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Analysis of Vibrations in Power Saws

Analys av motorsågars vibrationer

by

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FOREWORD

The present study was carried out with the aid of a number of institutions and individuals.

Professor *Anders Staaf* gave tactful guidance and showed a personal interest by helping to determine the general line the study was to take.

The work involved was carried out at the National Swedish Testing Institute for Agricultural Machinery, Röbäcksdalen, Umeå. The head of this institute, Professor *Harald A:son Moberg,* and the local manager of the testing department at Röbäcksdalen, *Torsten Lindqvist,* B.Sc. (Agric.) gave me all the necessary support for the work, showed great patience with me and allowed me to carry out the experiments in the way I desired. *Nils Eriksson,* B.Sc. (Eng.), Ultuna, showed stimulating interest and expertly helped me to acquire and use the necessary and complicated measuring instruments. Valuable assistance and encouragement came from my colleagues at Röbäcksdalen, *Mrs. Inga Wikström, Rune Axelsson,* B.Sc. (Eng.) and the two mechanics *Jan-Eric Forssén* and *Hans Wikström.*

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I also received good ideas in my discussions with employees of the Professional Forestry Inspection Board at Umeå.

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To all of them I should like to convey my sincere and heartfelt thanks.

This paper represents a summary of a licentiate thesis "Analysis of Vibrations in Power Saws", submitted to the Royal College of Forestry, which has appeared as No. 31 in the series of Research Notes published by the Department of Operational Efficiency of the Royal College of Forestry, Stockholm, Sweden.

Introduction

Nearly all forestry workers in Sweden nowadays use power saws for felling. The daily period of utilisation has increased greatly as a result of necessary productivity-boosting changes in method called for by modern logging techniques.

The modern power saw has undergone a great deal of technical development since it was first generally introduced in Sweden at the beginning of the 1950s. It now has a low service weight, practical design and high cutting capacity. The productivity of the forestry worker has risen considerably thanks to the power saw.

As is so often the case with the forced technical development of a product, essential ergonometric considerations have been pushed into the background in favour of other, more sales-oriented features in the development of the modern power saw.

The responsible authorities in Sweden, as in numerous other countries, are aware that prolonged occupational handling of power saws may involve the risk of injury to fingers and hands as a result of vibration, principally circulatory disorders (vasoconstriction). This is supported by experience from other occupational categories, chiefly in the mining industry, where vibrating tools and machines are handled.

Deep concern for the possible risks of injury has recently been expressed among forestry workers.

Only one major medical investigation of vibration injuries in forestry workers has been undertaken, and in no instance did this reveal any clinical symptoms of definite circulatory disorders in the fingers and hands. On the other hand, subjective symptoms of circulatory disorders and discomfort in hands and arms attributed to work with power saws were widely reported. In view of the growing use of power saws since this investigation was made in 1961—1962, the lack of correlation between the clinical results and the subjective symptoms reported by the forestry workers, and the incomplete state of medical knowledge on this particular point, there appears to be a good case for fresh medical studies of vibration injuries among forestry workers to be instituted as soon as possible, perhaps with different methods of examination and with a direct follow-up of persons with vibration injuries.

No technical study of the vibrations of power saws has hitherto been made in Sweden. A certain amount of experience is, however, available from other countries, although there has been no exhaustive scientific investigation of these problems.

The National Testing Institute for Agricultural Machinery, a government-operated organisation in Sweden which is responsible for the official testing of both agricultural and forestry equipment, has also tested power saws for many years. With reference to the load generated by the vibrations of power saws, a need has arisen for a method of measurement permitting objective comparisons to be made between the vibration levels of different power saws, and the original object of the present study was in fact to establish such a method of measurement on a scientific basis.

However, in view of the extensive public importance of these questions and the limited knowledge existing in this field, the scope of the investigation was greatly broadened. With the support of the National Testing Institute for Agricultural Machinery, it was possible to conduct the investigation on these broader lines.

The objects of the study were:

1. To establish clinically based criteria for the risk of incidence of vibration injuries in conjunction with work with power saws.
2. To make a scientific study and analysis of the vibrations of power saws from the engineering and physical standpoints.
3. To determine the causes of vibration in power saws.
4. To propose practicable measures designed to reduce the risks of injury.
5. To construct an objective and, as far as possible, simple method of determining the vibration levels of different power saws.
6. To examine power saws currently on sale in Sweden with reference to vibration.

1. Tolerance Limits of Vibration Effects on Fingers and Hands in Work with Power Saws

Why does the woodpecker never get a headache from the constant drumming of his beak? Many a forestry worker has probably pondered on this question on hearing the intensive drum-roll of a woodpecker during a break in his work with the power saw.

The question is pertinent. According to tape recordings made by the Royal Institute of Technology in Stockholm, birds of the family *Picidae* display an impressive tempo in their pecking. Thus, for example, the greater spotted woodpecker makes about 23 beak strokes per second, the lesser spotted woodpecker about 20, and the three-toed woodpecker about 14. An unmated woodpecker rattles off some 500—600 flourishes a day, while after mating the intensity falls off to 100—120 flourishes a day.

The reason why the woodpecker does not suffer from headaches is that it is specially equipped by nature to stand up to such extremely severe battering. Its beak is not rigidly joined to the frontal bone of the skull as in others birds, but is provided with a resilient pad that cushions the vibrations.

Compared to the woodpecker, man is poorly equipped to cope with vibrations. The ways in which vibrations of different kinds affect the human body have been the subject of exhaustive medical study (8, 10, 54). When it comes to the vibration tolerance of specific parts of the body such as fingers and hands, however, the medical literature is more vague and uncertain.

It is well known that the effect of prolonged vibration, especially on the hands and arms, can lead to discomfort and in certain cases to injuries of different kinds. These injuries are usually of a physiological nature and are restricted to the circulatory system and the peripheral nervous system. The principal symptoms are pain, numbness, cyanosis and abnormal temperature reactions (1, 15). In addition to these symptoms of vasoconstriction, deformation of the joints and bones of the hand has been noted in more severe cases (51).

The injuries in question consist of circulatory disorders in the fingers and hands, i.e. constriction of the fine blood vessels. These are symptoms of traumatic vasopastic disease, which in plain language means a disease arising from restricted flow of blood through contraction of the blood vessels caused by repeated mechanical shocks. The disease manifests itself in numb, white, cold fingers and loss of sensation. When the fingers are warmed, this is frequently accompanied by pain. The first attacks generally occur only at work, especially in cold weather, but once the disease is established, attacks can be brought on by any exposure to cold, often outside working hours. Even washing the hands in cold water may be enough to start an attack.

The injuries, then, are caused by certain vibrations and triggered by cold. The disease does in fact show a geographical distribution, having a definite correlation with temperature. Thus it occurs among miners in Scandinavia and North America but is very rare among miners in warmer regions (44, 51).

The symptoms in question do not seem to be produced by the effects of vibration alone, nor yet by chilling alone.

Individual predisposition to this type of vasoconstriction varies widely. Case histories, mainly from the mining industry, show that some workers experience no discomfort despite years of constant work with vibrating hand tools, while others show symptoms after only a few months of work. For the purpose of this investigation we shall hereafter discuss the effects on a statistical "normal person".

Medical knowledge is incomplete with regard to the level of vibration above which the risk of vibration injury is present; nor is adequate data available on the incidence of vibration injuries among forestry workers using power saws.

The following preliminary conclusions can be drawn on the basis of studies in other occupational fields made in Sweden and elsewhere as well as of medical studies of forestry workers mainly originating from Russia (1, 3, 6, 7, 19, 48, 49, 56, 57).

A risk of vibration injuries (vasoconstriction) occurring in the fingers arises on exposure to vibrations within a frequency range of 50 to 500 cycles per second (cps). Frequencies outside this range can be disregarded in the present instance. The risk of injury depends on the intensity of vibration, the duration of exposure, recuperation breaks, and the aggregate exposure time in months or years. Recuperation breaks may consist of actual rest or of other work not involving exposure to vibrations. Such a recuperation break should last about ten minutes (31, 56, 57).

Curves in Figs. 1 and 2 show the tolerance limits for work with a power saw. The frequency in cps is plotted on the horizontal axis and the amplitude in mm on the vertical axis.

