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NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #2001-0073-2869
City of Cincinnati Sewers, Water Works & Public Services
Cincinnati, Ohio

February 2002

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Ren G. Dong and Thomas McDowell of the Engineering & Control Technology Branch (ECTB), Health Effects Laboratory Division (HELD). Field assistance was provided by Dan Welcome, ECTB, and Randy L. Tubbs, HETAB. Desktop publishing was performed by David Butler, HETAB. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of pneumatic tools and their vibration levels

The National Institute for Occupational Safety and Health (NIOSH) was asked by the City of Cincinnati to measure the vibration levels on the tools used by work crews to repair and maintain the water, sewer, and street systems.

What NIOSH Did

 # We gathered vibration measurements from the tools used by the city workers.

 # The measurements were made at several work sites and at the city garage.

 # We watched workers at the job site and timed their use with the tools.

What NIOSH Found

 # We found that the paving breakers and jackhammers are the tools used most often.

 # We measured vibration levels high enough to limit the daily use of these tools.

 # We discovered that older tools produced more vibration than newer models.

What City of Cincinnati Sewers, Water Works & Public Services Managers Can Do

 # Limit the use of tools that generate high levels of vibration.

 # Replace older model tools with newer ones designed to produce less vibration.

 # Purchase suitable gloves; inform workers that some gloves cannot provide sufficient vibration protection.

 # Medically examine an individual for potential risk before he/she uses the vibrating tools.

 # Maintain sharp cutting edges on chisels and blades.

 # Regularly inquire about the health effects of vibration among the workers who use vibrating tools extensively.

What the City of Cincinnati Sewers, Water Works & Public Services Employees Can Do

 # Wear clothing and gloves to keep warm and dry while using vibrating tools.

 # Let the tool do the work. Grip the tool as lightly as possible, provided that this is consistent with safe work practice and tool control.

 # Avoid or minimize smoking before and during work.

 # Rotate tool use between the members of the work crew to reduce total exposure duration.

 # Avoid continuous long-period use of vibrating tools.

 # Use sharp chisels and blades.

 # Stop using a tool that shows abnormal vibration and return it to supply shed.

 # Report attacks of white or blue fingers or long periods of finger tingling and/or numbness. Seek medical advice.

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for
HETA Report #2001-0073-2869

Health Hazard Evaluation Report 2001-0073-2869
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February 2002

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SUMMARY

On November 17, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a management request from City of Cincinnati Sewers, Water Works & Public Services (CSWP) to evaluate vibration exposure of employees on various pieces of equipment, review work procedures and practices, and offer suggestions for reducing risk from vibration exposure. In response to the request, NIOSH investigators conducted field vibration exposure measurements on the power hand tools used by CSWP employees.

Measurements of employees' vibration exposure were obtained while work crews affected repairs or during simulations at the city's storage garage. Unweighted acceleration data in a tri-axial configuration were collected from a representative sample of tools that are used by the city's crews. These data were analyzed and compared to evaluation criteria used in the United States to quantify the levels of vibration exposure for CSWP employees.

Many of the evaluated tools generate high levels of vibration that would require limits on the amount of time workers can safely use them. Some of the most severe levels of vibration were measured on jackhammers, paving breakers, and chipping hammers, tools that are used most often by the workers. Recommendations to reduce the vibration exposures are presented in the report.

Keywords: SIC 4941 (Water Supply), SIC 4952 (Sewerage Systems), pneumatic tools, hand-arm vibration, vibration white finger, VWF, ergonomics.

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INTRODUCTION

On November 17, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a management request from the City of Cincinnati Sewers, Water Works & Public Services (CSWP) to evaluate vibration exposure of employees on various pieces of equipment, review work procedures and practices, and offer suggestions for reducing vibration exposure. In response to the request, NIOSH investigators conducted a field vibration exposure measurement on the power hand tools. The tests were carried out from July 23 to August 2, 2001. This report presents the results of the tool vibration measurement and evaluation.

BACKGROUND

The City of Cincinnati Sewers, Water Works & Public Services (CSWP) performs maintenance and repairs of the city's road, water, and sewer systems. Many of these activities often involve the use of vibrating power hand tools. Table 1 lists the number of crews and individuals regularly involved in construction activities and an estimation of the maximum number of hours a crew may use vibrating equipment. The major vibrating tools used include jackhammers, paving breakers, chippers, tampers, and hand-held gasoline-powered saws. Table 2 is a detailed listing of the tools used in each sector of the department.

METHODS

The vibration data collection was based on guidance outlined in International Organization for Standardization (ISO) 5349[1] and American National Standards Institute (ANSI) 3.34.[2] Triaxial accelerometers (PCB Model 356A11) were used in the measurement. Whenever possible, the tool being evaluated was fitted with two accelerometers, one affixed to each of the tool's two handles. Thus, there was usually a total of six channels monitored for each tool.

Before and after each day of data collection, the investigators used a calibrated, hand-held shaker (PCB Model 394C06) and a Human Vibration Meter (Larson Davis Laboratories Model HVM100) to determine amplifier gain adjustments for each of the six channels. The investigators also used the HVM100 to determine the sensitivities for each channel's system, which included an accelerometer, cables, an amplifier, and the digital audio tape (DAT) recorder (TEAC Model RD-145T). Figure 1 shows a schematic of the equipment set-up for the accelerometer calibration.

Each accelerometer was attached to the tool handle by screwing it into a 3-axis mounting block that was fixed on the tool handle with a hose clamp (refer to Figure 2). This attachment method is recommended in ISO 5349-2/FDIS.[3] A layer of rubber was inserted between each accelerometer and its mounting block to serve as a mechanical filter to reduce the potential for measurement errors at the low frequency range. The mounting locations of the accelerometers for different tools were selected based on the recommendations in ISO/FDIS 5349-2[3] and/or ISO 8662.[4] Data collected in this fashion are suitable to evaluate the vibration exposure according to the methods specified in ISO 5349-1[1], ANSI S3.34[2], and ACGIH[5], which are currently used in the United States.

A DAT recorder was used to record the real time vibration data. To avoid overloading the DAT recorder, the investigators monitored the signal levels on an oscilloscope and the DAT level indicator and adjusted the amplifier gains accordingly. A video camera (Panasonic Model AJ-D200) was also used to record each worker's activities in all the field measurements, except on the first day (July 23, 2001). The workers were instructed to work normally as raw, unweighted vibration data and video were recorded.

