J. S. Afr. Inst. Min. Metall., vol. 91, no. 3.
Mar. 1991. pp. 89-94.

The use of modified handles on jack-leg drills to reduce hand vibration

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SYNOPSIS

This paper details a study conducted in Canada on the use of a drill with two different types of elastomer-covered handles in place of the standard steel handles. One type of handle was covered with a relatively stiff elastomer with a durometer of 70 (referred to as the plastic handle), and the other was covered with a more compliant elastomer with a durometer of 56 (referred to as the rubber handle).

It was found that, compared with the steel handle, the overall acceleration at the interface between the plastic handle and the drill operator's hand was 2,5 times less, and that between the rubber handle and his hand was 3 times less. This reduction occurred predominantly in the frequency range above 500 Hz, and was greater with increasing frequency. However, an analysis based on the methodology of an international standard (which places greater importance on low-frequency vibration), indicated that the reduction in vibration levels was minimal. The driller himself felt that operation with the plastic and rubber handles was more comfortable, the rubber handle being preferred.

SAMEVATTING

Hierdie referaat verstrek besonderhede van 'n studie wat in Kanada onderneem is in verband met die gebruik van 'n boor met twee verskillende soorte elastomeerbedekte handvatsels in plaas van die standaardstaalhandvatsel. Een soort handvatsel is bedek met 'n betreklik stywe elastomeer met 'n durometerhardheid van 70 (en word na verwys as die plastiekhandvatsel) terwyl die ander een bedek is met 'n meer buigsame elastomeer met 'n durometerhardheid van 56 (en na verwys word as die rubberhandvatsel).

Daar is gevind dat, vergeleke met die staalhandvatsel, die totale versnelling by die skeidingsvlak tussen die plastiekhandvatsel en die booroperateur se hand 2,5 keer minder, en tussen die rubberhandvatsel en sy hand 3 maal minder was. Hierdie vermindering het hoofsaaklik in die frekwensiestrek bo 500 Hz voorgekom en was groter by hoër frekwensies. 'n Ontleding wat gebaseer is op die metodologie van 'n internasionale standaard (wat groter waardes aan laefrekwensievibrasie heg) het egter getoon dat die verlaging van die vibrasievlakke minimaal was. Die booroperateur self was van mening dat dit geriefliker was om met die plastiek- en rubberhandvatsels te werk, en het voorkeur aan die rubberhandvatsel gegee.

Introduction

Operators of jack-leg drills often suffer from tingling, numbness, and blanching of the fingers, which is known as vibration syndrome or hand–arm vibration (HAV) syndrome. The symptoms associated with white-finger attacks and vibration entering the hands is termed 'vibration-induced white finger' (VWF). In the industry, this is more commonly called 'white fingers', 'waxy fingers', 'dead fingers', or 'dead hands'.

The symptoms associated with VWF include tingling, numbness, and prickling of the fingers in the early stages of the condition, with a loss of fine touch, and temperature sensations and pain between vasospasms in advanced cases. Reduced grip strength, formation of bone cysts in the fingers and wrists, joint degeneration in the wrists and elbow, and vegetative responses implying the involvement of the central nervous system may also result in some cases.

Since there is no cure or effective treatment for persons with HAV syndrome, the mining industry has recognized the need to minimize the exposure of operators to vibration induced by jack-leg drills. The authors, the Mining Industry Research Organization of Canada, and Teledyne Canada Mining Products therefore undertook a programme[1] to develop and test a handle of modified design on jack-leg drills in an effort to reduce hand-transmitted vibrations. This coordinated effort was also aimed at minimizing the economic penalties associated with HAV syndrome, which include reduced operator efficiency, lost time through increased absenteeism, and substantial compensation costs, which totalled almost four million dollars in Ontario, Canada, in 1988 alone.

Two variations of a 'cushioned' handle were developed for the Joy AL60 jack-leg drill, one employing a relatively stiff elastomer (durometer of 70), and the other employing a significantly more compliant elastomer (durometer of 56). A standardized hand-transmitted vibration measurement and analysis protocol was developed to evaluate the effectiveness of these new designs in reducing the hand-transmitted vibrations experienced with the standard steel handle.

This paper describes the vibration-measuring techniques used for the evaluation of the handles; the field testing programme used to monitor the hand-transmitted vibration levels produced by a jack-leg drill; and a quantitative and qualitative evaluation of the ability of a new 'cushioned' handle for a Joy AL60 to reduce the level of hand-transmitted vibration below that of the standard steel handle.

