-Contained Respirable Dust Recording Mass Monitor. USBM Contract Final Report (Contract No. H0232039), October 1974.

APPENDIX A

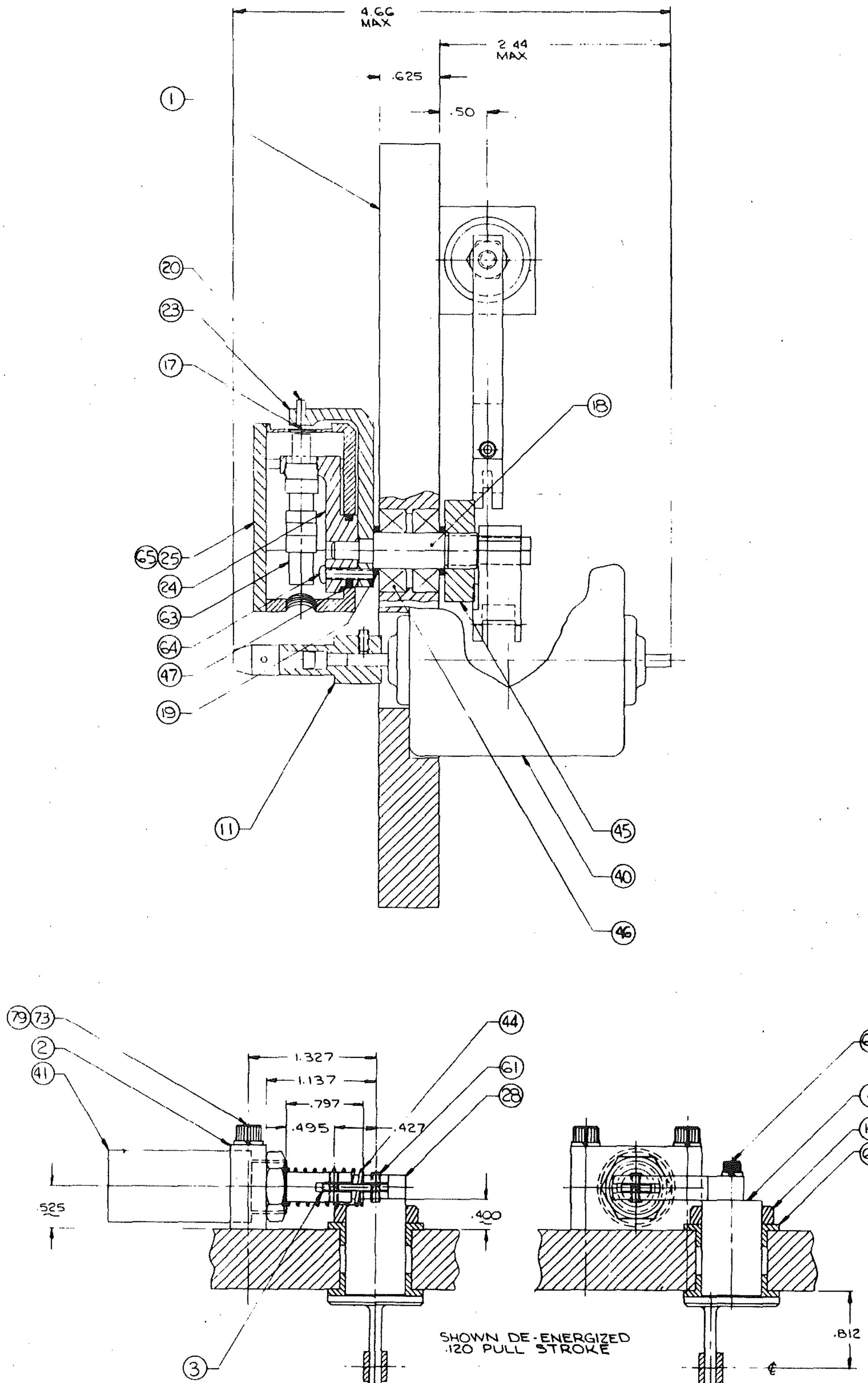
SCHEMATIC DRAWINGS OF COLLECTION-DETECTION HEAD


