MEASUREMENT PROBLEMS ASSOCIATED WITH THE STUDY OF SEGMENTAL VIBRATION

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ABSTRACT

This presentation discusses attempts to measure segmental vibration and the problems encountered. Since actual physical measurements are important to the study of shock and vibration response of the users of hand-held power tools, an accurate set of acceleration readings at typical input amplitudes and frequencies would aid in determining the vibration absorption characteristics of the hand and arm, and possibly lead to changes in power tool design. It is difficult to measure vibration of a power tool under various loading conditions. Response of the hand and arm is even more difficult to measure with any degree of precision. Limited studies of force transmission through the hand-arm system have been made by mounting accelerometers on bands tightly attached to the arm. In cadaver studies, accelerometers have been mounted directly on the humerus, radius, and ulna (of an arm severed at the shoulder and excited at the hand). In addition, the dynamic mass, spring constant, and damping of the hand-arm system have been determined by using a shaker with an impedance head.

INTRODUCTION

It is desirable to establish the energy absorption pattern in the hand-arm system when subject to the shock and vibratory load of hand-held power tools. It is difficult, however, to make precise measurements on the hands and arms of power tool operators. Some investigators have attached accelerometers to the human body using belts and bands.[1-2] Others have turned to animal and cadaver experimentation.[3-6] In addition, human subjects have been used to obtain impedance measurements that may be used in constructing analytical models of the tool-hand-arm system.[7-9]

ANIMAL STUDIES

Occupational disease due to normal use of hand-held power tools occurs after long periods of exposure. In animals, the process can be accelerated by using higher stress levels (greater loads relative to the animal size). In addition, animals can be sacrificed to permit an examination of the damage.

A number of investigators have subjected laboratory animals to whole-body vibration. Extreme acceleration levels of 10 to 20 g at 15 to 25 Hz have killed mice within a few minutes.[4] Heart damage, lung damage, and brain injury have been observed on autopsy. Other whole-body vibration studies have utilized rats, cats, and monkeys.

Animal studies designed to simulate hand-arm-system vibration in power tool users present a number of problems. In addition to the significant differences in structure and use of the limbs, it is unlikely that laboratory animals could be induced to cooperate with the researcher. Thus, restraints would generally be required, possibly reducing the validity of any findings. For example, Guinea pigs were used in a study by Simon et al.[5] The animals were held in a rack with splinted, fully extended hind legs (Figure 1). The splint on one leg touched a table vibrating at 25 Hz. The force in the leg, measured by strain gauges in the splint, approximated the animal's weight (1.0 to 1.25 kg). The knee joints developed cartilage degeneration over a 3-week period. Suggs[6] used the limbs of freshly sacrificed and embalmed pigs in studying vibration transmission. Accelerometers were bone-mounted to obtain the response to a sinusoidal input from a shaker.

CADAVER STUDIES

Cadavers provide one source of information on the structure, dimensions, and relative masses of components of the hand-arm system. Available data include the size of the cartilage-covered surface of the