Modified Handles

The standard handle on the Joy AL60 jack-leg rock drill is solid steel with a knurled grip surface and a diameter of 3,8 cm. The two cushioned handles are shown in Fig. 1. Both handles consist of a steel post covered with

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SA ISSN 0038-223X/3.00 + 0.00. Paper received 8th September, 1990.

a layer of relatively compliant material. The handle shown on the left employs a material known as 'Cellulor 40', with a durometer of 70. For the purposes of discussion, this handle is referred to as the plastic handle. The handle shown on the right employs a material known as HD Damped Elastomer, with a durometer of 56. This handle is referred to here as the rubber handle. Neither of the cushioned handles was designed to have a knurled grip surface, although the plastic handle has a pitted surface as a result of the turning-to-size of the cellular material. Both handles are approximately 4,13 cm in diameter.

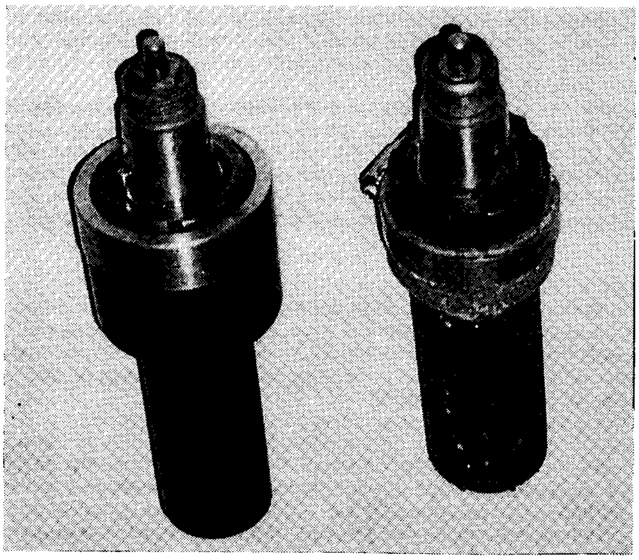

Fig. 1—The modified drill handles

Both cushioned handles had been designed to provide motorcycle-grip control of the jack-leg air pressure; that is, the operator controls the pressure by twisting the handle. This is in contrast to the steel handle, which is fixed, and in which the operator controls the jack-leg pressure by adjusting a regulating knob located close to the handle.

Measurement Protocol

A measurement protocol for the evaluation of the drill handles was developed based upon the International Standard ISO 5349-1986(E)[2]. This protocol ensured that generally accepted measuring techniques were employed, and that the results obtained would be directly comparable with the results obtained by other researchers who utilize the same Standard.

Direction of Vibration

A biodynamic coordinate system was used to characterize vibration, with acceleration components X, Y, and Z. The three mutually orthogonal directions of vibration were selected so that the Z axis is parallel to the arm direction (negative towards the operator's body), the Y axis is across the hand (positive to the left of the operator's field of vision), and the X axis is positive downwards and perpendicular to the Y and Z axes.

Magnitude of Vibration

The quantity used to describe the magnitude of vibration is acceleration expressed as an r.m.s. value. The acceleration value is expressed both in metres per second squared (m/s^2) and, in terms of an acceleration level, in decibels (dB). In the latter case,

$$L_n = 20 \log (a/a_o),$$

where L_n = acceleration level of the hand (dB), a = r.m.s. acceleration (m/s^2), and a_o = a reference acceleration of 1 μm/s^2.

All the acceleration levels reported in this study are unweighted except where explicitly noted otherwise.

Frequency Range

The frequency range of all the measuring and analysis systems was at least 5 to 1500 Hz. In all instances, the actual frequency range of the system used to obtain a particular measurement was clearly noted. Owing to the high peak accelerations associated with percussive tools, the accelerometer used had a resonant frequency of more than 25 kHz and a cross-axis sensitivity of at least 20 dB below the sensitivity in the axis to be measured.

Mounting of Vibration Transducers

Measurements were made in all three coordinate directions, a fixture having been built to permit the accelerometer to be mounted in the appropriate directions. The smaller the transducer used in this type of work the better, although the durability of cables and connections can be a problem with very small transducers. When the fixture was adjusted properly, the origin of the coordinate system was directly over the third metacarpophalangeal joint (knuckle) of the hand. The height of the fixture was such that the mounting block just cleared the knuckle.