The nature of the CSWP's work made it impossible to measure the vibration on all types of listed tools at the working sites because many of them were not used or not available during the 10-day site visit. However, the vibration from tools that are most frequently used by CSWP was measured at either the actual or simulated working sites. A variety of working conditions was involved in the tests. The recording time for each trial measurement was usually more than 2 minutes. The recommended minimum duration for the data analysis is 1 minute.[3]

The raw data recorded on the tapes were replayed, and the output signals were input to a multi-channel data acquisition system (B&K 2816) to conduct the 1/3-octave band analysis. The videotape was replayed to verify the exposure duration and working conditions. The results can be directly applied for the risk assessment using ANSI S3.34.[2] To use the ISO and ACGIH standards, the weighted accelerations were calculated using the 1/3-octave band results and the weighting function specified in ISO 5349-1.[1]

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[6] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[5] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[7] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5.(a)(1)]. Thus, employers should understand that not all hazards have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

Hand-Arm Vibration (HAV) and Risk Assessment Standards

Hand-Arm Vibration

Vibration is oscillatory motion, which is usually described in terms of the oscillation frequency and amplitude of displacement, velocity, or acceleration. Frequency is the inverse of the period of a vibration cycle and is measured in cycles per second or Hertz (Hz). The reported studies on HAV are mostly based upon the acceleration response since it is directly associated with the force or stress and is believed to have a strong positive correlation with the physical injury caused by the HAV. Furthermore, the HAV and tool vibration can be conveniently measured in terms of acceleration, which exhibits appropriate sensitivity for the ranges of frequencies and magnitudes of major concern. The hand-arm response to vibration is thus described in terms of the acceleration in the majority of the published studies and the current national and international standards. The dimensions of acceleration used in this report are meters per second squared (m/s^2) or g ($1g = 9.8m/s^2$), which is the standard unit found in the International System of Units.

Occupational HAV is produced by power hand tools that are electric, pneumatic, gasoline-powered, or hydraulic. Paving breakers, drills, saws, grinders, and tampers are all examples of common power hand tools found in industry that expose workers to HAV. Depending on the working posture and vibration frequency and magnitude, the vibration generated on these tools can enter one arm only, or both arms simultaneously, and may be transmitted through the hand, arm, and shoulder to the head.

Health Effects of Hand-Arm Vibration

The vibration of body parts and the perceived vibration are often a source of discomfort and possibly reduced task proficiency. Continued, habitual use of many vibrating power tools has been associated with various patterns of disorders affecting the blood vessels, nerves, bones, joints, muscles, or connective tissues of the hand and forearm. These disorders are collectively called hand-arm vibration syndrome (HAVS).[8]

Usually triggered by cold exposure, workers exposed to HAV may complain of episodes of pale or white fingers. This disorder is one of the major components of the HAVS. It is believed that vibration can disturb the digital circulation such that the vasoconstrictive action of cold can become more sensitive and lead to temporary absence of blood circulation to the fingers. There are various synonyms that have been used to describe vibration-induced vascular disorders: dead or white finger, Raynaud's phenomenon of occupational origin, traumatic vasospastic disease, or vibration-induced white finger (VWF). VWF is a prescribed occupational disease in many countries.[1]

Vibration-exposed workers may experience tingling and numbness in their fingers and hands, which often appear at an early stage of HAVS. These symptoms are sensorineural components of HAVS. If vibration exposure continues, these symptoms tend to worsen and can interfere with work capacity and life activities. Vibration-exposed workers may also exhibit a reduction in the normal sense of touch and temperature sensitivity as well as an impairment of manual dexterity during clinical examination. Some workers may show signs and symptoms of entrapment neuropathies, such as carpal tunnel syndrome (CTS), a disorder due to compression of the median nerve as it passes through an anatomical tunnel in the wrist. It is believed that repetitive movement, forceful gripping and pushing or pulling, awkward hand posture, in combination with vibration can cause CTS in workers handling vibration tools.

Another major component of HAVS is a group of musculoskeletal disorders. This group includes pain in hands and arms, local swelling, joint stiffness, wrist and elbow osteoarthritis as well as ossifications at the sites of tendon insertion, and muscular weakness.

Standards and Criteria

Four recommended standards and criteria for assessing HAV exposure are currently used in the USA: (1) ANSI S3.34, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand;[2] (2) ISO 5349-1, Mechanical vibration - Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration[1] (which has been recently revised from its first version published in 1986);[9] (3) TLVs and Biological Exposure Indices by the ACGIH;[5] and (4) NIOSH Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration.[10]

The ANSI and ISO standards provide similar accepted measurement and reporting techniques. Both define the biodynamic and basicentric coordinate systems for positioning the accelerometers used to measure the vibration in the three orthogonal axes of direction; up and down, side to side, and back and forth. The basicentric coordinate system was chosen for this study. This system is easier to apply since the Y-direction is based on the tool geometry rather than the hand position. The tested tools in this study have cylinder-shape handles, which makes it easy to define the coordinate system on the handles. The Y-axis parallels the handle of the tool. The X-axis runs perpendicular to plane containing the top of the hand. The Z-axis follows and usually aligns with the forearm.

In the ISO and ACGIH standards, the measured acceleration data are weighted with a specified weighting function to find a single value for risk assessment. The basic weighting concept in the ANSI is the same as that in the ISO and ACGIH but its assessment approach is not based on the single value of the overall acceleration, but rather the critical value in the vibration spectrum. The weighting function for each center band frequency can be found in both the ANSI and ISO standards. The weighting function in the revised ISO standard[1] is updated from its early version[9] to make it practical to build a weighting filter for measurement instruments. The ANSI standard has not been updated to adopt the changes made in the revised ISO standard. The current ACGIH standard also uses the weighting function found in the 1986 version of the ISO standard. It is expected that the weighting function in the revised ISO standard will likely be adopted in the ANSI and ACGIH standards. The original weighting function mainly differs from its updated version at frequencies up to 16 Hz, which may not affect these evaluation results significantly since the dominant vibration on most tools is higher than 16 Hz. In this study, the updated weighting function was used with both the ISO and ACGIH evaluation methods. The evaluations utilizing the ANSI method employed the weighting function in the previous ISO standard.[9] However, using the original weighting function made no significant difference with the ANSI evaluation approach because the ANSI method incorporates the weighting filter into suggested HAV exposure zones. These zones demonstrate that acceleration levels at higher frequencies are considered to be less dangerous. In the analysis for this report, the exposure zones were overlaid on the unweighted data to reveal the suggested daily use limitations of the hand-held power tool being evaluated. The weighting function suggests that the significance of acceleration beyond 20 Hz is dramatically reduced.