Amplitude here refers to the vector value of the maximum vertical,

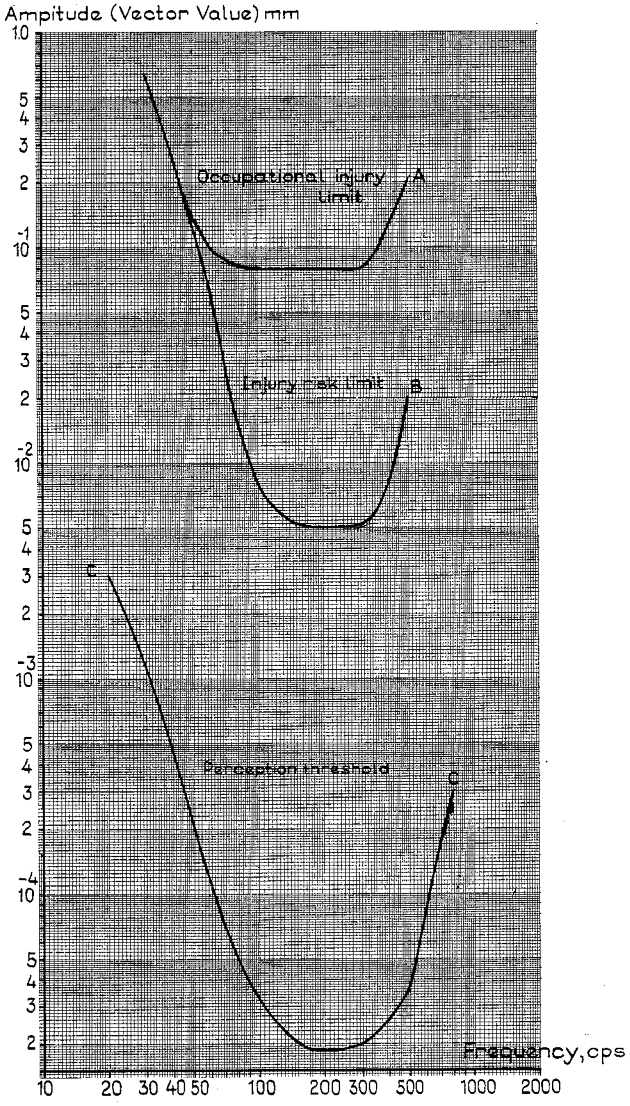

Fig. 1. Limits of tolerance for occurrence of vibration injury in work with power saws. Note the decisive influence of the time of exposure on the risk of injury.
A. Occupational injury limit
B. Injury risk limit
C. Perception threshold

horizontal and axial amplitudes measured in the front or rear handgrip (see also Chap. 6).

Curve C in Fig. 1 indicates the threshold value for perception in the fingers. Vibrations of lower amplitude than that represented by this curve are too weak to be felt.

Curve B indicates the limit of injury risk. The zone between curves C

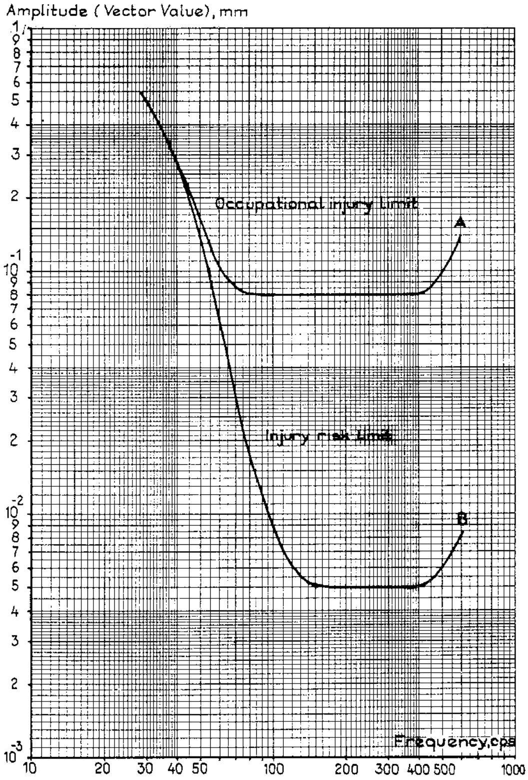

Fig. 2. Limits of tolerance for occurrence of vibration injury in work with power saws.
A. Occupational injury limit
B. Injury risk limit

and B is quite safe with regard to injury. Vibrations of higher amplitude than that shown by curve B involve a certain risk of injury, this risk being dependent on the time of exposure. Thus in the zone between curves B and A the risk of injury is present only in conjunction with continuous prolonged exposure, e.g. in assembly-line work without recuperation breaks in an industry where vibrating tools are used. This zone can thus be regarded as fairly irrelevant to the question of work with power saws.

Curve A shows the approximate injury limit for the occupational use of power saws. If the amplitude vector value (see Chap. 6) measured during cross-cutting (sawing of felled trees into logs) is higher than that given by curve A, i.e. greater than about 0.08 mm in the 50—500 cps (cycles per second) frequency range, there is a definite risk of eventual vibration injury. This applies, however, only in the case of occupational use of the power saw in modern, specialised logging operations with a high rate of production, prolonged daily use of the saw (in excess of 4 hours), the absence of the usual recuperation breaks provided by other phases of work, and the use of the power saw for cross-cutting, felling and limbing. This last operation (see Chap. 8) is accompanied by a sharp increase in vibration intensity and consequently by an increased risk of injury.

The same is true with power clearing saws. These are usually run at high speed, which produces very high relative amplitudes. Moreover, the utilisation factor per shift is high with little in the way of recuperation breaks.

If on the other hand the power saw is used only for felling and cross-cutting but not for limbing, so that the periods of exposure to vibration are brief and interspersed with frequent recuperation breaks for other work such as cross-cut marking, end marking and stacking of the timber, the risk of injury is negligible even if the vibration intensity lies above the injury limit curve A.

Work with a vibrating power saw may also cause fatigue and discomfort in the hand and arm muscles owing to the static load imposed on these muscles when they are tensed to withstand the vibration shocks (36, 37).

An appreciation of the physiological load can be obtained through measurement of the force, hereinafter called the vibration force, acting between the saw handgrip and the hand.

This vibration force is directly dependent on the intensity of vibrations in the handgrips and on the weight of the power saw. The vibration force increases with rising vibration intensity and saw weight. This means for example that a heavy power saw with a low vibration intensity may impose the same physiological load (expressed in vibration force) as a light saw with a high vibration intensity. When the vibration force is measured in kiloponds (kp) at the front handgrip of the saw, the physiological load can be measured directly from Table 1 (18, 27, 30).

Table 1. Threshold values of physiological load through effects of vibration on hands and arms during work with a powersaw

Vibration force, kp	Subjective effects	Effects on work performance
1	Noticeable, not uncomfortable	No impairment
1—3	Noticeable, but scarcely uncomfortable	No impairment
3—5	Quite noticeable, prolonged exposure uncomfortable but tolerable	Very slight impairment
5—10	Distinctly noticeable, unpleasant after an hour or so; still tolerable	Performance impaired but work still possible
10—15	Uncomfortable, barely tolerable after more than ten minutes' exposure	Performance heavily impaired; more than 10 minutes' work without a break inadvisable
15—30	Even brief exposure highly uncomfortable	Work difficult to perform
over 30	Extremely uncomfortable	Work impossible

2. The Modern Power Saw

A. General Technical Data

The power source of the modern motor-saw is a one-cylinder, two-stroke petrol engine. The saw chain is driven by the sprocket, which is usually connected direct to the motor crankshaft through a clutch device, in other words a direct drive system. Ignition current is obtained from a magneto with magnets mounted on a flywheel at one end of the crankshaft. Power saws have become much lighter in weight since they were first introduced in Sweden on a large scale at the beginning of the 1950s. Figure 3 (partly derived from lit. ref. No. 11) shows how the average weight of power saws on the Swedish market has fallen from about 18 kg in 1952 to 9.5 kg in 1965—1966. Over the same period the weight of the lightest model available has been reduced from about 12 kg to 6.5 kg. In order to maintain adequate motor and chain power despite this significant reduction in service weight, manufacturers of power saws have been compelled to raise the volumetric efficiency, i.e. the number of brake horse power per litre of rated stroke volume. The stroke volume in modern saws is usually 55—110 cc and the braked motor power on the crankshaft is 2.5—5 hp. The higher volumetric efficiency has been achieved partly by improvement of the fuel and ignition system, but mainly through increased motor speed. Figure 4 traces the development of a Swedish-made power saw from 1952 to 1965. Over this period the service weight has been reduced from 20.0 to 9.6 kg, while at the same time the rated volumetric efficiency has risen from 30 to 64 hp/litre, and the motor speed at peak power has been increased from 4,500 to 7,300 rpm. The maximum power delivered to the saw chain has been boosted from 2.4 hp at 4,800 rpm to 3.4 hp at 7,100 rpm. These facts have an essential bearing on power saw vibrations.

B. Utilising Factor

In 1965, nearly 40,000 power saws were sold in Sweden (see Fig. 5). A large proportion of these were built within the country by five domestic power-saw manufacturers. Thirteen foreign makes of power saws are currently on sale in Sweden through agents representing 7 American manufacturers, 2 Canadian, 2 German, 1 Finnish and 1 Norwegian. Most manufacturers and agents market several models of the same brand. Consequently, there are at present some 35 models of power saws on the Swedish market. Selling prices

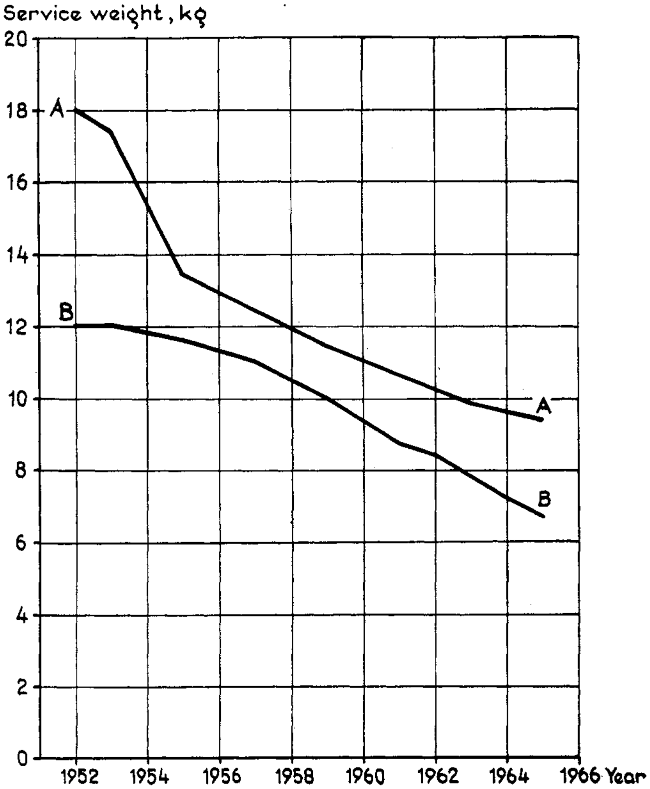

Fig. 3. Service weight of power saws in Sweden, 1952—1965.
A. Average weight
B. Weight of lightest saw

range from 900 to 1,400 Swedish kronor, which makes the annual total investment in power saws over 40 million kronor.