Measurements

The acceleration measured in all three coordinate axes was reported. The International Standard ISO 5349 suggests that the acceleration can be reported either as a frequency-weighted value or analysed in 1/3-octave bands, and the latter approach was used in this study. For research and development purposes, the 1/3-octave measurement is far more useful since it provides a clear record of the frequency content of the measured acceleration. For comparative purposes, such measurement clearly shows the frequencies at which the cushioned handles began to provide significant reduction in vibration. In addition to the 1/3-octave values, the overall vibration levels (for a specified frequency range) and the narrowband frequencies were measured.

All the measurement and analysis systems were calibrated prior to use, and were checked sufficiently often to guarantee continued calibration.

It should be noted that changes in coupling between the hand and the vibrating surface can considerably affect the vibrations measured. In the present study, the vibration levels measured were for a grip pressure and static force that are representative of typical operation.

Field Testing

Field testing of the modified handles was conducted at the Queen's University Blast Test Site, which is administered by the Department of Mining Engineering. The basic test approach was to drill a series of holes under

Fig. 2—The setup for the field test

essentially identical conditions, the only difference being the type of handle used on the rock drill. In this manner, the measured vibration provided a direct comparison of the isolation performance of the cushioned handles. Test holes were drilled in a vertical rock face composed of granite with a compressive strength of approximately 200 MPa. All the holes were horizontal, and were drilled using a 1,8 m steel rod. The air and water pressures were controlled and maintained constant at 6,9 MPa and 0,4 MPa respectively. The hole depth and drill-leg angle were also monitored before and after each test. Other test variables, such as the arm position and the hand grip of the operator were controlled and maintained the same from test to test. The drill bit was carefully monitored and changed if there was any evidence of excessive wear or fracture of its cutting inserts. The bit contained four tungsten carbide inserts. Fig. 2 shows a typical hole being drilled. The operator was an experienced driller, and he did not use gloves during the drilling sequences.

Since a single accelerometer was used for the measurements (to reduce the mass applied to the mounting fixture), the accelerometer had to be mounted sequentially in the appropriate orientation. The vibration level was thus obtained for each orientation using each of the three handles. This series of tests was repeated three times. The measuring system consisted of a Bruel & Kjaer Model 4371 accelerometer, a Bruel & Kjaer Model 2635 preamplifier, and a Hewlett Packard Model 3960 tape-recorder, a Bruel & Kjaer Model 2305 level recorder, a Wavepac Dual Channel FFT analyser, and a Bruel & Kjaer Model 3513 vibration analyser. The upper frequency limit of the measuring system was fixed by the tape-recorder at 6000 Hz. For each test condition, the acceleration measurements were recorded for approximately 90 seconds.

Analysis of the Measurements

Overall Vibration Levels

The overall vibration level for each test condition was obtained using the tape-recorder and the level recorder. This produced a paper trace of the vibration levels versus time. Table I gives the averaged overall level for the three series of tests for a given direction and type of handle.

TABLE I
AVERAGED OVERALL ACCELERATION LEVELS FOR EACH TYPE OF HANDLE

Coordinate direction	Type of handle					
	Steel		Plastic		Rubber	
	dB	m/s^2	dB	m/s^2	dB	m/s^2
X	176	631	170	316	168	251
Y	171	355	165	178	161	112
Z	175	562	168	251	165	178

Narrowband Frequency Analysis

Narrowband frequency analyses were obtained for each test condition using the tape recorder, the analyser, and a hardcopy device. The spectra were obtained for frequency ranges of 0 to 2000 Hz and 0 to 8000 Hz. All the spectra have a resolution of 400 lines and were averaged using five ensembles. Fig. 3 presents typical results for each of the handles and *X, Y,* and *Z* directions over the frequency range 0 to 8000 Hz.

1/3-Octave Frequency Analysis

This analysis was limited to the measurements taken during the third test series since it was felt that the measurements were a fair representation of the performance of each handle. The analysis system used consisted of the tape-recorder, the vibration analyser, and the level recorder. Typical results of this analysis for the *X, Y,* and *Z* directions are shown in Fig. 4.

