

# Industrial Vibration—an Overview

By

**Donald E. Wasserman**, Research Engineer

**Donald W. Badger**, Ph.D., Research Physiologist

**Thomas E. Doyle**, Electronic Technician

**Leonard Margolies**, Biological Technician

Dept. of Health, Education, and Welfare,  
Public Health Service,  
Center for Disease Control,  
National Institute for Occupational Safety and Health,  
Cincinnati, Ohio

**ABSTRACT.** This paper presents the results of several industrial walk-through surveys conducted by the authors. Examples of worksites visited are: paper mills, textile mills, food and beverage can manufacturing, steel mills and steel manufacturing operations, aluminum mills, nickel plants, heavy machine tool manufacturing, uranium processing plants, pneumatic tool manufacturers, heavy equipment and farm tractor manufacturing, printing and publishing plants, lumber mills, sawplants, plywood plants and wood product plants, furniture manufacturing, quarries, foundries, automotive assembly plants, vehicular engine manufacturing, and others. Worker vibration exposure is discussed by job and industry type and an estimate of the total number of workers exposed to occupational vibration in the United States is given.

In the past, most research effort concerning the effects of vibration on man in the United States has been primarily military-oriented; usually utilizing young, physically fit, military personnel for human subjects. Unfortunately, very little research has taken place on the effects of vibration on the worker as it occurs in the work situation in the United States.

Recently, we, in keeping with NIOSH's legal mandate, began research activities into the possible health and/or safety effects of vibration on the worker. A systematic plan<sup>1</sup> for such research was developed. This plan calls, in part, for three interdependent means of identifying the possible problem

areas of occupational vibration: 1) literature search, 2) morbidity studies, 3) industrial surveys.

## Annotated Bibliography Completed

As a result of our literature search, an annotated bibliography<sup>2</sup> has been completed and has served to elucidate the worldwide research effort attempting to assess the effects of vibration. Also, it has served to indicate to these authors the various types of industries where vibration might be a part of the workplace situation. Morbidity studies help correlate vibration exposure with possible health records and/or accident claims. Finally, walk-through plant tours allowed us to see vibration first-hand in United States industry.

This will be followed up by quantitative measurements at some of the job sites on the worker's body and the vibrating tools, machines, seats, floors, etc., thereby allowing us to better simulate actual vibration in our laboratory research efforts as well as allowing us to learn how the worker and his vibrating work process interrelate.

It is in this third area, namely that of walk-through plant tours conducted by these authors, which we would like to address the remainder of this paper. Before doing so, however, a brief definition of a few technical terms is necessary.

There are essentially two forms of vibration of interest. The first is called *whole body vibration* and is the application of vibration usually to the entire body, applied from head to toe (vibrating floor) or at the buttocks (vibrating seat). The second is called *segmental vibration* and is the application of vibration to specific body parts such as the hands due to vibrating hand tools, for example. Whole body vibration is concerned with a frequency range of about

2 to 100 Hertz (Hz). Segmental vibration is concerned with a frequency range of about 8 to 1,400 Hz.

A special form of whole body vibration is the so-called *transient vibration or buffeting* which one might experience while driving a bulldozer, for example. The human body can be more or less in tune or "resonance" with vibration sources. When the body is in resonance it is thought to be most susceptible to the vibration effects. In whole body vibration the prominent resonance occurs at about 5 Hz; for segmental vibration, parts of the human body can be in resonance with other frequencies. Thus, the entire body or parts thereof can be in resonance with the vibrating source.

### Rationale

During the latter part of 1971, these authors appealed to United States industries to allow us to conduct "walk-through tours" of their workplace facilities. The response was quite favorable. Subsequently, 45 actual tours were taken by us during 1972. Table I summarizes the types of industries visited.