Nearly all forestry workers in Sweden nowadays use power saws in logging operations. The daily utilisation time at the end of the 1950s was 1 ½—2 hours. The greatly increased utilisation of power saws, principally for limbing, together with more highly organised working methods and a higher tempo of work, has led to an extension of the daily utilisation time, which now frequently amounts to 4—6 hours. In cutting timber by the assortment method, where the power saw is used for felling and cross-cutting but not for limbing, the utilisation factor of the power saw comes to about 30 per cent of the operational time, whereas in felling work, where the power saw is used for both felling and limbing, felling occupies about 15 per cent of the operational time and limbing 60—70 per cent, which puts the total utilisation factor of the power saw between 75 and 80 per cent of the operational time (2, 5, 51, 55).

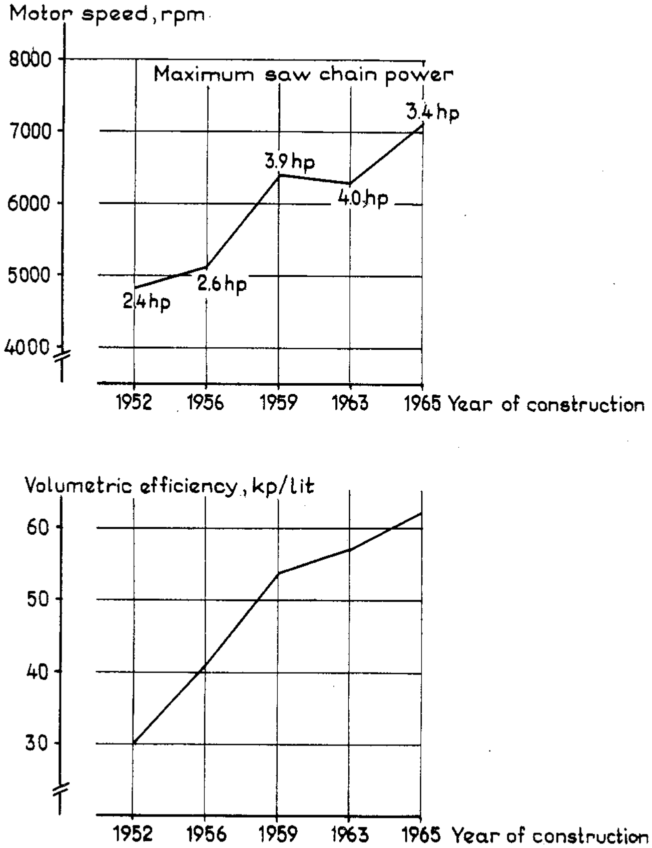

Fig. 4. Changes in nominal motor volume rating and maximum saw chain power in a Swedish-made saw from 1952 to 1965.

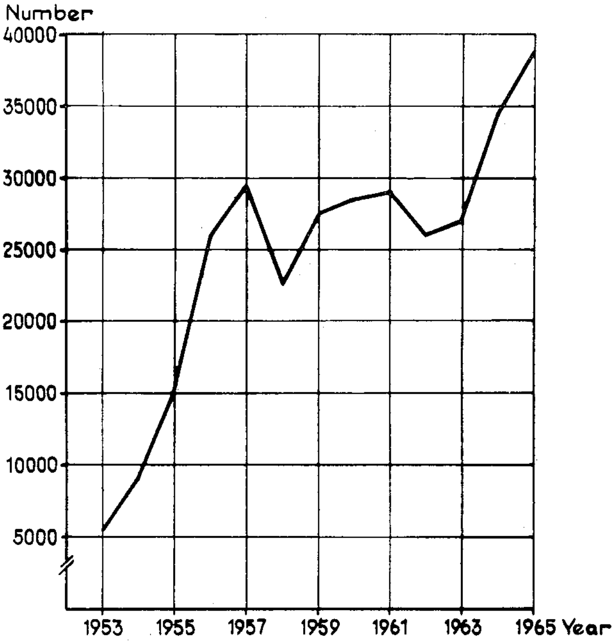

Fig. 5. Number of power saws sold in Sweden, 1953—1965.

3. Causes of Vibrations in Power Saws

Vibrations in a power saw are caused by the moving parts of the motor and the saw chain. The vibration intensity in the saw handgrips also depends on the design and method of attachment of the latter.

The moving parts of the motor describe both reciprocating and rotary motions.

The rotating parts of the motor consist of part of the connecting rod, the whole of the crankshaft, the flywheel mounted on the crankshaft, the clutch, and the sprocket. A well-balanced assembly of rotating parts produces only very small free forces.

The reciprocating parts of the motor consist of the piston and part of the connecting rod. The weight of these parts gives rise to periodical free forces when the piston and part of the connecting rod are braked, change direction and are accelerated on reaching each end position. These forces are proportional to the mass of the reciprocating parts and to the square of the motor speed. The forces cause vibrations which are transmitted to the body of the saw through the frame bearings.

The vibrations caused by the reciprocating parts of the motor cannot be compensated by balance weights on the crank shaft in the same way as can the vibrations produced by the rotating parts. The direction of these vibrations can, however, be influenced and determined by the size of the balance weights. The latter give rise to forces which, in relation to the axis of the cylinder, act mainly at right angles to the vibrations caused by the piston. Thus a sufficiently large increase in the size of the balance weights can convert the original motor vibrations in line with the cylinder axis to vibrations in a different direction, e.g. at right angles to the cylinder axis. Consequently, we can see that it makes no difference to the direction and magnitude of the vibrations that occur whether the power saw is designed with a vertical, horizontal or diagonal cylinder.

The reciprocating motion of the piston in a two-stroke motor is produced by two phases of work, the compression and expansion strokes. In the expansion stroke, a torque is imparted to the crankshaft through the big-end bearing. In the compression stroke, on the other hand, the motion of the piston, and consequently that of the crankshaft, is retarded. Thus for every full turn of the crankshaft (motor revolution), a rhythmic energy impulse (torque) is delivered to the crankshaft. This intermittent supply of energy

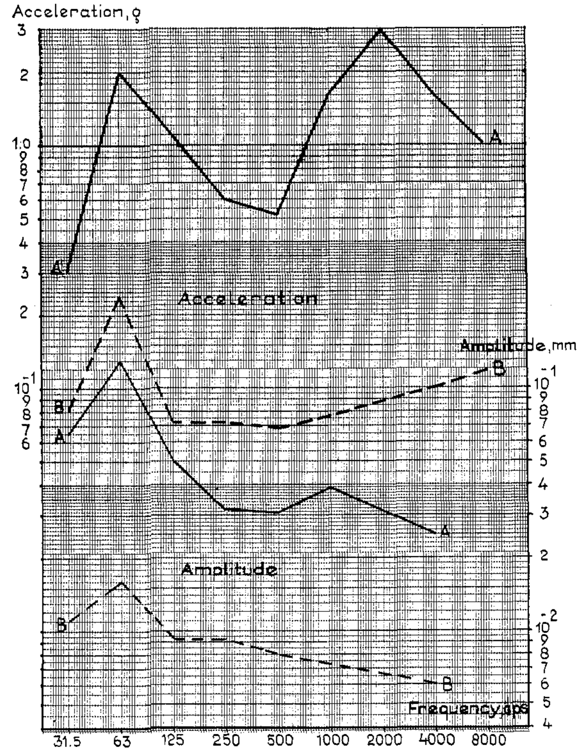

Fig. 6. Effect of saw chain on intensity of vibration, measured axially.
No load, motor speed 4,200 rpm
A. With chain
B. Without chain

is smoothed out by the flywheel but cannot be entirely compensated. A torque is therefore imparted through the frame bearings to the body of the saw and attempts to twist the latter back and forth about an imaginary axis running through the centre of gravity of the saw body and parallel to the crankshaft. This process results in vibrations, the intensity of which rises with increasing stroke volume and motor speed.

In addition to the design and attachment of the handles (which are dealt with later in Chap. 8), the total wegtht of the power saw has a decisive influence on the character of the vibrations to which the operator of the saw is subjected. According to the rules of classical mechanics, a lightweight power saw will give a larger vibration amplitude than a heavier saw at the same motor speed if both saws are equipped with the same motor and are otherwise identical in design.