As informative material, the ISO standard provides a plot for predicted 10% prevalence of vibration-induced white finger in a group of exposed persons as a function of frequency-weighted root-mean-square (rms) acceleration. It does not specify permitted exposure level and duration. The ANSI standard is a counterpart of the first version of the ISO standard. In addition to the difference in the weighting function as above-mentioned, there are three other major differences between the ANSI standard and the revised ISO standard. First, the evaluation of vibration exposure in the ANSI standard is based on the directional component with the greatest frequency-weighted rms acceleration, but in the revised ISO standard, evaluations are based on the vector summation of all the three directional components. Second, the ANSI standard specifies the allowable exposure limits. Third, the ANSI standard emphasizes the effect of the dominant vibrations or the critical peak value in the frequency domain, but the evaluation with the revised ISO standard depends on the overall rms value of the acceleration.

In the ISO standard, an 8-hour TWA of the overall weighted acceleration (OWA), called $A(8)$, for the total vibration exposure (three axis vector summation) is calculated for the risk assessment. ACGIH TLVs determine a time-weighted average of the OWA for the dominant axis of each exposure, defined as the axis with the highest overall acceleration. ACGIH also specifies the allowable exposure limits for different vibration magnitudes. Both the ISO and ACGIH methods provide the investigator with a single value for the HAV assessment of multiple tools and/or tasks.

Unlike ANSI, ACGIH, and ISO, NIOSH does not recommend any exposure limit for HAV. The NIOSH criteria document[10] emphasizes reporting unweighted data since the weighting factors used in the other criteria are based on limited research. This criteria document also recommends conducting HAV measurements from 5 to 5,000 Hz. Although no current standard exists that links unweighted acceleration levels to health risks, some studies have suggested that high frequency vibration may cause more damage than once believed.[11] It is very difficult to measure the vibration up to 5,000 Hz while avoiding the measurement errors at the low frequency range. The measurement at such high frequencies was not attempted in this study and the data presented in this report may not be valid for the risk assessment based on the NIOSH recommendation.

RESULTS

The 1/3-octave band acceleration data for each tool and working condition were graphed onto the ANSI recommended exposure zones for the three orthogonal directions and are presented in Appendix A. The sequence of the three figures corresponds to the sequence of the coordinate on the tri-axis accelerometer, which may not correspond to the handle coordinate in some cases. The dominant axis of vibration is in the direction on which there is the maximum vibration, which is of concern for the risk assessment with the ANSI and ACGIH standards. With the revised ISO standard, the vector summation of the vibration in all three directions is used.

The vibration on both handles was usually measured and presented, except in a few cases where it was difficult to affix an accelerometer to one of the handles, or the measured data were not valid. Whenever the vibration on both handles is presented, the two figures for a measurement are numbered as N-1 for one handle and N-2 for the other handle, where N is the measurement identification number. It should be noted that the measurement identification number does not always correspond to the sequence of the measurement.

Also included in each of the figures in the Appendix are tool descriptions, test conditions, test date, sampling duration of data analysis, overall weighted acceleration for each vibration direction, and the equivalent 8-hour exposure value, $A(8)$. The nature of the CSWP's work makes it very difficult to estimate the actual $A(8)$ values. As a reference, the $A(8)$ values were estimated by assuming 30 minutes of vibration exposure per day in the use of a single tool. For any duration of exposure, the $A(8)$ can be calculated using the following formula:[1]

$$A(8) = A_t \sqrt{\frac{T}{T_0}}$$

where A_t is the weighted total vibration sum, T is the total daily duration of exposure to the vibration A_t, and T_0 is the reference duration of 8 h (28800 seconds).

The weighted rms acceleration (Wt. RMS Acc.) in the dominant axis (Dom. Axis) and the total vibration sum (SUM) for different tools, together with the tool information and test conditions are summarized in Tables 3, 4, and 5. The permitted maximum exposure time (Max. Exp. Time) for each measurement case evaluated from ANSI[2] and ACGIH[5] are also listed in the tables. The ISO standard[1] does not specify the permitted exposure time, but it provides a prediction of 10% prevalence of vibration-induced white finger for a given daily exposure level, $A(8)$. As a reference, the latency (D_y) of the 10% prevalence (ISO 10% Preval.) shown in the last column of the tables is calculated based on the 30 minutes total vibration $A(8)$ using the following formula:[1]

$$D_y(years) = 31.8\, A(8)^{-1.06}$$

For example, in the first case in Table 3, for 0.5 hour (30 min) of exposure duration,

$$A(8) = 19.4\sqrt{\frac{0.5}{8}} = 4.85(m/s^2)$$

and

$$D_y = 31.8 * 4.85^{-1.06} \approx 6.0(years)$$

This means that it would take about 6 years for 10% of the persons daily exposed to the vibration level of 19.4 m/s^2 for 30 minutes to develop the symptoms of vibration white finger.

The results for each group of tools are briefly summarized as follows:

Paving Breakers and Jackhammers

The vibration spectra measured on the paving breakers and jackhammers are presented in Figures A1-A12 in the Appendix. The NIOSH Sullair paving breaker with flexible handles is the same as that used by CSWP. This paving breaker was used because CSWP's paving breaker was not available at the test site. NIOSH investigators used the NIOSH's Sullair paving breaker for comparison with other jackhammers at the same working site.