In conducting each plant tour, we were concerned with either the vibration component associated with the use of the *product manufactured* and/or the vibration caused by the manufacturing process itself. For example, pavement breakers have a large vibration component associated with their use as a product. There might also be vibration associated with the manufacturing of these pavement breakers per se. On the other hand, a paper mill's product obviously does not have a vibration component associated with its use, but the process of manufacturing paper might have a vibration component. Also, during each plant tour we asked to see the *entire* manufacturing process and not just those elements which might have a vibration component associated with their use. Thus, we developed insight and appreciation for what workers did in their work situation, how all processes combined to produce an end result, and if and where vibration played a part in this interaction.

We did not take measurements during these plant tours, feeling they would be meaningless at this point because many of the techniques have not yet been developed. Finally, we should like to point out emphatically that, at this writing, we do *not* know the relationship between the different parameters of vibration and the possible health and/or safety effects in long-term occupational vibration exposure.

### Industrial Tours

A brief statement of each of the 45 tours follows:

#### Food & Beverage Can Manufacturing Plant

This plant employed 375 workers in three shifts. Whole body vibration was observed in those machines manufacturing the "pull-top" lids on beverage cans. Several workers operated these machines;

there was very close coupling between the workers and the machines (i.e. workers stood on metal grid work integrally attached to these vibrating machines). We contacted the manufacturers of these machines, and it turns out their operating speed was approximately 5 Hz (or whole body resonance). It was obvious that the workers were "uncomfortable" as they had placed cardboard between their feet and the metal grid work in an effort to dampen out the vibration. It appeared they were not entirely successful.

#### Textile Plant

We estimated there were perhaps 150 workers in this plant during our tour. There were some 60 looms arranged in long rows on a concrete floor in a modern single story structure. Workers were required to wear hearing protection, as the noise level appeared high. Vibration levels appeared very low despite the noise. We believe that the large concrete floor dampened out most of the vibration from the looms. Had this type of floor not been present, or had the looms been situated on a second or higher floor, this probably would not have been the case, and vibration levels may have been higher.

#### Paper Mill

This mill employed about 330 people in three shifts. This was a modern automated plant. There was considerable vibration present near the large motors and pumps used in the various paper processes. However, only a few maintenance personnel occasionally worked in these areas. Thus, there appeared to be little worker exposure in this particular plant.

**Table I**

<u>No. of Plants Toured</u>	<u>Plant Type</u>
1	Food & Beverage Can Manufacturing
1	Textile Plant
1	Paper Mill
3	Steel Mill & Mfg. Operations
2	Aluminum Mills & Mfg. Operations
1	Nickel Plant
4	Heavy Machine Tool Mfg.
1	Uranium Processing Plant
2	Pavement Breaker Mfg.
2	Heavy Equipment & Farm Tractor Mfg.
3	Printing & Publishing Plants
6	Lumber Mills, Sawplants, Plywood, & Wood Plants
1	Heater & Refrigeration Mfg.
1	Fork Lift Trucks
1	Large U.S. Post Office
1	Large Distillery
3	Foundry Operations
1	Vehicular Engine Mfg.
2	Quarries
2	Furniture Mfg.
2	Shoe Mfg.
1	Railroad
1	Vehicular Body Stamping Plant
1	Coal Mining
1	Chain Saw Mfg.

## **Steel Mills & Steel Operations**

Two steel mills were toured, one quite large, one small. A steel company customer service plant was also toured.

In the large steel mill (employing several hundred persons) whole body vibration was observed in three areas: 1) near the areas where automatic oxygen jets were introduced into the molten metal—the entire building vibrated from this process, 2) near the sheet metal cutting operations and the steel rolling operations, and 3) in the cabs of the overhead cranes.

In the small steel mill (employing fewer than 500 employees), it was customary to use electrically-operated arc furnaces which are not feasible in high-volume large mills. Whole body vibration was observed in the following three areas: 1) near these electric furnaces, 2) near the steel rolling operations, and 3) in the overhead crane cabs.

In the customer service plant, raw steel stock in the form of beams and sheet steel was cut to the purchaser's requirements. Here, considerable transient vibration was observed from the manually-operated cutters and presses.