Discussion of the Results

For this discussion, the level of acceleration measured

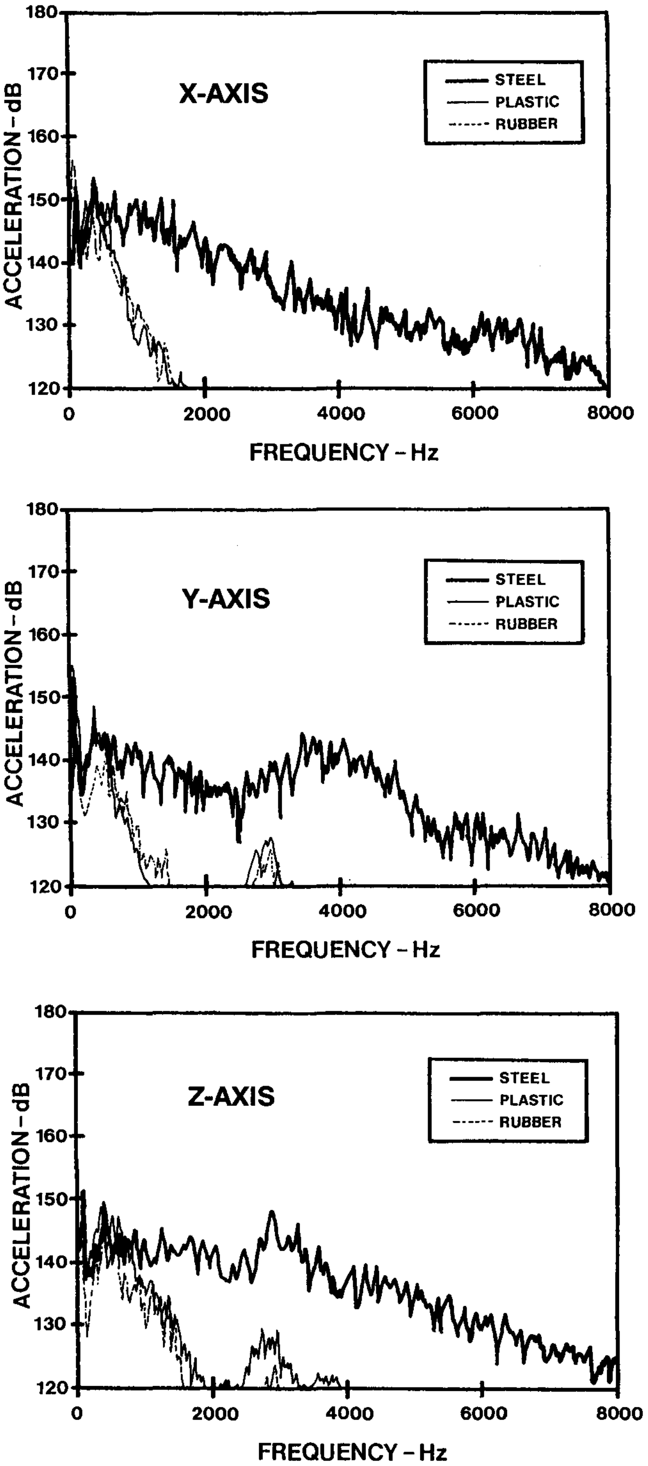

Fig. 3—Typical narrow-band spectra for the *X*, *Y*, and *Z* directions

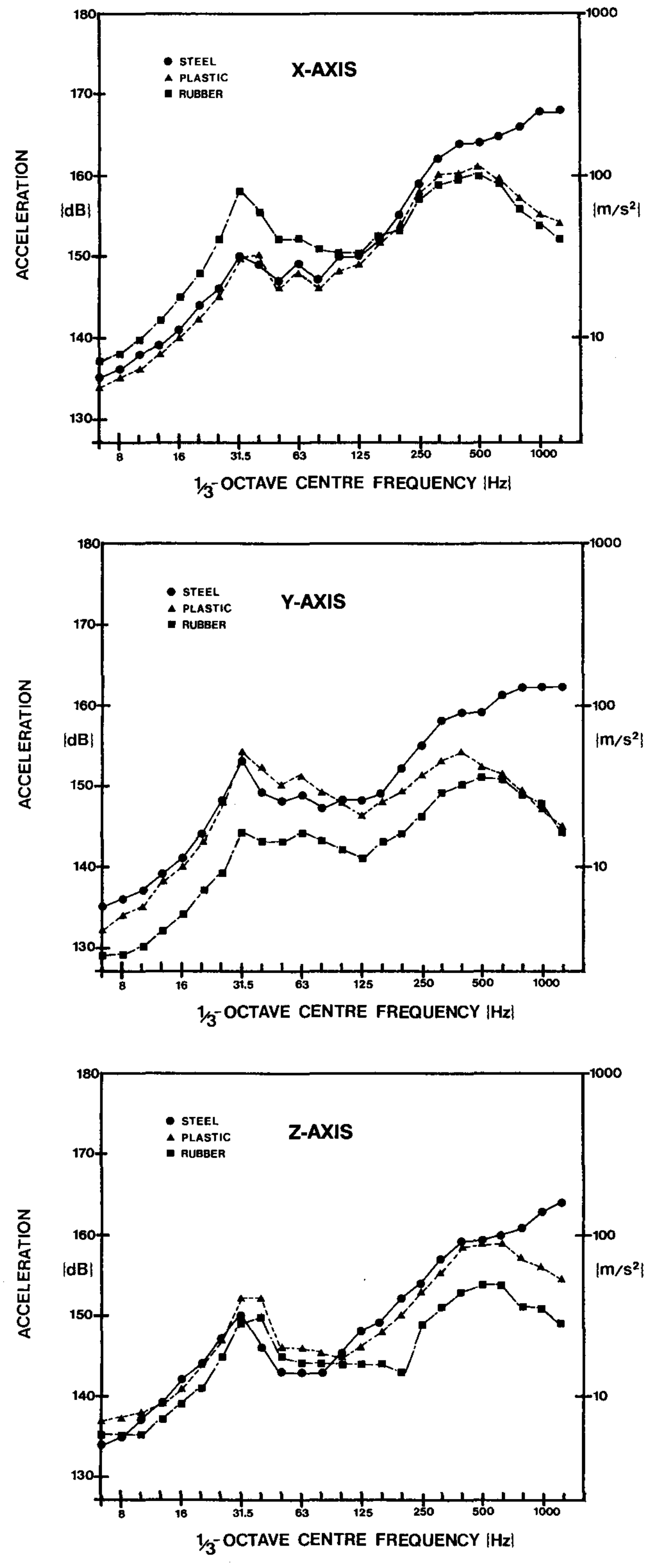

Fig. 4—1/3 octave spectra for the *X*, *Y*, and *Z* directions

at the hand-handle interface during drilling operations is taken as the basic performance indicator. Thus, a decrease in measured acceleration level with respect to that with the steel handle is considered to be an improvement in performance.

Overall Vibration Levels

It is apparent from Fig. 4 that both the plastic and the rubber handles provide a significant reduction in overall vibration at the hand-handle interface. This is also shown in Table I, in which the values are averages of the three test runs for each handle. For each co-ordinate direction, the rubber handle consistently provided the lowest vibration level (greatest vibration isolation), with the plastic handle giving a somewhat poorer performance.

For the rubber handle, the reduction in overall level (relative to the steel handle) is approximately 10 dB in each coordinate direction. This represents a reduction of the transmitted vibration by a factor of 3; that is, the overall vibration transmitted by the rubber handle is approximately one-third that of the steel handle. The plastic handle results in a reduction of approximately 8 dB in each coordinate direction, representing a reduction in the transmitted vibration by a factor of 2,5. Of the two cushioned handles, the rubber handle provides an additional 17 per cent reduction in transmitted vibration relative to that given by the plastic handle. It is also evident that the highest vibration levels occurred in the X and Z directions, the values in the X direction being slightly, but consistently, higher for all three handles.