The comparison test was carried out on a bridge with steel-reinforced concrete pavement. This site probably represents the worst-case working condition for paving breakers and jackhammers. The highest vibration was observed at this test site. The paving breaker with flexible handles (MPB-60AF) had the lowest vibration level. It may be used for 1-2 hours per day based on ANSI criteria[2] (see Table 3 or Figures A1-A2). The older, 60-lb jackhammer (#86561) had the highest vibration magnitude (see Table 3 or Figures A3-A7). Its measured vibration was much higher than either the ANSI or ACGIH exposure limits, regardless of test conditions and test subjects. The older, 90-lb jackhammer

(#9590) produced lower vibration levels than the 60-lb hammer, but its vibration was also found to be over the limits (see Table 3 or Figure A8). The workers tested reported feeling a difference in the vibration levels between the old jackhammers and the paving breakers with flexible handles.

At a simulated working site in the machine shop, CWSP's Sullair paving breaker (#9029005) was tested. The result is similar to that for the NIOSH tool used on the bridge (see Table 3 or Figure A3). At an asphalt pavement working site, a similar old jackhammer belonging to the city showed lower vibration magnitude (see Table 3 or Figure A9), but it was still beyond the limits. There was no significant difference between the vibration values measured on the two handles.

Saws

All of the pavement cutting saws had a narrow frequency range of dominant vibration, which was between 80 to 110 Hz (see Figures A10-A13). The vibration on the rear handle was usually below any exposure limit. The critical vibration was on the front handle. During pavement cutting, the permitted working time was determined to be between 0.5 to 2 hours/day (see Table 4). Longer working times are permitted when saws are used to cut clay pipe (ANSI: 8 hours/day; ACGIH: 4-8 hours/day). The results show that the small DOTCO saw can be used without limit based on ANSI recommendations.

Compactor

The vibration on the compactor handle was negligible and well below the ANSI and ACGIH exposure limits (see Figure A14).

Chipping Hammers

The chipping hammers generated high levels of vibration in the dominant axis (22.8 to 39.8 m/s^2) (see Table 4 and Figures A15-A18). The hammers were generally found to be above the ANSI and ACHIH exposure limits. The vibration on the front body of the hammer was higher than that on the main handle. It is certain that the vibration on the chisel must be much higher.[12,13] However, the vibration produced by the chisel damaged an accelerometer, and therefore, no further attempt was made to measure its vibration.

Die Grinder

The measured vibration of the die grinder suggests use should be limited to 2 hours/day according to the ANSI exposure limit and less than 1 hour/day according to the ACGIH limit (see Table 4).

Tamper

The Tamper is a typical low frequency tool. Even though its peak value was not very high, its weighted rms value (17.6 m/s^2) was over the ANSI 0.5h and ACGIH 1h exposure limits (see Table 4 or Figure A20).

Clay Spade

Similar to the chipping hammers, the vibration on the front body of the clay spade was higher than that on its main handle. The measured vibrations on the front body were over both the ANSI and ACGIH limits (see Table 5 and Figure A21-2). The magnitude of vibration measured on the main handle permits work for 0.5 to 1 hour according to the ANSI standard, but it is over the ACGIH 1 hour exposure limit (see Figure A21-1).

Rock Drill

The rock drill produces more high frequency components of vibration on concrete block than those produced on the asphalt pavement (see Figures A22 and 23). Based on the results, the rock drill may be used on asphalt pavement for 0.5 hours/day according to the ANSI standard (see Table 5 or Figure A22). On concrete block, its vibration was found to be over both the ANSI and ACGIH limits (see Table 5).

DISCUSSION

Due to the nature of the repair work performed, the NIOSH investigators could not assess all tools and working conditions encountered by CSWP employees. Therefore, the results presented here may not be statistically valid for making an accurate evaluation and risk assessment of total vibration exposure. However, the results should be useful for the management of vibration exposure within CSWP. The vibration of each group of tools, its reduction methods, and potential health effects are discussed below.

Paving Breakers and Jackhammers

The basic characteristics of the vibration spectra measured on the paving breakers and the jackhammers (Figures A1-A9) are comparable to those of similar tools reported in the scientific literature.[14] The weighted rms values of the Sullair paving breakers are also in the range of those measured on similar tools.[15,16] However, the values measured on the old jackhammers are generally higher than those reported in the scientific literature. One of the possible reasons is that the test working material (steel + good concrete) was very hard, resulting in a high level of vibration. The high impact vibration might have caused some artificially high readings. Nevertheless, the vibration on the old jackhammers was definitely very high.

The test results indicate that the most important factor that affected the vibration exposure is the tool itself. The direct comparison test on the concrete bridge suggests that the paving breakers with flexible handles produce much less vibration than the old jackhammers, especially the 60-lb jackhammers. Furthermore, the old jackhammers did not appear to be more productive than the newer models. Based on feedback from CSWP workers, the new Sullair paving breaker with the flexible handle seemed to work better.

The results presented in Figures A1 to A9 show that the critical vibration peak value of the paving breakers and jackhammers is usually in the frequency range of 15 to 60 Hz. Any approach that would significantly reduce the vibration in this range would effectively increase the permitted working time. Using an estimation method developed by NIOSH,[17] it is predicted that the best anti-vibration glove available on the market may provide a reduction of the rms value on such tools by 10% to 20% at the back of the hand, depending on the specific tools and working conditions. For the fingers, the vibration attenuation of the gloves is usually less effective. However, anti-vibration gloves can usually effectively reduce the high frequency components of the vibration. Therefore, the use of anti-vibration gloves may be far from sufficient in bringing down the vibration to an acceptable level, but it can improve the situation to some extent.

The paving breakers and jackhammers are heavy tools. The use of these tools does not require much grip force in the operation, except in the pulling-out process. It was observed that some workers applied unnecessary grip force on the handles. Minimizing the grip force can reduce the vibration that is transmitted to the fingers, and therefore reduce some of the potential adverse effects of the vibration produced by the tool.

Saws

Saws are frequently used during repair work. With a good anti-vibration glove, it is anticipated that the peak vibration value can be reduced by 10% to 30%, which may help minimize the effects of the vibration exposure.[17]

Compactor

The compactor generates little vibration and is not an item for concern.