## **Aluminum Plant & Manufacturing Operations**

Two large aluminum plants were toured. The first plant toured was large and modern and employed several hundred workers. A small amount of transient vibration was observed during the molding of anodes used in the large crucible pots where molten aluminum is present. This same aluminum operation actually manufactured sheet aluminum, aluminum foil, etc. There was some whole body vibration associated with rolling, stamping operations, and overhead cranes. The electric power to operate the electrodes was commercially purchased.

In the second plant, employing several hundred, considerable whole body vibration was observed near rows of gasoline-operated, low-voltage, high-current generators which produced the power needed to operate the electrodes. The second area where both whole body and transient vibration were observed was during the so-called "crust-breaking" operation when workers had to break the hardened aluminum crust of the pots in order to extract molten aluminum. This required a type of large, pulsating, pneumatically-operated tool.

## **Nickel Plant**

A large nickel plant employing some 500 workers in three shifts was toured. This plant used electric arc furnaces about 12 feet high and 25 feet in diameter. The horizontal component of vibration was so severe that those of us on this tour had difficulty breathing! This vibration was later identified as "infrasound." The vertical component of vibration appeared minimal. A few workers per shift had need

to move through this area. Estimated total exposure per worker per shift was two hours. Transient vibration was observed in the "scull-drilling operation" where large crucibles were cleaned using a gigantic chipping type hammer. The operator worked close to this hammer.

## **Heavy Machine Tool Manufacturing**

Four plants, each of a different company, were toured. The types of products manufactured in these plants were gigantic lathes, drill presses, cutting tables, and compression presses. In the use of the lathes and drill presses, vibration was almost non-existent because it had been engineered out of the product since the metal products produced by these lathes and drill presses would show imperfections if there were "chattering" of the machinery.

The large compression presses could possibly represent a potential buffeting vibration problem since operators are closely coupled to these units, especially the long-stroke, hydraulically-operated units. Such large presses are widely used in the automotive industry.

In the use of cutting tables, there appears to be a transient vibration problem as we observed them used in steel-cutting operations.

In the manufacturing operations producing these lathes, drill presses, etc., segmental vibration was observed in the use of hand grinding, chipping, and polishing tools.

## **Uranium Processing Plant**

A large uranium processing plant employing some 400 workers was toured. Whole body, transient, and segmental vibration were found in areas where large "molded" uranium cylinders were made. This process includes tamping, shakeout, and chipping operations. Also, the uranium cylinders were cut using a low-speed vibrating saw, closely coupled to the worker. Other instances of vibration were evident when uranium oxide was mixed in large vibrating vats; workers were required to be stationed on large overhead inter-connecting grid structures between these vibrating vats.

## **Pavement Breaker Manufacturing Plants**

Two plants manufacturing pavement breakers, jack hammers, tamping tools, mining tools, and other pneumatic and hydraulic tools were toured. In these plants vibration was observed only in the product testing areas. The larger of these two companies designs pneumatic pavement breakers, jack hammers, drilling, and mining tools. The smaller company manufactures hydraulic pavement breakers and construction tamping tools.

The larger company stated that some of these products had a significant vibration component associated with their use. They have developed a new pneumatic pavement breaker with significantly re-

duced noise and vibration. They allowed us to test their older and newer units side-by-side, and it was quite obvious there was an improvement. It is significant to note, however, they were having difficulty selling the new units. They claim the "old-timers" don't believe that the newer units are doing the job because these units don't "kick them in the stomach and make noise!"

The smaller company also stated they were having difficulties selling their hydraulic pavement breakers to the "old-timers." We were allowed to operate a breaker unit and found a considerable degree of noise reduction, but the vibration appeared to be shifted to a lower frequency; and we surmised it possibly could approach whole body resonance, depending on how the breaker was operated.