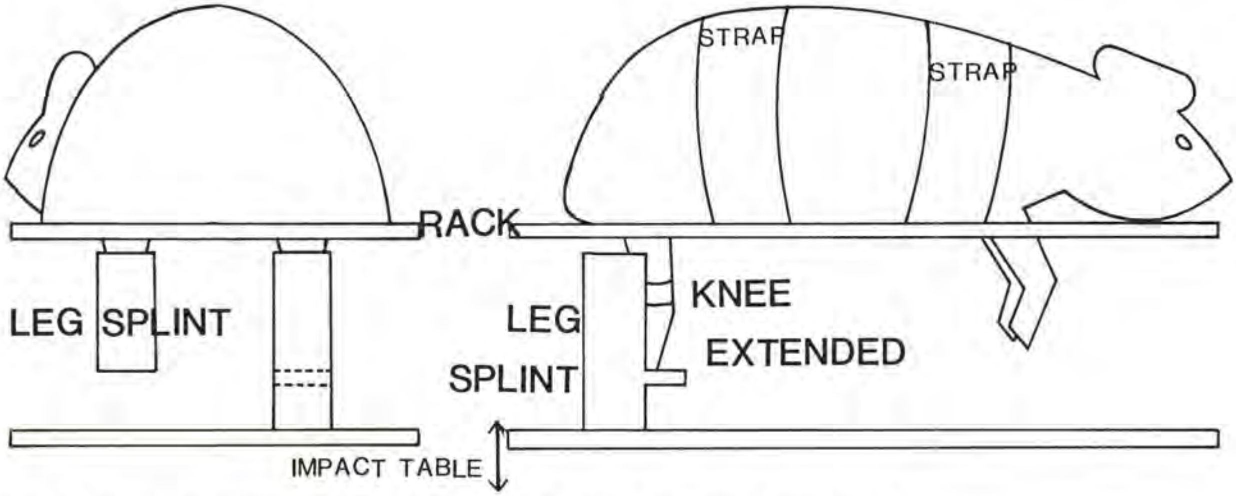

Figure 1. Repeated impact loading on knee joints of guinea pigs (from Reference 5).

joints and the physical properties of articular cartilage.

Cadavers have been used as subjects for dynamic experimentation. Accelerometers and other instrumentation mounted directly on the skeletal structure eliminate the problem of compensating for motion of the skin surface relative to the bone. Major drawbacks include the problem of changed properties resulting from deterioration, particularly in the joints, and the problem of simulating muscular effort in holding and guiding a tool.

Vibration transmission studies by Abrams and Suggs[3] utilized the right arm of a cadaver, disconnected at the shoulder joint. Incisions were made into the arm, and accelerometers were mounted in tapped holes in the bones at locations shown in Figure 2. The end of the upper arm was secured to an anchorage stand, and the hand was lashed to a hand grip attached to a shaker. The shaker was excited sinusoidally in the vertical direction. The investigators observed that most of the vibrational energy was dissipated in the lower arm and hand. Note that the elbow was bent in this test and that the acceleration direction was perpendicular to the axis of the forearm. The acceleration measured at each point at an excitation frequency of 31.5 Hz is shown in Figure 3. As input frequency was increased, a greater fraction of the vibration was absorbed before reaching the accelerometer mounting points near the wrist. In Figure 4, the acceleration at the end of the radius near the wrist is shown as a fraction of the input level, plotted against excitation frequency.

ACCELERATION MEASUREMENTS OF WHOLE-BODY VIBRATION

Accelerometers have been attached to the human body for measurements of acceleration and deceleration and whole-body vibration. When displacement amplitudes are large, relative motion of the accelerometer with respect to the skeletal structure is not important.

In a study of whole-body vibration of seated subjects, Sjoflot and Suggs[1] measured acceleration at the hips and shoulders. They used strain gauge accelerometers attached to a broad, relatively stiff belt.