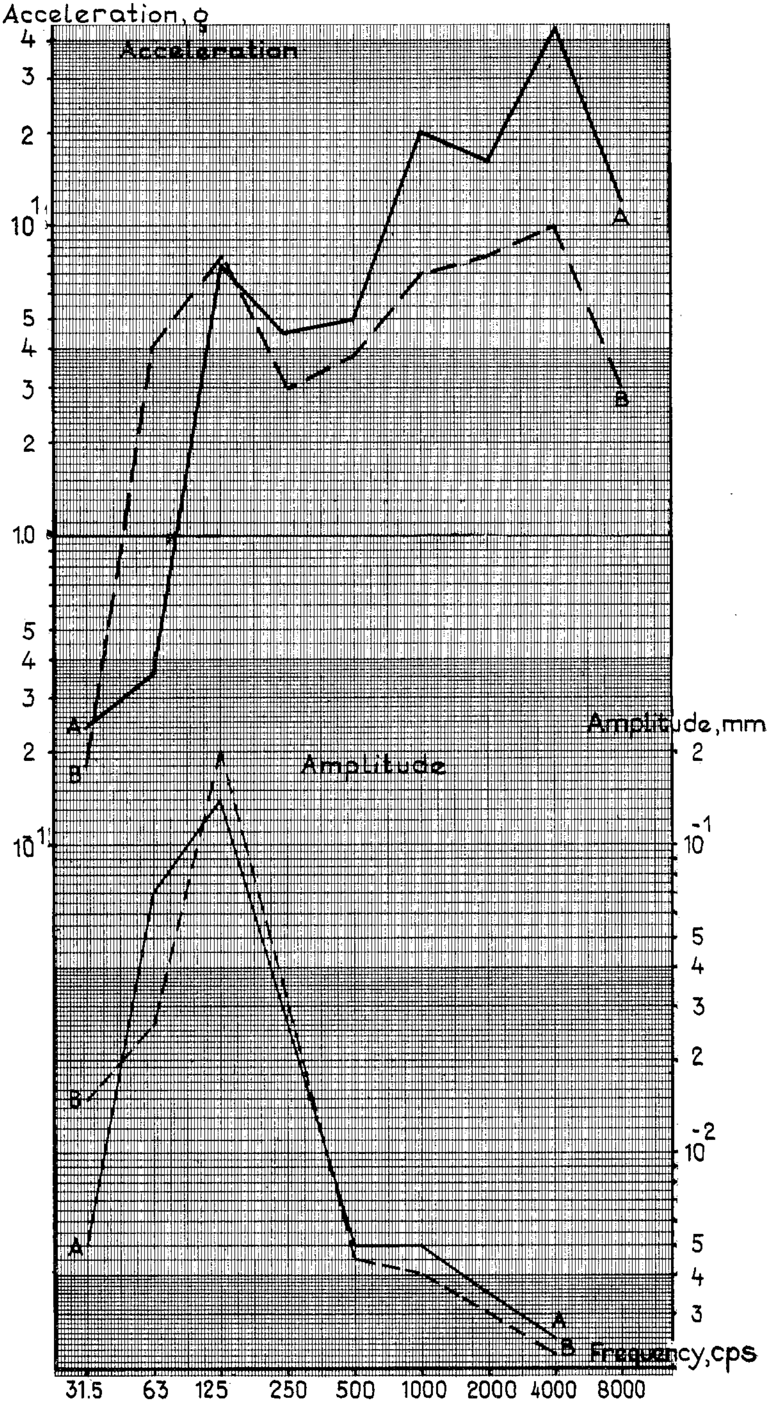

Fig. 7. Effect of saw chain on intensity of vibration, measured vertically. No load, motor speed 6,000 rpm
A. With chain
B. Without chain

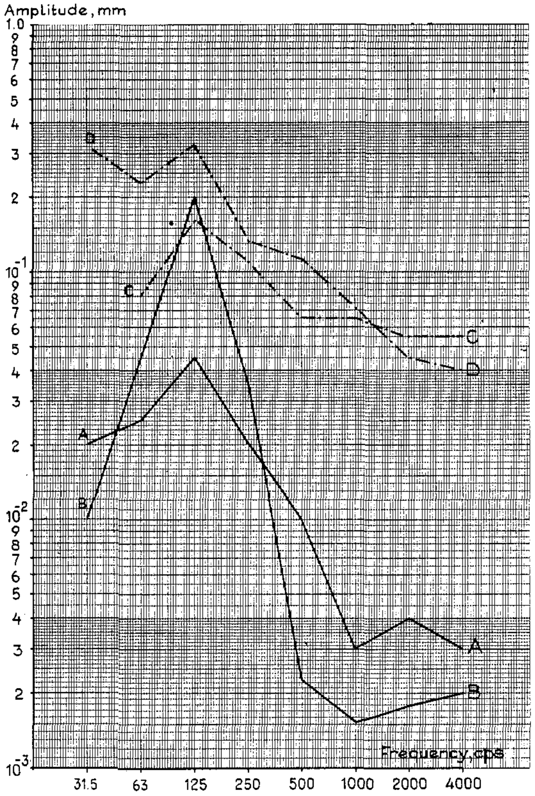

Fig. 8. Intensity of vibration in front handgrip during cross-cutting and without load at same motor speed, 7,200 rpm.
A. Vertical measurement, cross-cutting
B. Vertical measurement, no load
C. Axial measurement, cross-cutting
D. Axial measurement, no load

The dilemma of the power-saw manufacturers in designing a modern power saw with minimum vibrations is thus that of adapting the motor speed and the weight of the saw to each other for a given stroke volume.

The movement of the saw chain causes the power saw to vibrate, principally in an axial direction. Figure 6 shows examples of how the amplitude and acceleration in the axial direction are considerably greater when the saw is run with the chain on than with the chain off. The maximum amplitude with the chain is 0.13 mm as against 0.015 mm without the chain at a motor speed of 4,200 rpm, the corresponding accelerations being 22 and 0.23 g respectively.

The saw chain also causes vertical and horizontal vibrations, which however are considerably less intense than those in the axial direction. Figure 7 shows examples of how the movement of the saw chain gives rise to a sharp increase of acceleration in the vertical direction in the higher frequency range. In the frequency range below 300 cps, the saw chain has no appreciable effect on the magnitude of the acceleration, while the amplitude is practically unaffected by chain movement. The same applies to the effect of the saw chain on vibrations in the horizontal direction. The motor speed is here 6,000 rpm.

The vibration intensity seems to be less with small chain links than with larger ones.

When the power saw is in use the vibration intensity is affected by the nature of the operation being performed (cross-cutting, felling or limbing), the material properties of the timber (type and hardness) and the condition of the chain, sprocket and saw blade.

In cross-cutting and felling the level of vibration is about the same. In limbing, on the other hand, the vibration intensity is generally very high owing to the virtual absence of damping.

Sawing of hard wood, e.g. deciduous wood or frozen conifer wood, involves some increase in vibration intensity due to the higher motor speed.

A badly filed chain or a worn sprocket and saw blade will cause a considerable increase in vibration intensity.

The vibrations are considerably damped, when the saw is in use, as they are partly absorbed by the log (Fig. 8).

4. Vibrations in Power Saws from the Physical Standpoint

Vibrations are caused by three primary functions of the power saw, namely the reciprocating motions of the motor, the rotary motions of the motor, and the saw chain. These vibrations can be expressed in equation form according to Fourier's series. They are transmitted to the body of the saw and thence to the handgrips. In the course of this transmission the

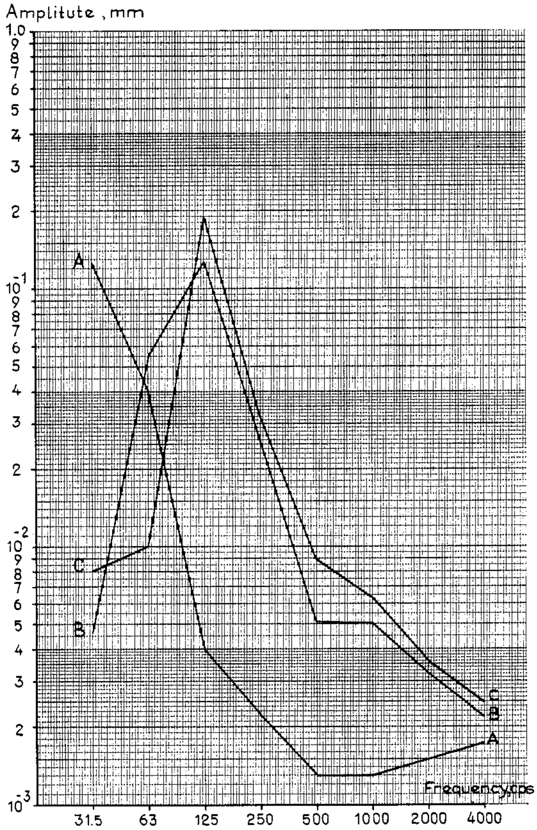

Fig. 9. Frequency analysis of vibration intensity in a power saw, measured vertically.
A. Motor speed 2,000 rpm
B. Motor speed 6,000 rpm
C. Motor speed 8,000 rpm

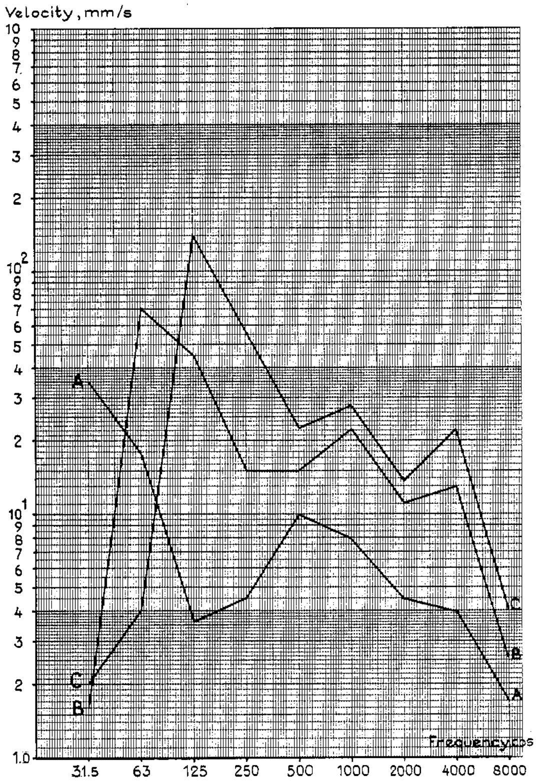

Fig. 10. Frequency analysis of vibration intensity expressed as velocity, mm/sec. Point of measurement, front handgrip; direction of measurement vertical; no load.
A. Motor speed 2,000 rpm
B. Motor speed 6,000 rpm
C. Motor speed 8,000 rpm

vibrations are altered by the damping proportionality factors and the spring constants, the magnitude of which is determined by the design of the powersaw. The resulting vibrations in the saw handgrips mainly take the form of forced compound oscillations; these can likewise be expressed in the form of equations and their magnitudes numerically computed.