### **Heavy Equipment & Farm Tractor Manufacturing**

Two manufacturers of heavy construction equipment and farm tractors were toured. Both manufacturers agreed that low-frequency whole body and buffeting vibration was a problem with the use of their equipment. Both manufacturers had been working with seat manufacturing companies in order to decouple the operator from his vibration-producing machine. One company had taken an entirely new design approach by trying to mechanically isolate (i.e., decouple) the driver's cab from the rest of the vehicle. This was found unfeasible as the operator lost control and "feel" of the equipment. Thus, the present-day engineering approach appears to be directed at the operator's seat in order to protect him from vibration. Thus far the new seat designs have been met with only moderate sales success.

### **Printing and Publishing Plants**

Three printing and publishing operation tours were conducted. Two were large metropolitan newspapers; the third was a large specialty printing operation. One newspaper had its presses on an upper floor; and although this floor appeared to be sturdy enough to contain the presses, whole body vibration was quite evident near the presses where several workers were performing their duties. The second newspaper had a similar large press. However, this press was situated on the ground floor and on a specially-designed isolated concrete floor; vibration was not evident in this area. The large specialty printing operation had a small amount of whole body vibration which was observed in the final cutting, inspection, and packaging sections of the plant.

### **Lumber Mills, Sawplants, Plywood Plants, Wood Products Manufacturing**

Six multi-operation lumber plant sites, utilizing primarily large fir trees as the basic raw material, were toured. According to the industrial hygienists, lumberjacks were exposed to segmental vibration from using chain saws for three to four hours per

work day. We observed four sawmill operations where logs from two to three feet in diameter and an average of 34 feet long were processed. Transient and whole body vibration was noted in those areas where workers were located near moving logs (i.e., cut-off saw operation, throw-away operation, and debarking operations). Also, various wood-planing operations produced whole body vibration and noise (workers wore ear protection). Two plywood plants were toured where transient vibration was evident in the debarking and stripping (i.e., lathe type) operations, sanding operations of large sheets of plywood, and in some wood-patching operations.

Two window and door plants were visited. Whole body and transient vibration were present in various types of wood-sorting and resaw operations. Two wood specialty plants were toured, one a veneer plant, another producing "architectural wood" products for special structures such as churches, public buildings, etc. In the architectural wood facility, several large beams (perhaps 40 feet in length) were laminated together in depth, adding structural support to the beams. These beams were "sandwiched" together using steel straps and bolts situated about one foot apart and placed lengthwise along the beams. It was necessary for multiple teams of two workers to use large pneumatic hammers to tighten many sets of bolts. These teams traveled up and down the length of these beams (which were lying horizontally) tightening and loosening the bolts as one would tighten multiple vises. Considerable vibration was present in this operation.

### **Heater & Refrigeration Manufacturing**

One manufacturer of aircraft heating and refrigeration systems was visited. Buffeting type of vibration was present in the sheet metal cutting operation where the operator's feet controlled the shearing operations.

### **Fork Lift Trucks**

The repair and sales plant of a national fork lift truck manufacturer was toured. The main objective of this visit was to learn about these vehicles. We learned that they can be gasoline, propane, or electrically-operated and are fitted with a variety of tire types and seats, depending on how and where they are used. Once again, the emphasis on vibration reduction in the newer units appears to be in improved seat design; it appears these units have met a moderate degree of sales success. It should also be pointed out that some manufacturers of heavy equipment also manufacture fork lift trucks. Thus, the approach of improved seat design appears to be a natural consequence of heavy equipment experience.

### **Large United States Post Office**

We toured a large metropolitan post office to observe the automatic mail-sorting machinery in opera-

tion. It turns out that older type mail sorters have a small vibrating platform which the worker uses to get pieces of mail symmetrically matched on two orthogonal edges. The mail then is fed into rolling tracks which distribute the mail to various distant stations. The new units replacing the old units do not, it appears, require this human handling of mail. We observed some of these newer units in operation.