Narrowband Frequency Analysis

The narrowband frequency analyses indicate that the reduction in overall vibration that was noted for the plastic and rubber handles occurs as a result of the attenuation of the higher-frequency components of the vibration. Generally, a significant reduction in acceleration components was noted above 500 Hz. Below that frequency, all the handles performed essentially in the same manner, with the cushioned handles providing minimal vibration isolation. Also, large peaks in acceleration were found at approximately 25 Hz (fundamental) and 70 Hz (2nd harmonic), and these are a consequence of the 'hammering' frequency of the rock drill.

1/3 Octave Frequency Analysis

The 1/3 octave results essentially confirm the results obtained from the narrowband frequency analysis. Although the spectra differ somewhat in detail for each coordinate direction, the overall trend is clear: there is a significant reduction in acceleration only after approximately 500 Hz. The results for the Y direction are somewhat anomalous in that they show, for the rubber handle, a consistent reduction across the entire spectrum, with the reduction increasing significantly after 500 Hz. Such a consistent reduction in vibration level at lower frequencies is not evident in the X and Z directions. Since the severity of hand-transmitted vibration is to be based on the results for the 'worst case' coordinate direction, the rubber handle must be considered effective only above frequencies of 500 Hz.

Vibration Exposure

Another means of evaluating the relative performance of the test handles would be to determine their effect on the operator's exposure to hand-transmitted vibration. Thus, a reduction in exposure level would be considered to indicate an improvement in performance.