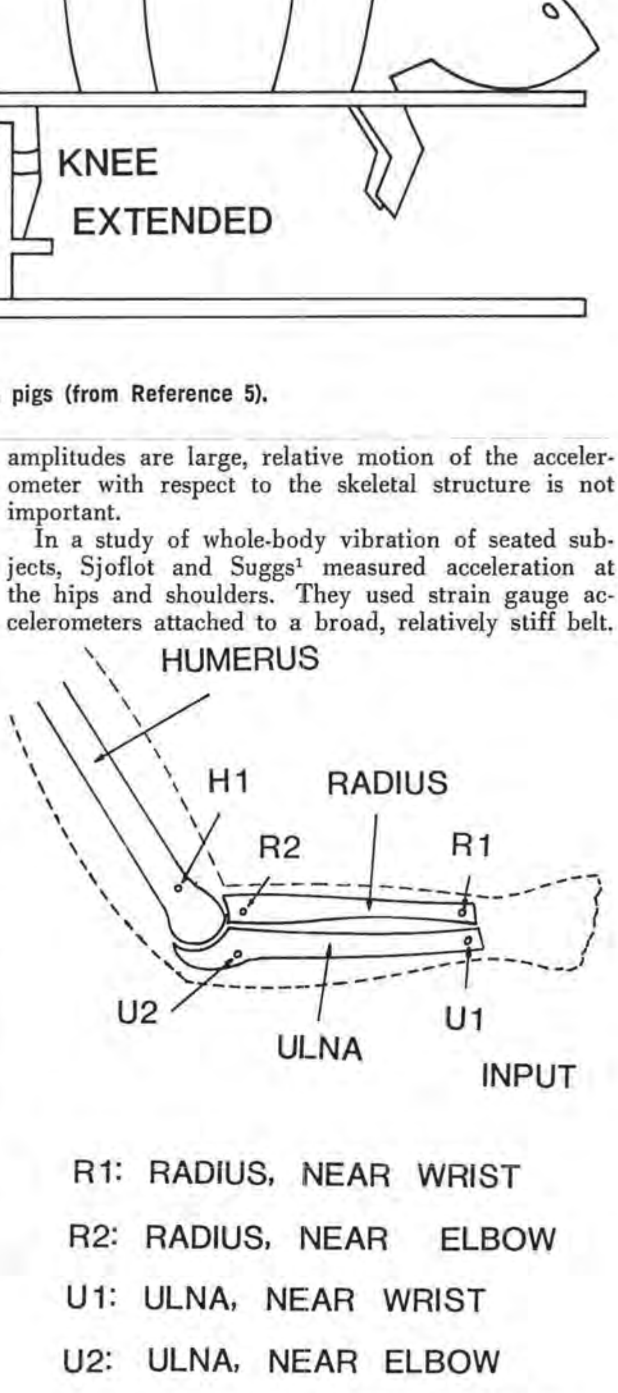

Figure 2. Approximate accelerometer locations for cadaver transmissibility measurements (from Reference 3).

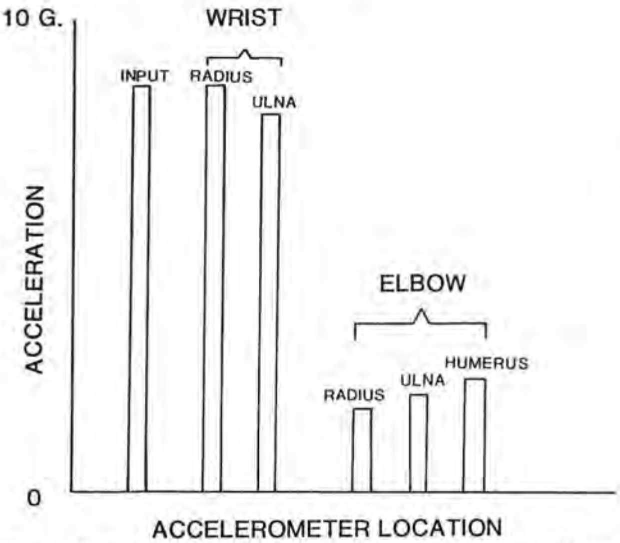

Figure 3. Response to 31.5 Hz sinusoidal imput (from Reference 3).