The magnitude of the vibration force transmitted from the power saw to its operator can be computed when the rate of oscillation in the handgrips and the impedances of the human body and the power saw are known.

The frequency at which the maximum vibration amplitude occurs is directly dependent upon the motor speed of the saw (Figs. 9 and 10). Since the motor speed varies approximately between 2,000 and 10,000 rpm (i.e.

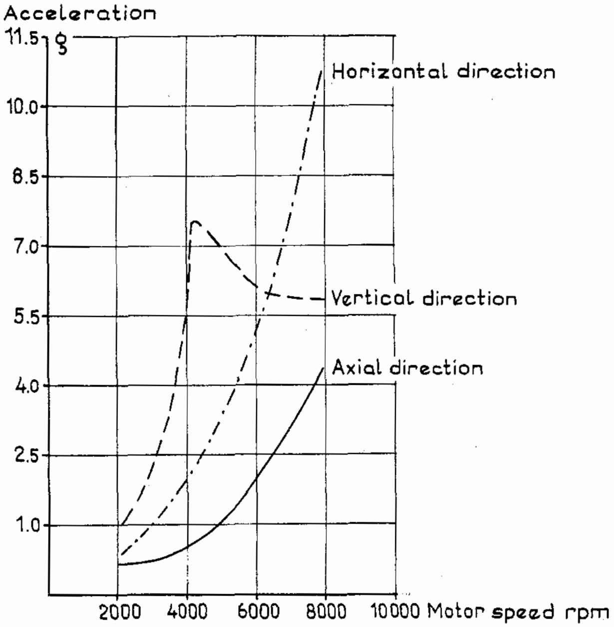

Fig. 11. Magnitude of acceleration in different measured directions in a power saw at increasing motor speed, measured in the frequency range 0—300 cps.

35—165 cps), this means that the maximum vibration amplitude will always occur within the zone of risk of vibration injury.

Within this zone, 50—500 cps, the vibrations consist principally of simple harmonic oscillations with a sine wave-form. The relationship between acceleration, amplitude and frequency given in the following formula can therefore be computed as a check on instrument readings:

$a = \omega^2 A$ or $a = (2\pi f)^2 A$

where

a = acceleration in mm/sec^2
ω = angular velocity
f = frequency in cps
A = amplitude in mm

This also means that the example of acceleration magnitude in different measured directions at rising motor speed given in Fig. 11 likewise gives a picture of the rate of amplitude increase with rising motor speed.

At some speeds, which are different for different saws, the power saw may show a natural oscillation, the intensity and direction of this are conditioned by the internal balancing and the positioning of the hanpgrips. Resonance,

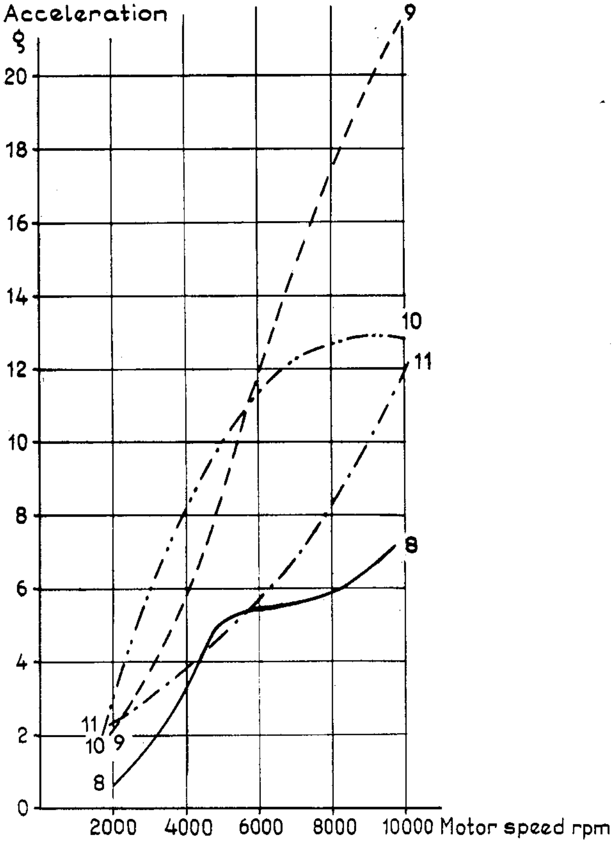

Fig. 12. Acceleration vector value for four different power saws at increasing motor speeds, measured in the frequency range 0—300 cps.

i.e. magnified amplitudes, may often occur in these circumstances because the natural frequency of the saw handle is the same as the oscillation frequency of the body of the saw. In such cases a further increase in the motor speed does not intensify, but rather diminishes the vibrations in the particular direction of measurement.

The vibration intensity expressed as the vector value, however, always rises sharply with increasing motor speed (Fig. 12).

5. Vibration Force from the Theoretical Standpoint

From the point of view of oscillation physics, the hands and arms of a human being can be regarded as a system of masses and springs.

If an oscillating system acts upon a system of masses and springs, the latter is brought into a state of sympathetic oscillation by the transmission of a force whose magnitude is determined by the mechanical properties of both systems. The system acted upon may in its turn influence the primary oscillating system. After a transition period of greater or lesser duration, a steady state is reached and the transmitted force can then be measured.

When a man operates a vibrating power saw, the phenomena occurring in conjunction with the contact between hands and power-saw handgrips can be regarded from the point of view of physics as a contact between a primary oscillating system (the handles) and a system of masses and springs (the hands and arms).

Impedance

The phenomena arising out of contact between a physical oscillation and a mechanical oscillation system can suitably be treated by the introduction of the concept of impedance (7, 18).

In *alternating current theory,* the relationship between the effective values of total voltage drop and amperage in a coil with alternating current flowing through it is formulated as follows:

$$U = I\sqrt{R^2 + (2\pi f L)^2}$$

where

U = AC voltage
I = AC amperage
f = AC frequency
R = conductor resistance
L = conductor inductance (coefficient of self-induction)
$2\pi f L = \omega L$ is denoted by X where
X = conductor reactance (inductive resistance)
$\sqrt{R^2 + (2\pi f L)^2} = \sqrt{R^2 + X^2}$ is denoted by Z where
Z = *conductor impedance* (*apparent resistance*)

The relationship between voltage drop and amperage can thus be written as

$$U = IZ \text{ (Ohm's law for alternating current),}$$

whence

$$\text{impedance } Z = \frac{U}{T}$$

In *mechanics* a mechanical impedance Z is defined by analogy with the above as

$$Z = \frac{F}{v}$$

where

F = the transmitted vibration force in kp and
v = velocity in m/sec.

The impedance is thus expressed in terms of $\frac{\text{kp} \times \text{sec}}{m}$

With regard to its nature, impedance can be considered as a property of materials. At the point of resonance, impedance attains its maximum value, and the vibration force is likewise at its maximum at this point.

Vibration force $F = vZ$

The concept of impedance as defined here can also be applied to the human body, the latter being regarded as an oscillating physical system of masses and springs. The magnitude of the impedance is then affected by the nature of the work, the attitude of the body and the point of application of the vibration force.

If the impedance of the power saw is Z_s and the impedance of the man in the hand holding the saw is Z_m, we obtain a total impedance Z_g.

$$Z_g = Z_s + Z_m$$

If the vibration force is considered as a periodic oscillatory motion of wave amplitude A, we obtain (according to the definition of velocity)

$$A = \int v \, \text{dt} \text{ or } \left(\text{since } Z_g = \frac{F}{v}\right)$$

$$A = \int \frac{F}{Z_g} \, \text{dt}$$

If we call the period T, we obtain:

$$A = \int_{0}^{T/4} \frac{F}{Z_m + Z_s} \, \mathrm{dt} = \frac{\mathrm{F}}{Z_m + Z_s} \cdot \frac{T}{4}$$

$$\text{(and since } T = \frac{2\pi}{\omega}$$

$$A = \frac{F}{Z_m + Z_s} \cdot \frac{\pi}{2\omega}$$

If the power saw is considered as a pure mass (m_s), its mechanical impedance can be defined as

$$Z_s = \frac{F}{v}$$

or $Z_s = \dfrac{m_s \cdot a}{v}$ which may be developed to

$$Z_s = m_s \frac{\omega^2 \, A \text{ sine } (\omega t + \pi)}{\omega A \text{ sine } \left(\omega t + \frac{\pi}{2}\right)} = m_s \frac{\omega}{\frac{\pi}{2}} = m_s \frac{2\omega}{\pi}$$

and since $\omega = 2\pi f$ we obtain

$$Z_s = m_s \frac{2 \cdot 2\pi f}{\pi} = 4 \, \mathrm{fm}_s$$

Kuhn 1953 and Scheffler 1954, on the basis of studies of work with pneumatically powered tools, put the impedance of the human hand-arm system at frequencies in the region of 60 cps at about

$$Z_m = 20 \frac{\mathrm{kp} \times \mathrm{sec}}{m}$$

The total impedance between the power-saw handles and the hand-arm system thus comes to about

$$Z_g = 4 f m_s + 20$$

It should be stressed that this value is only approximate and refers to sine-wave oscillations.