Unfortunately, the vibration exposures required to cause HAV syndrome are not known exactly, either with respect to vibration level and frequency content, or with respect to the duration of daily and cumulative exposure. In view of the complexity of the problem and the lack of quantitative data concerning the occupational-health effect of hand-transmitted vibration, it is difficult to develop a comprehensive method for the assessment of vibration exposure.

However, based on the limited data available and on experience with current exposure conditions, ISO 5349 provides guidelines for the evaluation of hand-transmitted vibration exposure. The basic approach is to calculate a weighted acceleration level and then relate this value to an expected exposure time before the occurrence of finger blanching (in years). The lower the weighted acceleration level, the longer the time to the appearance of finger blanching.

For the plastic handle, the level of weighted acceleration was found to be essentially the same as the values for the steel handle for all coordinate directions. This results from the relatively small contribution that higher-frequency components make to the overall weighted acceleration. Thus, the reduction in levels at higher frequencies for the plastic handle does not translate into a significant reduction in weighted level. There was some variation in the performance of the rubber handle for the different coordinate directions. For the Z direction, there was a small reduction in weighted acceleration relative to that for the steel handle ($30\ \mathrm{m/s^2}$ versus $34\ \mathrm{m/s^2}$). In the X direction there was an anomalous increase in weighted acceleration for the rubber handle ($65\ \mathrm{m/s^2}$ versus $38\ \mathrm{m/s^2}$), while in the Y direction there was a definite decrease in weighted level ($17\ \mathrm{m/s^2}$ versus $40\ \mathrm{m/s^2}$). However, since the 'worst case' coordinate results were used in the assessment of exposure, the rubber handle was considered to provide the basically minimum reduction in vibration exposure for the evaluation scheme proposed in ISO 5349.

Qualitative Performance of Handles

The drill operator felt that both the plastic and the rubber handles provided a significant improvement in comfort over the steel handle. Of the two cushioned handles, he preferred the rubber handle. It should be remembered that the drill operator was bare-handed in the drilling tests. The wearing of gloves may have changed his perception of relative comfort.

Comparison of Handles

The cushioned handles definitely produced a reduction in the overall vibration level at the hand–handle interface. This reduction occurred at vibration frequencies of more than approximately 500 Hz, with the performance improving at increasing frequency up to approximately 6000 Hz. However, based on the guidelines provided by ISO 5349, the vibration exposure resulting from the use of cushioned handles was not significantly less than for steel handles. This is primarily because the methodology of the Standard allows for a very low contribution to exposure level at frequencies above 500 Hz. Also, the frequencies beyond approximately 1500 Hz, at which the cushioned handles performed very well, were not used at all in the calculation of vibration levels.

It should, however, be kept in mind that a conservative approach to health protection would dictate that any significant reduction in vibration level is a desirable goal. Whether the reduction occurs at lower or higher frequency is not so important. This is particularly true when it is remembered that the present knowledge of the mechanism of HAV syndrome, and the vibration exposures required to cause it, are not known exactly.

Conclusions

The investigation described in this paper showed that the plastic handle reduced the overall vibration (over the frequency range 0 to 6000 Hz) by a factor of 2,5, while the rubber handle reduced the levels by a factor of 3. These reductions were consistent for all three coordinate directions. Relative to the steel handle, both types of cushioned handle were found to reduce the vibration at frequencies above approximately 500 Hz. Isolation performance improved for increasing frequency up to 6000 Hz.

Based on the calculations of vibration exposure detailed in ISO 5349, the cushioned handles provided a minimal decrease in vibration exposure. This is a consequence of the greater importance the Standard places on low-frequency vibration in the calculation of exposure levels. However, a conservative approach to health protection dictates that any significant reduction in vibration level is a desirable goal. Whether the reduction occurs at lower or higher frequency is not so important, particularly as the present knowledge of the mechanism of HAV syndrome, and the vibration exposures required to cause it, are not known exactly.

A qualitative assessment of the cushioned handles by the drill operator indicated a significant improvement in comfort over the steel handle, the rubber handle being preferred.

Acknowledgements

The authors express their appreciation to Mr R.H. Penner for his contribution to the field work. Appreciation is also extended to Teledyne Canada Mining Products for providing the drill handles, and to INCO Ltd for providing a jack-leg drill for the field tests. Financial assistance was provided by the Mining Industry Research Organization of Canada (MIROC), for which the authors are greatly indebted.

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Automation

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