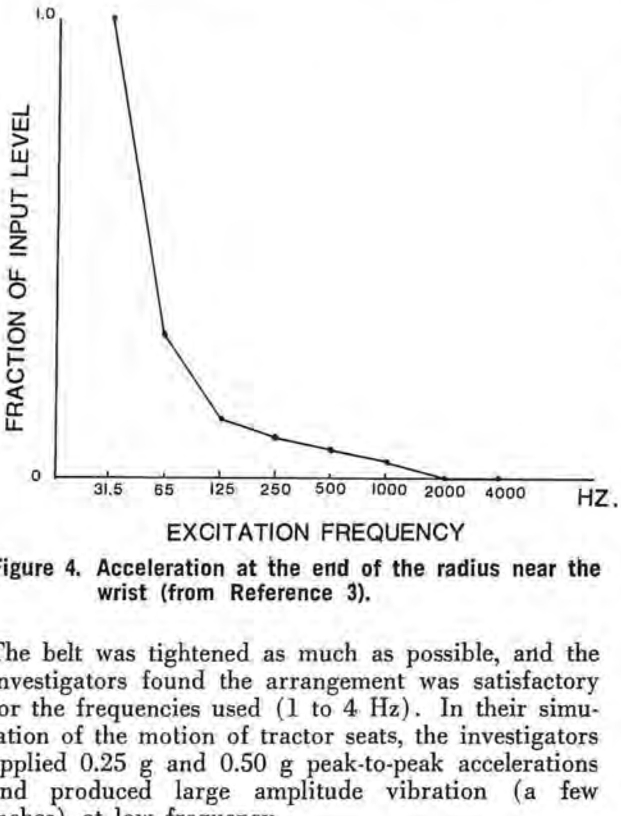

Figure 4. Acceleration at the end of the radius near the wrist (from Reference 3).

The belt was tightened as much as possible, and the investigators found the arrangement was satisfactory for the frequencies used (1 to 4 Hz). In their simulation of the motion of tractor seats, the investigators applied 0.25 g and 0.50 g peak-to-peak accelerations and produced large amplitude vibration (a few inches) at low frequency.

ACCELERATION MEASUREMENTS ON THE HAND-ARM SYSTEM DURING IMPACT LOADING

The resilience and mass of the tissues surrounding the bones of the hand and arm may introduce considerable error into direct measurement of vibration. At some points on the arm, a light axial force will move the skin 1 or 2 cm relative to the bone. The problem of accelerometer mounting is more significant with hand-held power tools than it is in large amplitude whole-body vibration studies.

Impact loads caused by a pneumatic hammer and a bolt gun were studied by Carlsoo and Mayr.[2] They used piezoresistive accelerometers attached to the operator's upper arm and forearm as close to the skeleton as possible without surgery (Figure 5). Using the mass and mass moment of inertia of the arm segments, they employed Newton's second law to calculate forces from the measured accelerations. Arm segment masses were based on typical percents of body weight. In their study, the trunk was assumed to be fixed. Based on their measurements, 80% to 90% of the shock load that the pneumatic hammer exerted on the hand did not reach the wrist. Shock load at the elbow and shoulder ranged from 39% to 74% of the shock load at the wrist joint, depending on the operator's position. The shock loads shown in Figure 6 correspond to the operator position shown in Figure 5.

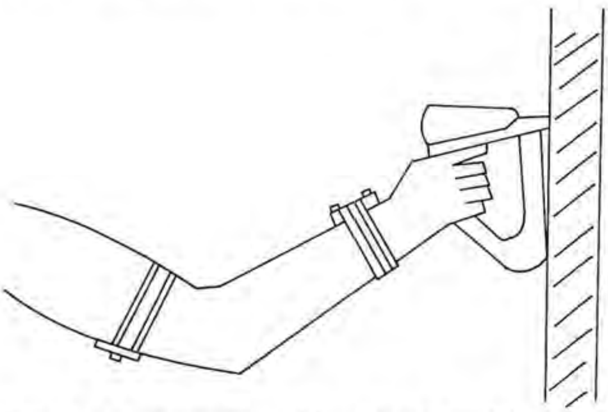

Figure 5. Accelerometer positions for determining joint loading due to a pneumatic hammer (from Reference 2).

When a bolt gun was used, the shock load on the operator's wrist was about 10 times as great as that experienced with the pneumatic hammer. The impact at the hand, however, was not determined for the bolt gun. Stresses measured by Carlsoo and Mayr fall well below mechanical failure stresses of cartilage in in vitro studies. They concluded that impact-induced damage in joints may be due to secondary effects such as impaired circulation.