The value of the total impedance can be used for numerical computation of the vibration force generated and as a rough check on the instrument readings of vibration force.

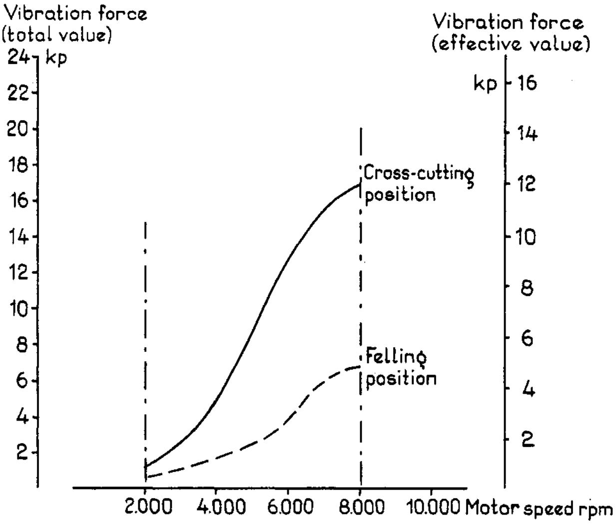

Fig. 13. Increase in vibration intensity at increasing motor speed.

Computation example:

$f = 63$ cps, weight of saw $= 11.5$ kg, speed of saw motor $= 6{,}000$ rpm
Thus

$$Z_g = 4 \times 63 \times 11.5 + 20 = 2{,}918 \ \frac{\text{kp sec}}{m}$$

the velocity $v = 70$ mm/sec $= 0.07$ m/sec

The magnitude of the vibration force expressed in newtons is then obtained according to the equation $F = vZ$ as

$$F = 0.07 \times 2{,}918 = 204 \ N$$

or, expressed in kp,

$$F = 21 \text{ kp}.$$

The relationship between the value of the vibration force computed in this way and the instrument reading value is $2\sqrt{2}$, as the effective value has been given by instrument readings.

$$\frac{21}{2\sqrt{2}} = 7.3 \text{ kp}$$

It will be seen from Fig. 13 that the measured vibration force at the motor speed in question is about 9 kp. The discrepancy between the computed value (7.3 kp) and the measured value (9 kp) is due partly to the fact that the oscillatory motion does not have the form of a pure sine wave and partly to the fact that the frequency used, 63 cps, has not been exactly determined but simply represents the mean frequency value of the octave band. Thus the frequency in actual fact could equally well be 75 cps, in which case the computed and measured values of the vibration force would be in full agreement.

6. Vector Value of Vibration Intensity — Definition and Motivation

In this study the intensity of vibration in the handles of power saws has been measured in three different directions, or axes. The designations of these measurement axes are referred to the power saw when the latter is held in the cross-cutting position.

Definition of Measurement Axes

The power saw is imagined to occupy a right-angled spatial co-ordinate system (Fig. 14).

Axial axis of measurement: Parallel to a line through the suspension points of the crankshaft (frame bearings), i.e. the z axis of the co-ordinate system.

Horizontal axis of measurement: Parallel to a line drawn from the sprocket to the far end of the saw blade at right angles to the axial axis of measurement, i.e. the x axis of the co-ordinate system.

Vertical axis of measurement: Parallel to an imaginary line at right angles to both the axial and horizontal axes of measurement, i.e. the y axis of the co-ordinate system.

From the point of view of physics the vibrations can be regarded as mechanical oscillations. The Anglo-American literature uses certain terms in this connection as shown in Fig. 15. Peak-to-peak corresponds to displacement, i.e. amplitude. In Swedish and other literature, however, the term amplitude is used to refer to the peak value, and this definition of amplitude is the one used here.

The average is $= \frac{\pi}{2} \times$ peak, and RMS (Root-Mean-Square) is defined as the effective value, i.e. $\frac{1}{\sqrt{2}} \times \text{peak} = 0.707 \times \text{peak}$.

Measurement with instruments usually yields the effective value direct, and such has in fact been the case with the instruments used in the present study.

The following conclusions can be drawn from the evaluated results of measurements of the magnitude of acceleration and amplitude along the

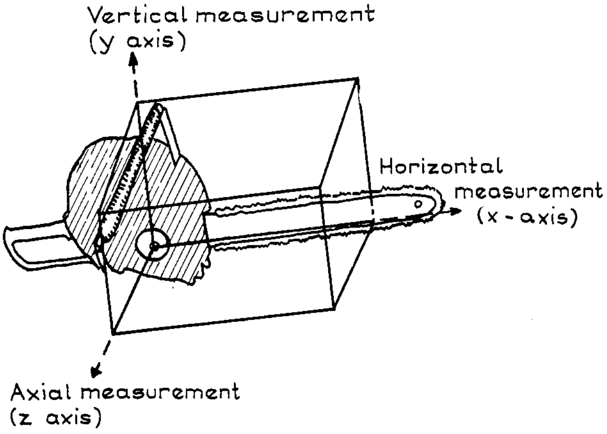

Fig. 14. Axial, horizontal and vertical measurement.

different axes of measurement (cf. Fig. 11) over a range of motor speeds rising from idling to racing speed:

Owing to the widely varying vibration spectra displayed by the saws which were studied, with variations between individual saws as well as in the magnitude of the acceleration (and consequently also of the amplitude, since the oscillation is of sine-wave type) along the different axes of measurement, it is evidently insufficient for an analysis of power saw vibrations to make measurements of vibration intensity along one axis only. This, however, is what has been done in all measurements of vibration undertaken in other countries. If, for example, the vibration intensity is recorded on the vertical axis only, which is the most usual practice, this may give an entirely

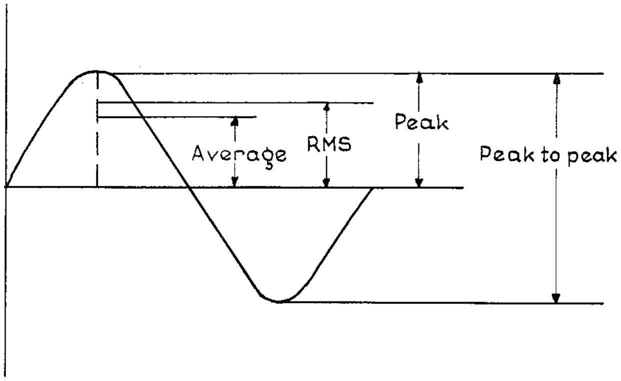

Fig. 15. Peak-to-peak. Amplitude and its effective value.

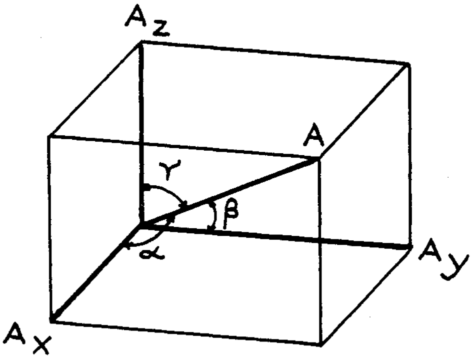

Fig. 16. Vector value (A) and its components (A_x, A_y and A_z).

misleading picture of the total vibration load imposed by the power saw in question.

Since it is quite possible, both in theory and in practice, to influence the direction of vibrations by the internal balancing of the saw motor in such a way that these vibrations exert most of their effect in one specific direction, e.g. horizontally, it is clearly essential to a complete analysis of the vibrations of a power saw that such an analysis should be based on measurements of vibration intensity in all directions, i.e. along the axial, vertical and horizontal axes.

The literature contains no indication as to whether differently oriented vibrations involve different degrees of risk of injury. However, after discussing this point with prominent Swedish and foreign medical men, the author has come to the conclusion that from the medical standpoint there is no reason to suppose that there is any difference with regard to injurious effects on fingers and hands.

On the other hand it is reasonable to assume that a power saw which vibrates intensely in all three axes of measurement is more likely to cause injury than a power saw which vibrates intensely in one axis of measurement only and only slightly in the other two axes.

Therefore, in order to establish a parameter for the total vibration load and consequently the actual risk of injury involved in the use of power saws, the *vector value* of the amplitude in the axial, vertical and horizontal axes of measurement has been computed for the purposes of the present study.

The vector value has been computed as follows:

The three measured amplitude values (effective value) can be considered as co-ordinates or cartesian components in a spatial co-ordinate system (see Fig. 16).