### **Large Distillery**

One large distillery was toured because we wondered about the vibration created by various types of labeling and bottling machinery. We found most employees were women, and a small amount of whole body vibration was produced by the tax-sealing machinery. Workers were loosely coupled to this machinery and moved about frequently. We consider the exposure to be low in this plant.

### **Foundry Operations**

Three large foundries were toured. Two manufactured large castings, the third manufactured smaller castings in very large volumes (i.e., 60 to 70 per hour). In all cases severe whole body, segmental, and buffeting vibration was observed. In particular, transient vibration and whole body vibration appeared during the so-called mold "shake-out" operation where the special sand and other material surrounding the castings are removed. Workers were closely coupled to this operation. Acceleration levels appeared high. Segmental vibration was observed in the hand tamping, casting, and chipping operations. Workers in the above operations were closely coupled to their hand tools. Finally, vibration was observed in the overhead cranes. Noise levels were high, but workers wore ear protection.

### **Vehicular Engine Manufacturing**

This plant employed several thousand employees manufacturing engines used primarily for large trucks and equipment. This plant did not have its own foundry, and thus castings arrived such that chipping operations were not necessary. Transient vibration was observed as small castings fell from a polishing operation onto a conveyor belt. A worker was closely coupled to this conveyor. Several instances of segmental vibration were observed in production-line workers using pneumatic hand tools in assembling the large vehicular engines.

### **Quarries**

Two granite quarries were toured. One was a large quarry employing 250 workers. Segmental vibration was observed during the drill bit sharpening, granite polishing, chipping, chiseling, grinding, and plug drill operations. Whole body coupled with transient vibration was observed during the splitting of granite sheets and in the rock-crushing operation where vibration was transmitted to workers through

the floor structure. Finally, vibration was observed in overhead cranes and heavy-duty fork lift trucks. In the smaller quarry employing 15 persons, vibration was observed during grinding and chipping operations.

### **Furniture Manufacturing Plants**

Two furniture manufacturing plants were toured, one employing 900 and the other employing 120. Segmental vibration was observed where workers used pneumatic stapling guns and wood-working tools such as routers, sanders, and hand saws.

### **Shoe Manufacturing Plants**

Two shoe manufacturing plants were toured. One employing 204 was located in an old two-story building. Punch presses, general shoe formings, perforating, and rough routing machinery were used. About 140 operators of the machines were exposed to segmental or whole body vibration. In the second plant toured, employing 480, the same shoe operations were observed. However, this plant was a modern one-story structure with a poured concrete floor, and much of the machine vibration appeared dampened out by the floor.

### **Railroad**

We visited the freight yards of a large railroad. Engineers, firemen, brakemen, and conductors all appeared exposed to whole body vibration, depending on which part of the freight train they rode. We toured several models of cabooses, and the newer units appeared to reduce vibration considerably. Segmental vibration appeared in the automatic track tamping machinery and tie-cleaning machinery. These machines usually employ a group of two or three workers per unit.

### **Vehicular Body Stamping Plant**

One vehicular body stamping plant was toured. It employed 2,400 production workers. There were several hundred stamping presses in this plant. Whole body vibration was observed where workers were closely coupled to some of these larger presses. Some workers placed cardboard under their feet in an attempt to reduce the vibration. Segmental vibration was observed near the smaller punch and shear presses.

### **Coal Mining**

A large strip mine operation and an underground mine were toured. Vibration was observed primarily in these areas employing hand tools.

### **Chain Saw Manufacturer**

We visited a large manufacturer of chain saws. It was discovered that such manufacturers are becoming increasingly aware of the segmental vibration associated with chain saws and apparently are consid-

ering redesigning such tools with vibration isolation systems in an effort to decouple the worker from his chain saw. Some foreign manufacturers of chain saws already have vibration isolated designs in the world market. There appears reluctance of some countries to accept outdated chain saw designs, primarily in Great Britain and Sweden.