Chipping Hammers

Chipping hammers are often used to chip concrete walls during repair work. Such a working condition usually generates high levels of vibration. The types of chipping hammers used by CSWP generated severe vibration during the study. The measured values are in the upper range of the data reported in the scientific literature.[12,18] The investigators observed CSWP workers holding the chisel of the chipping hammer with their hand during operation, which may be the worst exposure situation.[12] The shock peaks of the impact vibration on the chisel could be more than 30,000 m/s^2.[19] Minimizing the holding force exerted on the chisel can reduce the vibration that is transmitted to the hand. Using anti-vibration gloves may effectively isolate the high impulse, but it is difficult to significantly reduce the low frequency components (<100 Hz), which are the most critical to determine the allowable exposure time in the current standards. Similar to the case of jackhammers or paving breakers, selecting a chipping hammer that produces less vibration may also be the best strategy for limiting worker exposure.

Die Grinder

Because the die grinder is used infrequently, this tool is not an item for major concern. The vibration from the die grinder limits its use to 2 hours/day according to the ANSI standard (see Table 4).

Tamper

The tamper generates low frequency vibration. The predominant frequency of the tamper is less than 20 Hz. Few cases of VWF are associated with the use of low frequency tools.[13] The tamper may not cause a white finger problem, but the vibration can effectively transmit to the wrists, elbows, shoulders, and the head. Anti-vibration gloves would not successfully reduce the vibration on such a tool. However, minimizing the worker's grip force can reduce the vibration exposure.

Clay Spade

Similar to jackhammers, the clay spade is a type of percussive tool and also generates significant vibration. The vibration reduction methods discussed for jackhammers would also apply to the clay spade.

Rock Drills

Rock drills are often used to drill holes in pavement during water system repairs. Vibration produced when drilling concrete pavement can be very high. Because the vibration spectrum produced by rock drills contains significant high frequency components, anti-vibration gloves may provide more help to attenuate the vibration.

CONCLUSIONS

Exposure Duration

The exposure duration information provided by CSWP, as described in Table 1, is not tool-specific. Furthermore, the varied nature of the repair work performed by CSWP workers makes it difficult to make reasonable estimations of the exposure durations. This study was not intended to quantify the durations of worker exposures, but future investigations may be warranted to address this issue.

During the field visits, the paving breakers and jackhammers were the tools most frequently used. These tools were observed to be used for more than one hour per day cumulatively. The gasoline-powered pavement cutting saws were often used to cut pavement and walls before the jackhammers or chipping hammers were used to clear out the area to be repaired. The saws were observed to be used for less than half an hour per day. The rock drills were used occasionally for short periods of time (less than 0.5 hour per day) to drill holes during repairs to water and sewer systems. Hence, the saws and rock drills may not be major contributors to the risk for developing HAVS. Chipping hammers were used to seal water pipe joints and to chip concrete walls during repairs, and may be in use for more than one hour per day. The other tools were used infrequently. According to CSWP workers, most of the field repair work is conducted during the summer, and much of the repair work does not require the use of powered hand tools. Therefore, not all of the tools are used on a daily basis.

Potential Health Effects

The predominant frequencies of the vibrations from the paving breakers, jackhammers, chipping hammers, tampers, clay spades, and rock drills are usually below 100 Hz so they can be classified as low frequency impact tools. The jackhammers and chipping hammers are used often and generate severe vibration. Therefore, they have the most potential to cause vibration-induced problems.

If the ISO predictions are correct, 10% of CSWP workers could develop vibration white finger (VWF) within years even though they might only use these jackhammers and/or chipping hammers for an average of 30 minutes per day, as shown in the last column of Tables 3 and 4. A high prevalence and short latency of short-duration VWF among the workers would be predicted based on the measured vibration magnitude and the estimated exposure duration. However, several studies have reported that the prevalence and latency of VWF among road workers who used such tools irregularly were much lower than the ISO prediction.[13,20,21]

Jackhammers, paving breakers, and chipping hammers can generate low frequency (25 to 60 Hz) shock waves that could be transmitted effectively to the tool operator's wrists, elbows, and shoulders, and could cause disorders at these locations. It has been reported that these impact tools are associated with incidences of bone and joint injuries.[13,22] The use of chipping hammers requires powerful grip and feed forces as well as repetitive movements. Combined with impact vibration, these additional forces could cause CTS and other wrist symptoms.[23,24,25] Working with jackhammers and chipping hammers could increase the risk of elbow disorders and shoulder tendinitis.[26,27,28] However, the prevalence of these disorders is usually lower than the VWF.[13]

Paving breakers and jackhammers are quite heavy. Retracting the bit from the ground or rock sometimes requires a great effort. The repetitive and forceful motions required may cause other health problems such as back pains.[29]

RECOMMENDATIONS

Based on the measurements and observations made during this evaluation, the following recommendations are offered to help minimize vibration exposure and adverse health effects:

1. Use work processes that result in the lowest, shortest, and non-continuous vibration exposure.

2. Limit the use of jackhammers, paving breakers, and chipping hammers.

3. If possible, replace the old jackhammers and chipping hammers with tools that produce less handle vibration.

4. Wear adequate clothing and suitable gloves to keep dry and warm, particularly when using vibration tools in cold environments. High-quality, anti-vibration gloves can be used to help minimize vibration exposure. However, anti-vibration gloves should not be expected to provide a sufficient means of protection from tool vibration.

5. Rotate the tool assignments among workers to reduce the average vibration exposure duration.

6. Let the tool do the work. Grip the tool as lightly as possible, provided that this is consistent with safe work practice and tool control.

7. Avoid or minimize smoking or using smokeless tobacco before and during work with vibrating equipment.

8. Seek medical advice if attacks of white or blue fingers occur, or if long periods of finger tingling and/or numbness are experienced.

9. Properly maintain all powered hand tools in accordance with the manufacturer's instructions. Keep chisels and blades clean and sharp.

10. Carefully assess workers who are at greater risk for developing HAVS. These workers include those with:

   a. primary Raynaud's disease,

   b. vascular, peripheral nervous, musculoskeletal disorders in the hand-arm system, or

   c. past injuries to the hand causing circulatory defects or bone and joint deformities.

11. Regularly monitor the health effects of vibration among the workers who use powered hand tools extensively.

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Table 1
Water Works, Public Services, and Metropolitan Sewer District Crews and Employees Regularly Using Jackhammers and Other Vibrating Tools or Equipment

HETA 2001-0073
City of Cincinnati Sewers, Water Works, & Public Services
July - August 2001

Department/Division	Number of Crews	Number of Individuals	Hours/Day
Sewer/Collection	10	42	2.5 - 3
Water Works/Distribution	10	30	0.5 - 0.75
Public Services/Structures	7	40	1
Public Services/Asphalt	1	30	2
Public Services/Traffic Control	10	60	Irregular<10 Min

Note: The information in this table was provided by CSWP.