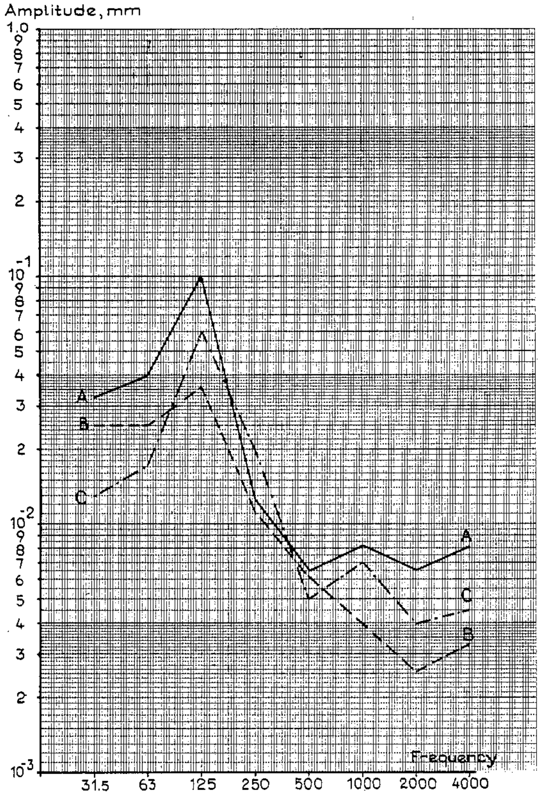

Fig. 17. Frequency analysis of vibration intensity measured vertically (A), horizontally (B) and axially (C). Motor speed 7,500 rpm. Point of measurement, front hand-grip. Cross-cutting.

A_z in the figure denotes for example the measured vertical amplitude, A_y the horizontal amplitude and A_x the axial amplitude.

The required total vibration load is then given in this case by the vector A.

Since the three amplitude values are measured at right angles to each other, the vector A can be regarded as the diagonal of a right-angled parallelepiped bounded by the three cartesian components A_x, A_y and A_x in Fig. 16.

According to the laws of stereometry we then obtain

$$|A| = \sqrt{A_z^2 + A_y^2 + A_x^2}$$

where

$|A|$ denotes the absolute quantity of the vector.

The direction of the vector can also be computed as follows:

$$\cos \alpha = \frac{A_x}{|A|} \quad \cos \beta = \frac{A_y}{|A|} \quad \cos \gamma = \frac{A_z}{|A|}$$

Computation example: (see Fig. 17)

At a frequency of 125 cps the vertical amplitude during cross-cutting is 0.10 mm, the horizontal amplitude 0.036 mm and the axial amplitude 0.06 mm.

The vector value thus becomes

$$\sqrt{0.1^2+0.036^2+0.06^2}=0.12 \text{ mm}$$

$$\cos\alpha=\frac{0.06}{0.12}=60.0^\circ$$

$$\cos\beta=\frac{0.036}{0.12}=72.5^\circ$$

$$\cos\gamma=\frac{0.10}{0.12}=33.6^\circ$$

Computing the absolute quantity of the vector in this way from the measured values of the acceleration or amplitude along three axes gives a measure of the total vibration load to which fingers and hands are subjected during work with a power saw.

Since, according to what has already been noted, the direction of the vibrations is of minor importance with regard to the risk of injury, only the absolute value of the vibrations, and not their direction, has been computed in the present study.

7. Power Saws in Sweden Studied from the Standpoint of Injury Risk

The vibration levels of a score or so of power saws in general use in Sweden were measured, and the findings were as follows:

The risk of injury arising from the vibrations of power saws is just as grave as that caused by the noise they make. The noise level of all power saws on sale in Sweden has been shown by earlier measurements to exceed the injury risk level established on medical grounds. There is therefore a definite risk of eventual deafness.

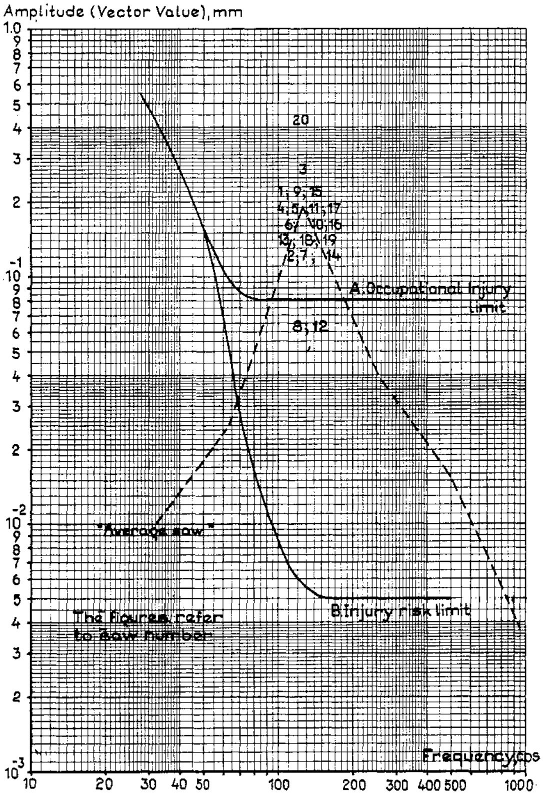

Fig. 18. Frequency analysis of "average saw" during cross-cutting in relation to established injury risk limits.

With regard to vibration, practically all the power saws now on the Swedish market have a vibration level in excess of the established injury limit (Fig. 18). The difference in maximum amplitude between different saws is very slight. Professional use of present-day power saws in modern logging operations where the tempo is rapid, the daily utilisation time long and recuperation breaks few and far between, together with the regular use of the power saw for limbing as well, would appear to involve appreciable risk of the eventual onset of vibration injury (vasoconstriction) in the fingers.

Moreover, the vibrations impose a physiological load on the human frame which tends to impair, and in many cases heavily impair, work performance (cf. Table 1).

8. Measures Designed to Reduce Risk of Injury

The alterations that can be effected with a view to reducing the risks of injury can be classified under three main heads:

A. Design of power saw
B. Design and attachment of handles
C. Handling technique and external factors
(17, 21, 24, 30, 36, 39, 44, 51, 57).

8 A. Design of Power Saw

The manufacture of heavier saws with lower motor ratings would reduce the vibration level, but it would be quite unrealistic to recommend this. The current trend towards saws of lower weight with undiminished cutting capacity, which is a welcome one from the forestry worker's point of view, presents the designers of power saws with difficult problems, but these problems do not by any means appear to be insoluble. It should be possible to reduce the vibration level, for example, by improved balancing of the motor and by improvements to the saw chains designed to increase the proportion of the braked power on the crankshaft accounted for by the chain.

The use of a two-cylinder motor or the provision of a counter-piston whose motion would neutralise the vibrations caused by the working piston would bring about an appreciable reduction in the total vibration load. Saw No. 8 features a counter-piston in its design, and the vibrations produced by this saw are indeed well below the established injury limit despite its relatively high motor rating and normal weight (Fig. 18).

Power sources other than the ordinary two-stroke engine, e.g. the Wankel engine, gas turbines, high-pressure water jets or electronic beams of the laser type, have probably some way to go before being practical for use in forest operations, and are thus for the time being of purely academic interest.

Electrically powered power saws with low vibration and noise levels have been used with some success in Russia. The practical problems of electricity supply are however great, and the use of such saws is therefore confined to central depots for cross-cutting and limbing. Since both these operations are more conveniently carried out with other methods at a central depot, the trend in Russia is towards diminished use of electric power saws. The introduction of such saws in Swedish forest operations cannot be adjudged realistic.

In view of the high degree of engineering skill evinced by power-saw designers in the development of the modern power saw, there are good grounds to suppose that these same designers would be capable of putting power saws with vibration and noise levels low enough to preclude risk of injury on the Swedish market within a short time, at unchanged prices and with unchanged low weight and high cutting capacity, if impelled to do so either by fiat of the responsible authorities or by the force of public opinion among forestry workers.

It should be emphasised that saw No. 12, the vibration level of which according to Fig. 18 is well below the injury limit, is an ordinary mass-produced modern power saw powered by a conventional one-cylinder two-stroke motor with a rating of about three horsepower at 7,000 rpm and a weight of about 9 kg.

8 B. Design and Attachment of Handles

With regard to the optimum design and attachment of the handles, there are several measures that could be put into effect at once; the problems in this connection are more easily solved than those relating to other features of power saw design.

In Russia, a great deal of attention has been devoted to the design of saw handgrips. By raising the front handgrip 450 mm and providing a spring shock-absorbing device, the Russians have succeeded in reducing the maximum measured vertical amplitude of vibration in the Drusba 60 saw from 0.6 to 0.08 mm (motor rating 3.5 hp at 5,300 rpm, weight 11.3 kg). This type of saw is used in Russia principally for felling.

Measurements made by the present author have revealed that such a simple adjustment as raising the front handgrip brings about a considerable reduction in vibration intensity. The front handgrip, weighing 150 grammes, of a power saw weighing 7.5 kg and with a rating of 2.6 hp at 6,000 rpm was replaced by a tubular handgrip weighing 340 g but otherwise of exactly the same appearance and fastened in exactly the same way to the body of the saw. These two handgrips, designated Original and Handgrip I respectively, proved on measurement to give the same vibration readings. Handgrip I was then replaced by another (Handgrip II) of the same material but with the grip raised 150 mm and with the weight increased to 515 grammes. The results of the vibration measurements are set out in Table 2.