## Conclusions

Based upon job type statistics<sup>3</sup> obtained from the Department of Labor and the Department of Agriculture (which are accurate to July, 1971, and January, 1972, respectively) and based upon our own observations, we make these tentative comments: There are 790,500 heavy construction contractors in the United States; we estimate some 2,500,000 construction workers are exposed to some form of industrial vibration.

There are 1,042,700 truck drivers and terminal workers; we estimate there are 1,000,000 vibration exposed drivers and terminal fork lift operators.

There are 2,831,000 farms in the United States, and we assume one farm tractor and/or chain saw on the average per farm. Thus, we estimate 2,831,000 exposed farm workers exposed to vibration.

There are 44,400 inter-city bus drivers in this country and some 69,600 local transportation bus drivers and employees. Our estimates are that nearly all of the long-haul bus drivers (44,000) are exposed to vibration and perhaps a conservative 10-11% (i.e. 7,000) of the local drivers.

There are 487,400 foundry workers, of which we estimate 40% are exposed, or about 194,000. Similar percentages for workers are estimated for: metal can manufacturing (76,900 total, est. 8,000), metal stamping (212,000 total, est. 22,000), steel mill and blast furnace workers (536,800 total, est. 54,000), printing and publishing (1,028,700 total, est. 100,000), lumber and wood, (596,800 total, est. 60,000), furniture manufacturing, (452,500 total, est. 45,300).

There are about 228,200 underground miners of all types in the United States; and, based upon the types of hand tools used, we estimate some 114,000 workers are exposed. There are some 616,200 railroad workers. We estimate roughly 50% are exposed to vibration, or about 300,000. There are some 1,000,000 workers involved in car and truck body manufacturing; we estimate 500,000 exposed workers.

Thus, we conservatively estimate at this time there are approximately 8,000,000 workers exposed to some form of industrial vibration in the United States. The term conservative is used because undoubtedly there are a few additional vibrating work situations which we have not seen. We also re-emphasize that we do not presently know what the safety and health effects are of this long-term vibration exposure in the United States, or the extent of this exposure.

There are some additional items which we have learned during these field trips. In seeking out vibration problems in areas other than transportation, we have continuously found vibration to be "pocketed;" that is, not ubiquitous. One can tour a plant, go from process to process, and then suddenly a group of workers will be involved in an operation which is vibrating.

Another observation we have made, especially when improved products are concerned, such as pavement breakers, improved tractor seats, etc., is that it is apparently difficult to get these improvements accepted by the older, experienced workers. Thus, it appears at this time that employers are hesitant to spend the additional amount for an improved design if their workers will not use these products.

Based upon the aforementioned plant tours and discussions with numerous industrial hygienists, international researchers in the field, industrial medical personnel, and others, we can only tentatively surmise that transportation (i.e., heavy equipment operations, off-road and truck drivers, bus drivers) and farming (i.e., use of farm tractors and/or chain saws) represent probably the largest groups exposed in industrial vibration. These are then followed by foundry operations, mining, forestry, lumber and wood products, printing and publishing, steel mills and blast furnace workers, metal stamping, and can manufacturing.

## Acknowledgement

We thank the many industrial hygienists, physicians, and supervisors in the various plants we toured for their time and interest in our project. In addition, the advice and interest of the following are also gratefully acknowledged: Dr. F. N. Dukes-Dobos, NIOSH, Dr. E. R. Tichauer, New York University, H. H. Jones, Central Missouri State College.

## References

1. Wasserman, D. E. & Badger, D. W., "The NIOSH Plan for Developing Industrial Vibration Exposure Criteria," *J. of Safety Research*, Vol. 4, No. 4, pp. 146-154, December, 1972.
2. Wasserman, D. E. & Badger, D. W., "Vibration and the Worker's Health and Safety," NIOSH Technical Report No. 77, January, 1973.
3. *Employment & Earnings*, Vol. 18, No. 3, September, 1971, United States Department of Labor.