ANALYTICAL MODELS

In many cases, the hand-arm system exerts a significant influence on the dynamic response of a power tool. An analytical model is necessary for an understanding of this influence. Furthermore, modeling is an important design tool that may be used in extrapolating a limited amount of experimental data con-

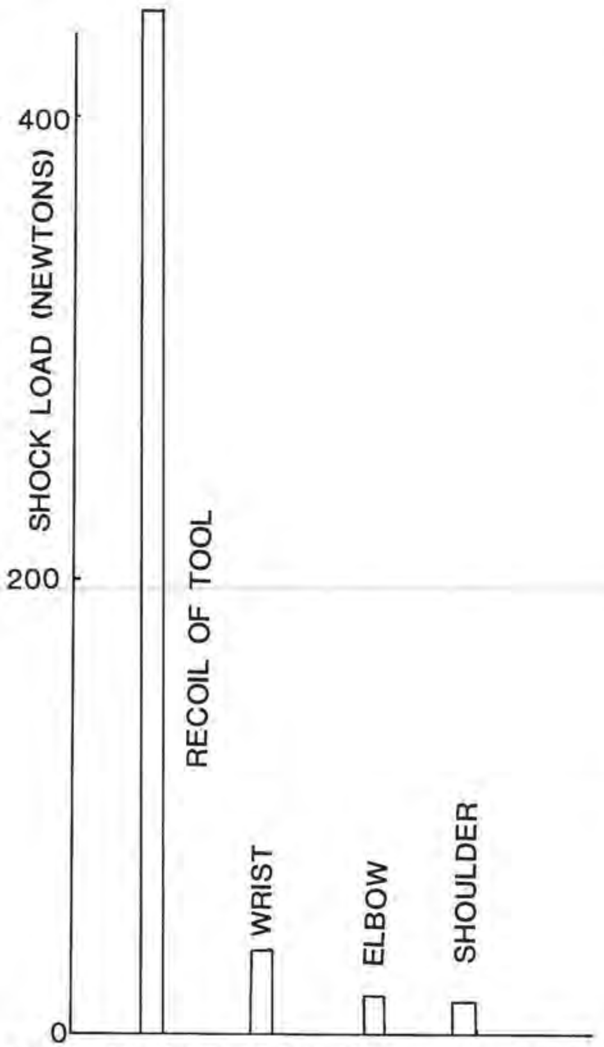

Figure 6. Shock load on joints due to a pneumatic hammer (from Reference 2).

cerned with variations in tool output, operator position, and other parameters.

A typical power tool may be treated as a rigid body generating a dynamic force and moment on the hand or hands. The hand-arm system may be modeled by a series of springs, masses, and dampers.

The mechanical impedance method was used by Reynolds and Soedel[6,7] to examine response of the hand to sinusoidal force input. They used a shaker fitted with a T-bar handle and an impedance head and, to compensate for handle mass, an on-line analog computer. Force amplitude in the handle was kept constant as frequency was varied. Based on their measurements, the hand-arm system was described in terms of a one degree-of-freedom system in each of three orthogonal directions. That is, mass (m), damping constant (c), and spring constant (k) were determined by fitting the data to the equation of motion.

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F \sin \omega t$$

For each direction, the constants were determined for a low frequency range and a high frequency range. Zaveri[9] did a similar impedance study on the hand-arm system, using a constant (1 g) acceleration.

CONCLUSIONS

Further study of the mechanism of vibration absorption in the hand-arm system is essential to a better understanding of vibration-induced occupational diseases. To date, only limited data are available on the dynamic characteristics of the individual joints and segments of the hand and arm. It may be possible to obtain the missing data by improved and standardized methods of mounting accelerometers directly on the hand and arm. Tests should be made under both shock and vibratory conditions. Acceptable accuracy may be obtained by compensating for relative motion between the transducers and the skeletal structure.

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National Institute for Occupational Safety and Health

PROCEEDINGS OF
THE INTERNATIONAL OCCUPATIONAL HAND-ARM VIBRATION CONFERENCE

Sponsored by
National Institute for Occupational Safety and Health
Cincinnati, Ohio, U.S.A.
October 1975

Editors:
D. E. WASSERMAN
W. TAYLOR

Manuscript Editor:
M. G. CURRY

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Cincinnati, Ohio 45226
April 1977

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

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DHEW (NIOSH) Publication No. 77-170