Table 2
Power Hand Tools Used at Water Works, Public Services, and Metropolitan Sewer District

HETA 2001-0073
City of Cincinnati Sewers, Water Works, & Public Services
July - August 2001

Department/Division	Equipment
Sewers/Collection	Sullair Paving Breaker, Flex Handle (new), Model # MPB90AF (90lbs)
	Sullair Paving Breaker, Flex Handle (new), Model # MPB-60 (60lbs)
	Sullair Clay Spade (new), Model # MCD-30A
	Chicago Pneumatic Impact Wrench, Model # CP-9541
	Hatco Paving Breaker (old style), Model# 4100
	Hatco Clay Spade (old style - 1987), Model # P 40l0
	Stihl Gas Saw, Model # TS350
	Hatco Paving Breaker (old style - 1987), Model # 100 (90lbs)
	Jet Chipping Hammer, Model # JCO-3H
	Air Hand Tamp, Ingersoll/Rand, Model # 792, Kent, Model # KT33
	Stihl Gas Saw, Model # TS400
	Saw Tec Air Saw, Model # HS –50
	Stihl Chain Saws, Model # 026, Model # 044
	Trench Compactors, Wacker, Model # WPI 550VW
	Stone, Model # 528A, Mikasa Multiquip, Model # MVCS-77H
Public Service	Stanley Hydraulic 80#
	Chicago Rock Drill
	Chicago Air Hammer 80#
	Stanley Air Hammer
	Thor Chipping Hammer
Water Works	Chicago Pneumatics 901b & 601b
	Atlas Copco Pneumatic Breaker Tex39rs

Note: The information in this table was provided by CSWP.

Table 3. Vibration evaluation of paving breakers and jackhammers

Tool	Test Conditions	Wt. RMS Acc. (m/s^2)		Max. Exp. Time (h/d)		Dy (years)
		Dom. Axis	Sum	ANSI*	ACGIH**	(Assum. 30
Sullair paving breaker, MPB-60AF (flexible handle), with flatend chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement	15.6	1.94	1	(over limit)	6.0
Sullair paving breaker, MPB-60AF (flexible handle), with point-end chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement	11.3	13.8	1-2	<1	8.4
Sewer's Sullair paving breaker, MPB-60AF (flexible handle), #9029005 with flat-end chisel	Good quality concrete blocks at a simulated working site	15.5	18.7	1	(over limit)	6.2
Old jackhammer, THOR, #86561, 60 lbs, wide chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement (Worker 1)	49.3	83.7	(over limit)	(over limit)	1.3
Old jackhammer, THOR, #86561, 60 lbs, wide chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement (Worker 1)	45.7	78.8	(over limit)	(over limit)	1.3
Old jackhammer, THOR, #86561, 60 lbs, narrow chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement (Worker 2)	50.6	86.4	(over limit)	(over limit)	1.2
Old jackhammer, THOR #86561, 60 lbs, narrow chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement (Worker 2)	37.9	62.7	(over limit)	(over limit)	1.7
Old jackhammer, KENT, #9590, 90 lbs, wide chisel	Good quality concrete with steel reinforcement, on a bridge sidewalk pavement	37.5	55	(over limit)	(over limit)	2.0
Old jackhammer, #CP1240, 60 lbs, narrow chisel	3" asphalt on 8" concrete pavement	22.9	37	(over limit)	(over limit)	3.0

*The critical peak value over the 0.5h curve is considered as cover limit in ANSI. **The weighted acceleration greater than 12 m/s^2 is considered over the ACGIH exposure threshold. ***ISO Latency of VWF in 10% of persons who would expose the measured vibration for 30 minutes per day.

Table 4. Vibration evaluation of gas saws, compactors, chipping hammers, grinders, and tampers

Tool	Test Conditions	Wt. RMS Acc. (m/s^2)		Max. Exp. Time (h/d)		Dy (years)***
		Dom. Axis	Sum	ANSI*	ACGIH**	(Assum. 30 min. Exp.)
Stihl gas saw	Cut asphalt & stone pavement	13.2	17.5	0.5	(over limit)	6.6
Gas saw	Cut street old brick pavement	10	14.2	1 - 2	<1	8.2
Air saw	Cut a clay pipe	5.4	7.8	8	2 - 4	15.8
Saw, DOTCO (Cooper Power Tools)	Cut concrete block	1.8	2.4	8	4 - 8	53.7
Compactor	Compact newly paved asphalt	2.6	3.7	8	4 - 8	31.8
Chipping hammer, CLECO OL-3, #AO-6054 on the main handle	Seal water pipe joint with used seal material	22.8	34	0.5	(over limit)	3.3
Chipping hammer, CLECO OL-3, #AO-6054 on the main handle	Seal water pipe joint with lead	28.5	43.8	(over limit)	(over limit)	2.5
Chipping hammer, JCO-2R, #36C27 on the main handle	Seal water pipe joint with lead	27.9	45.3	(over limit)	(over limit)	2.0
Chipping hammer, JCO-2R, #36C27 on the tool front body	Seal water pipe joint with lead	39.8	55.1	(over limit)	(over limit)	2.0
Chipping hammer, UCO-1-F, #708014	chip a concrete block	30	33.9	(over limit0	(over limit)	3.3
Die grinder, 44BWE, #T9914	cut water pipe	11.9	13.6	2	<1	8.7
Tamper	tamp mixed soil-gravel	17.6	18.3	(over limit)	(over limit	6.3

* The critical peak value over the 0.5h curve is considered as over limit in ANSI. ** The weighted acceleration greater than 12 m/s^2 is considered over the ACGIH exposure threshold.
***ISO latency of VWF in 10% of persons who would expose the measured vibration for 30 minutes per day.