55
54
34
39
67
29
12
53
37
78
81
36
1.22
FREE HT

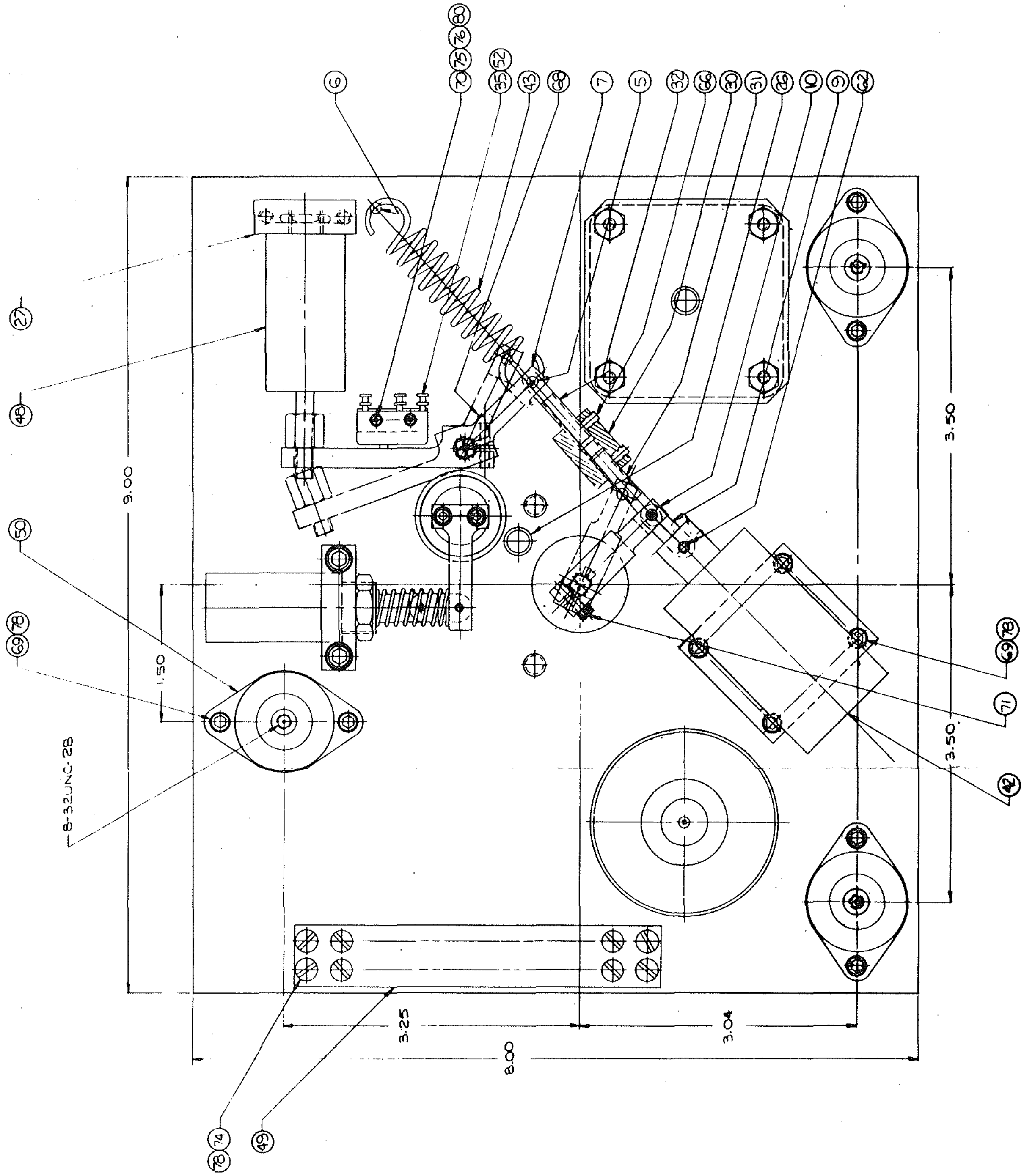

.812
1.60
MAX
15



4.500
1.500
.750
4.250
1.125
1.281
1.312
3.125
2.625
33
13
14
72
56
69
78
57
59
21
22
38
82
58