Table 5. Vibration evaluation of clay spaders and rock drills

Tool	Test Conditions	Wt. RMS Acc. (m/s^2)		Max. Exp. Tim (h/d)		Dy (years)***
		Dom. Axis	Sum	ANSI*	ACGIH**	Assum. 30 min.
Clay spade on the front body	Dig soil-gravel	29.2	32.6	(over limit)	(over limit)	3.4
Clay spade on the main handle	Dig soil-gravel	17.3	22	0.5-1	(over limit)	5.2
Rock drill	Drill asphalt pavement	17	19.3	0.5	(over limit)	6.0
Rock drill	Drill concrete block	28.2	32.9	(over limit)	(over limit)	3.4

*The critical peak value over the 0.5h curve is considered as over limit in ANSI. **The weighted acceleration greater than 12 m/s^2 is considered over the ACGIH exposure threshold.
***ISO Latency of VWF in 10% of persons who would expose the measured vibration for 30 minutes per day.

Figure 1: Accelerometer Calibration Set-up

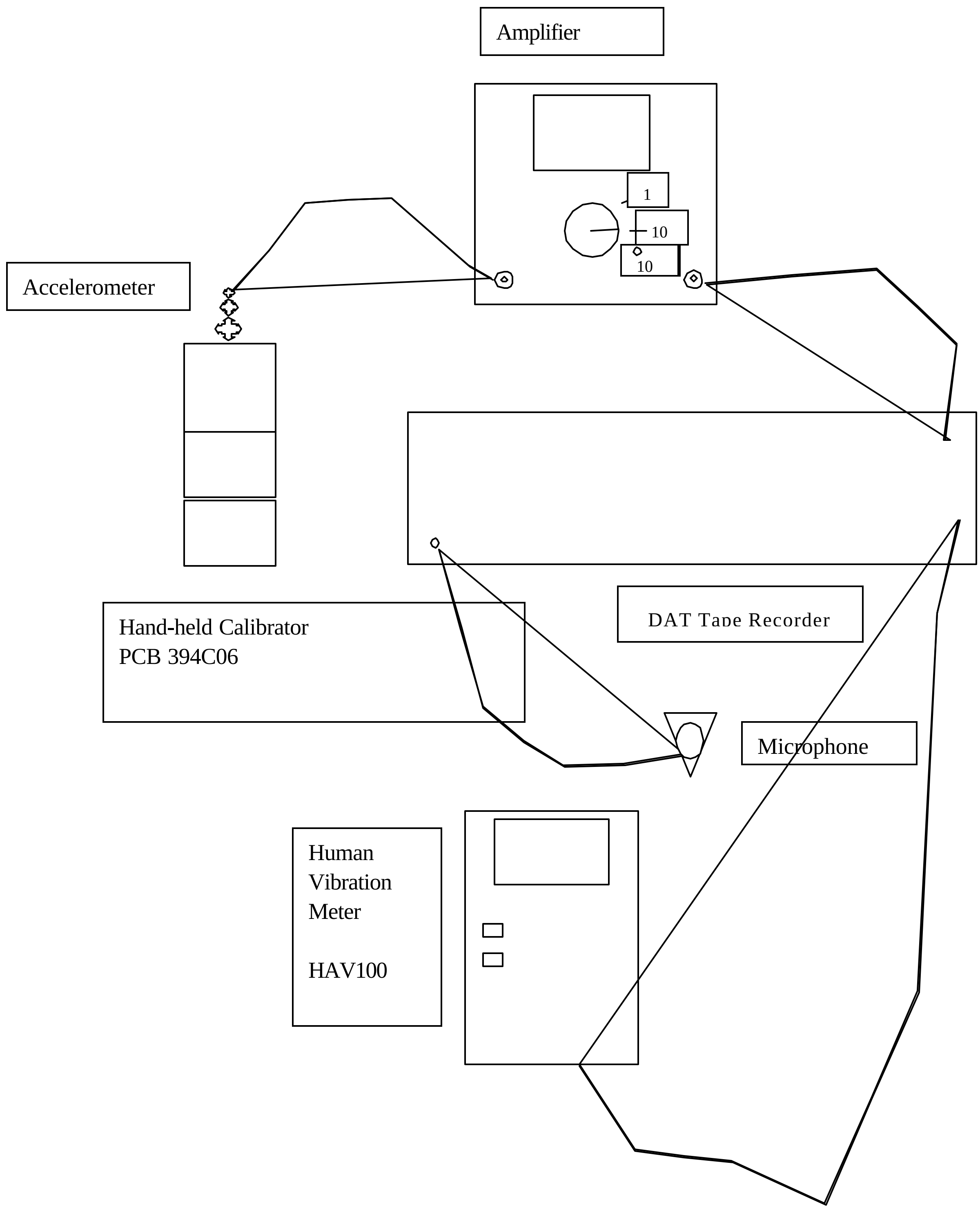


Figure 2: Affixing an Accelerometer to a Tool with a Hose Clamp

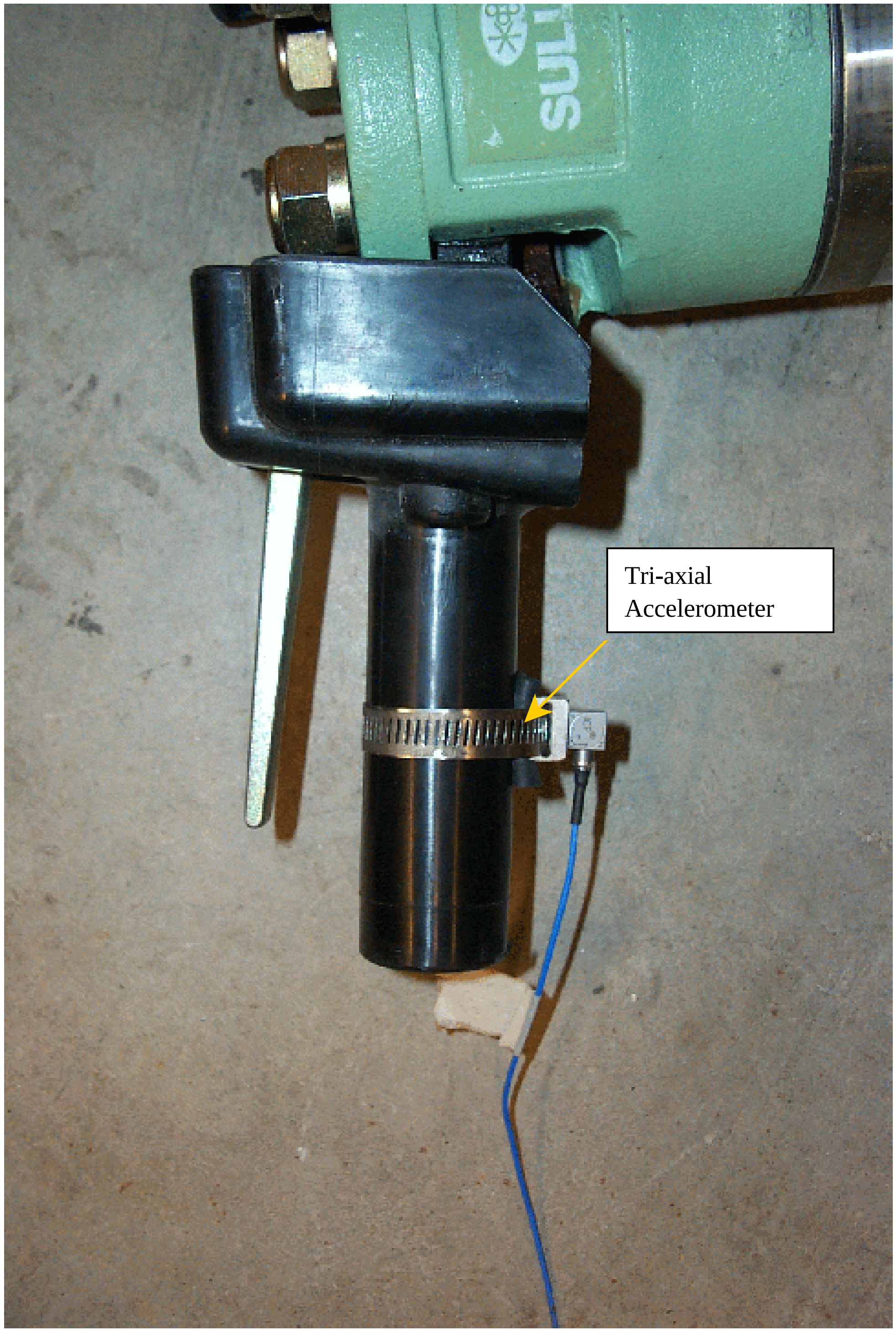
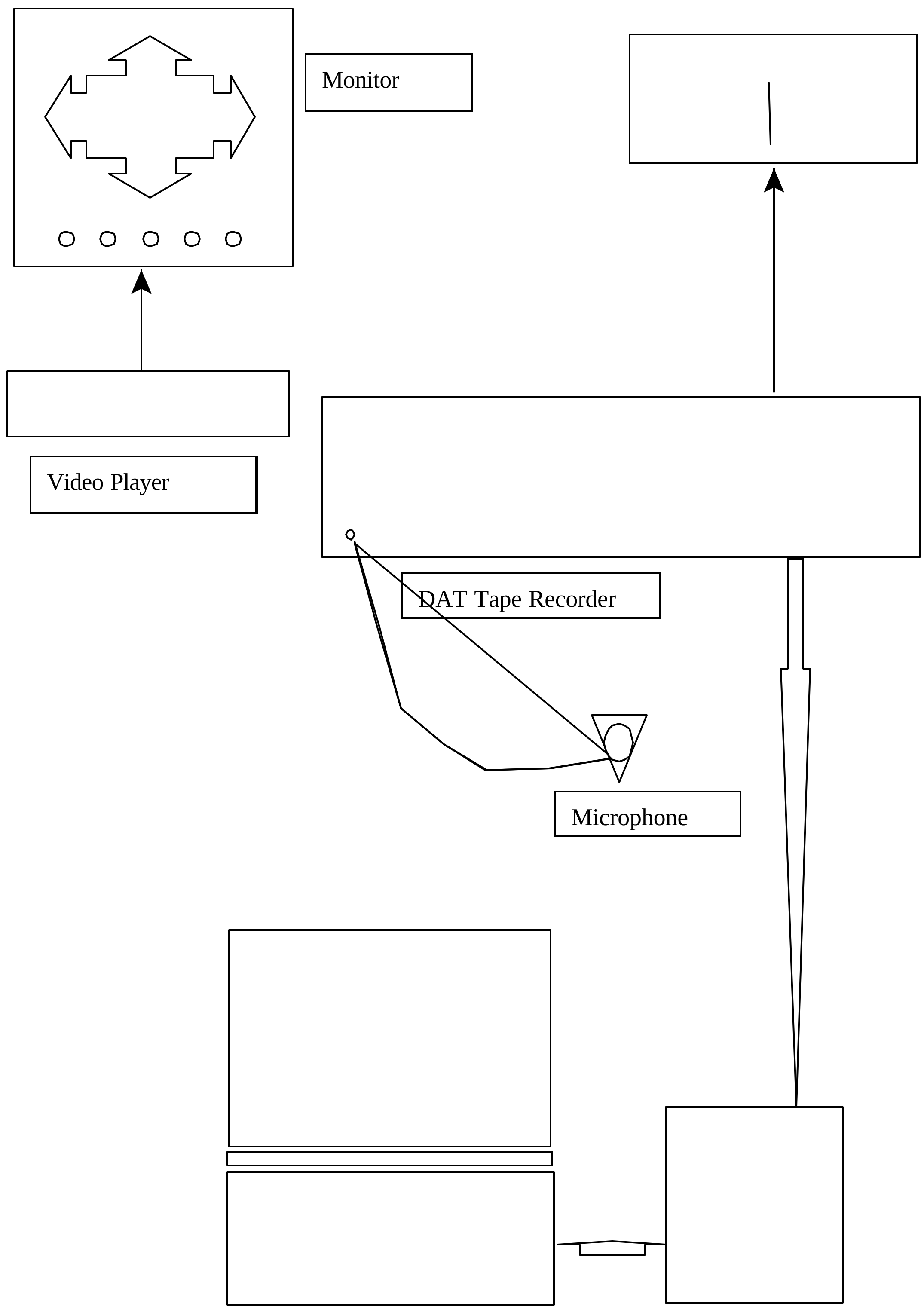


Figure 3: Data Analysis Set-up



APPENDIX

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