PINCH ROLL ASSEMBLY


9.00
8.00
3.25
3.04
3.50
3.50
1.50
8-32UNC-28

QTY	PART NO.	DESCRIPTION	F/N
			85
			84
			83
1		RESISTOR, 1/4 W 4.7 MEG. Ω	82
8		NUT, HEX #6	81
2		NUT, HEX, #2	80
2		WASHER, LOCK, #8	79
26		#6	78
2		#4	77
2		LOCK, #2	76
2		WASHER, FLAT, #2	75
4		SCREW, PAN HD, 6-32 × .22 LG	74
2		SOC HD CAP, 8-32 × 1.25 LG	73
2		SOC HD CAP, 1/4-20 × 1.00 LG	72
1		SOC HD CAP, 4-40 × .38 LG	71
2		SOC HD CAP, 2-56 × 1.50 LG	70
14		SOC HD CAP, 6-32 × .50 LG	69
3		SOC HD CAP, 4-40 × .50 LG	68
2		SET, CUP POINT, 4-40 × .12 LG	67
2		SET, SILVER TIP, 4-40 × 12 LG	66
5		PAN HD 4-40 × .25 LG	65
3		SCREW, BUT HD 4-40 × .50 LG	64
1	N202	TGM DETCTOR	63
2	9Y35-0414	SDP ROLL PIN 1/8 DIA × 7/16 LG	62
2	9Y35-0310	SDP ROLL PIN 3/32 DIA × 5/16 LG	61
2	7B4-F065	SDP SINTERED FLANGE BRG	60
2	.1199C	H.H. SMITH 3/8-32 JAM NUT	59
1	UG-657U	BNC CONNECTOR	58
1	97	FEURER BROS STYLE A CONTACT	57
1	9X31-0310	SDP DOWEL PIN 3/32 DIA × 5/16 LG	56
2	7B4-GF0808	SDP SINTERED FLANGE BEARING	55
2	C1-3	PIC SET SCREW COLLAR	54
2		KODAK 50' 16MM REEL	53
1	L4	UND LAB INC SWITCH 5A 250VAC	52
3/8 IN	192	GREENE RUBBER SURGICAL LATEX	51
3	T22-AB-5	BARRY SHOCK MOUNT	50
1	9-164	CINCH JONES TERMINAL BLOCK	49
1	160-K-T-X	AIRPOT DAMPING CYLINDER	48
1	Q-4016	QUAD-X 4 LOBED SEAL	47
2	SR655	BARDEN BALL BEARING	46
1	3/8-1655	STAFFORD MFG THD COLLAR	45
1	LC035F-5	LEE SST COMPRESSION SPRING	44
1	LE037E-1	LEE SST EXTENSION SPRING	43
1	174419-022	LEDEX SIZE 125 SOLENOID	42
1	174610-028	LEDEX SIZE 75 SOLENOID	41
1	CYQM83600-51	BARBER COLMAN D.C MOTOR	40
1	216612-023	LEDEX STEPPING MOTOR	39
1	A-376-1049	THREADED COUPLER	38
1	C-376-1048	VECTOR BOARD	37
4	A-376-1047	STAND-OFF, MOTOR	36
1	A-376-1046	MICRO SWITCH MOUNTING PAD	35
1	A376-1045	INLET TUBE HOLDER SHAFT	34
1	A376-1044	INLET TUBE	33
1	A-376-1041-2	TIE ROD	32
1	A-376-1041-1	TIE ROD	31
1	B-376-1040	TURNBUCKLE	30
2	A-376-1039	REEL SHAFT DETENT	29
1	C-376-1038	TIE ARM NO. 3	28
1	B-376-1036	MOUNTING BRACKET AIR POT	27
1	A-376-1035	VACUUM OUTLET TUBE	26
1	C-376-1034	COVER, TAPE GUIDE	25
1	C-376-1033	DETECTOR MOUNT	24
1	C-376-1032	SOURCE MOUNT	23
1	A-376-1030	CONTACT PLUNGER MOUNT	22
1	A-376-1029	CONTACT PLUNGER ADJ SCR	21
1	A-376-1026	SOURCE	20
2	A-376-1023	BEARING THRUST WASHER	19
1	C-376-1022	BEARING SHAFT	18
1	A-376-1021	SCREEN, TAPE GUIDE	17
1	A-376-1020	SHAFT COLLAR	16
2	A-376-1018	STAND-OFF, TAPE GUIDE	15
1	D-376-1017	TAPE GUIDE	14
1	C-376-1015	INLET TUBE HOLDER	13
1	B-376-1014	SUPPLY REEL HUB	12
1	B-376-1013	TAKE-UP REEL HUB	11
1	C-376-1011	LINK ARM	10
1	A-376-1010	TIE ARM NO. 2	9
1	A-376-1009	THRUST WASHER	8
1	C-376-1007	LINK & ACTUATOR ARM	7
1	A-376-1006-2	SPRING SHAFT	6
1	A 376-1006-1	SPRING SHAFT	5
1	C-376-1005	PINCH ROLLER	4
1	A-376-1004	LINK ARM, PINCH ROLL SOLENOID	3
1	B-376-1003	MTG BRKT, PINCH ROLL SOLENOID	2
1	E-376-1001	BASE PLATE	1

DR J. STELLA DATE 2-7-77
CHK
APPROVALS
RELEASED

GCA/TECHNOLOGY DIVISION

TITLE
MECH DRIVE & LINKAGE
LAYOUT & ASSEMBLY
MACHINE MTD MONITOR

SIZE J DRAWING NO 376-1000

SCALE 2:1 WT SHEET OF REV A