Table 2.

	Maximum intensity of vibration (at 125 cps)							
	Axis of measurement							
	Vertical		Horizontal		Axial		Vector value	
	Ampl. mm	Acc. g	Ampl. mm	Acc. g	Ampl. mm	Acc. g	Ampl. mm	Acc. g
Unloaded saw								
Motor speed 7,300 rpm								
Original and Handgrip I	0.18	13.5	0.22	16.5	0.09	6.0	0.30	22.5
Handgrip II	0.02	2.5	0.08	5.5	0.02	0.04	0.09	6.0
Motor speed 9,200 rpm								
Original and Handgrip I	0.27	27.0	0.15	15.0	0.32	8.5	0.43	32.0
Handgrip II	0.06	6.0	0.08	7.0	0.01	6.5	0.10	11.5

The table demonstrates that the simple step of making the front handgrip 150 mm higher and 175 g heavier resulted in a considerable reduction of vibration intensity in the handle along all the axes of measurement. The vector value of the amplitude at cross-cutting speed was cut from 0.30 to 0.09 mm.

This sharp reduction in vibration seems to be due partly to the greater weight of the new handle, and partly (and indeed mainly) to the longer leverage obtained from the point of measurement (the handgrip of the saw handle to the centre of gravity of the saw body.

From this simple investigation, which could not be pursued further owing to lack of time, one can draw the conclusion that the design of the saw handle may have a decisive influence on the extent of the vibrations. There would therefore seem to be a good case for continued investigations of the optimum design of the saw handles from the point of view of vibration. This should not involve any serious problems of design engineering as such.

The influence of handle design on vibration intensity is also indicated by the relatively large differences usually noted between the vibrations in the front and rear handgrips of the same saw.

Separate measurements of vibration in the body and handgrips of a number of different saws (details not given here) have shown that the vibration intensity in the handgrip is in some cases higher and in some cases lower that that in the body of the saw.

With regard to the attachment of the saw handle to the body of the saw, some Polish and Russian studies (reported to me verbally) indicate that a certain vibration-damping effect is obtained if the attachment points are placed as close as possible to the centre of gravity of the saw body. The suspension points of the motor in the frame of the saw body should also be located where the vibrations are least severe, i.e. on the crankcase as close to the crankshaft as possible.

The balance of the saw, i.e. the distribution of weight between the two handles, and the diameter of the handgrips are of great importance if a correct technique with a light grip is to be employed (see point 8 C below).

The insertion of vibration-damping elements, e.g. of rubber, between the handle and the body of the saw is often recommended as a suitable measure in this connection. Some of the power saws with rubber inserts placed between the body and handle examined in the course of the present study actually gave vibration readings which were among the highest measured in any of the saws under study. Simple experiments conducted by the author involving the placing of rubber inserts of varying shape and hardness between the saw handle and body have shown that the problem is a complicated one. The rubber inserts have in no case produced any vibration-inhibiting effect; on the contrary, in several cases an increase in the intensity of vibration was noted. The favourable experience gained from efforts to reduce vibration in other fields, e.g. the mounting of vibrating machines on rubber pads on their foundations or the use of rubber mountings in the chassis for vehicle engines, is thus not directly applicable to power saws.

It was not possible with the available equipment to study whether vibrations in fingers and hands can be reduced by sheathing the saw handgrips in porous material. It does not, however, appear improbable that such a damping effect can be achieved in this way, as indeed by the use of gloves with a cushioning layer of foam rubber or similar material. To clarify this point one could for example make electromyographic examinations of potential changes in the hand and arm muscles (37), test impairment of manipulation capability after exposure to vibration load (12, 13, 14) or determine the contraction of the blood vessels in fingers and hands by more purely clinical methods. Further investigations in this field seem to be called for.

8 C. Handling Technique and External Factors

With regard to handling technique, the manner in which the saw handgrips are held in the hands seems to have a highly significant effect on the extent to which the vibrations are transmitted to the fingers and hands. Figure 19 gives an example of a comparison of vibration intensity measured in the front handgrip when the latter was held with a tight grip and a normal

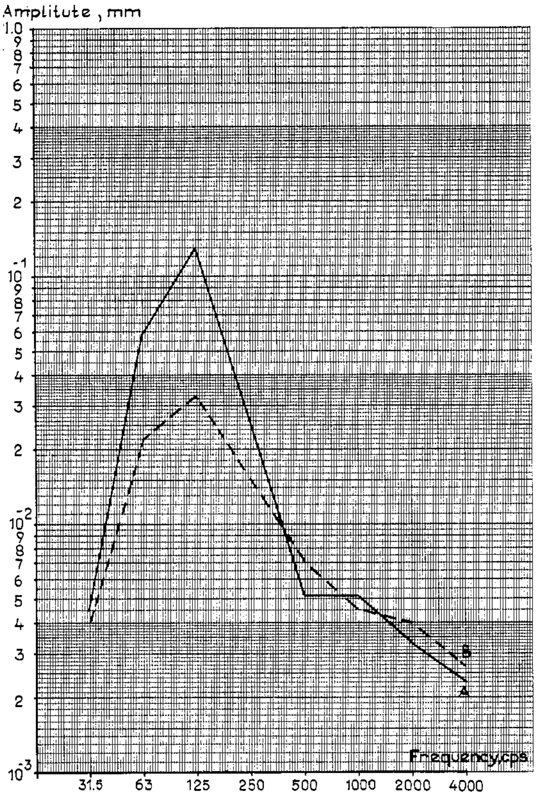

Fig. 19. Frequency analysis of vibration intensity with normal (A) and hard (B) static grip on handgrip with the hands. Point of measurement, from handgrip. Direction of measurement vertical. Motor speed 6,000 rpm.

grip respectively. The graph shows that the tight, static grip leads to considerably lower vibrations. This is because when the handles are held with such a tight, static grip, a considerably larger proportion of the vibration intensity penetrates into the fingers and hands than with a slack grip.

The organisation of the work, especially the duration of exposure and the length of recuperation breaks between exposures, has a decisive influence on the risk of injury. A recuperation break (consisting of rest or other work with no exposure to vibration load) of about ten minutes is sufficient for temporary effects on the fingers and hands to disappear (31, 57 and the author's own investigations not reported in detail here). Particular attention should be paid to introducing variation into work with power saws and to avoiding prolonged continuous exposure to vibration. The trend in modern logging operations with power saws is in fact in the reverse direction to this, and consequently involves appreciable risks of vibration injury occurring in the future.

Handling technique is most important, especially when it comes to limbing with a power saw, as the motor speed is then high and there is very little damping, the result being intense vibrations. In measurements of power saw noise made by the Swedish National Testing Institute for Agricutural Machinery (46) it has been found that inexperienced workers when limbing generally keep the engine speed very high, close to racing, for long periods. Experienced workers with a well-developed technique, on the other hand, vary the motor speed rhythmically during limbing so that the high vibration readings occur mainly during the actual sawing of the limbs but not in the intervals.

Chilling of fingers and hands in conjunction with the effects of vibration increases the risk of incidence of injury (44, 51). The wearing of gloves and knitted cuffs in wintertime can therefore be recommended as a suitable personal precaution (4). Persons predisposed to or showing symptoms of vibration injury should also avoid smoking because of the constricting effect of nicotine on the blood vessels (1).

In conclusion, it should be repeated here that great variations exist in personal predisposition to vibration injury, and the value of regular health check-ups on forestry workers is emphasised (16, 20, 22, 23, 27, 47, 52).

The risk of incidence of vibration injury is strongly influenced, as the above investigation has shown, by handling technique, work organisation and certain external factors. To sum up, we may note that the risks are increased by:

1. Poor or incorrect technique (e.g. tight, static grip on saw handles, unnecessary racing of motor during limbing)
2. Prolonged intensive use of power saw in any one day
3. Use of power saw for limbing
4. Constant work with power saw with no relief
5. Lack of recuperation breaks free from exposure to vibration; about ten minutes' rest or changeover to other work is sufficient for temporary effects on fingers to disappear
6. Use of a power saw with a badly filed chain or with a worn sprocket and saw blade
7. Chilling of fingers and hands during work
8. Smoking.

9. Suggested Methods of Measurement to Determine Vibration Load in Work with Power Saws

The proposal refers to measurement of:

A. Amplitude vector value in mm in the 50—500 cps frequency range

B. Vibration force in kp.

Measurement shall be made in conjunction with the cross-cutting of fresh, unfrozen pine or spruce logs of 20—30 cm diameter. A tape recorder or graph-paper-writing instrument shall be used to register the results. The saw used shall be new with a properly run-in motor and with a chain that is new or that has been filed by an expert. Each measurement should be repeated two or three times. The person operating the saw during the test should be experienced in practical work with power saws.

A. Amplitude Vector Value in Millimetres in the 50-500 Cycle-per-Second Frequency Range

Measurements shall be made at both the front and rear saw handgrips. The acceleration sensor shall be applied where the hands rest during cross-cutting. It is essential that the acceleration sensor should be in close contact with the handgrip of the saw—it is not sufficient to press the sensor against the handgrip with the hand. The amplitude shall be measured along three axes—vertical, horizontal and axial. These axes are referred to the power saw when the latter is held in the cross-cutting position. The three measured values shall refer to the effective value of maximum amplitude expressed in millimetres to three decimal places and measured within a frequency range of 50 to 500 cycles per second. The amplitude vector value is derived from these three measured readings according to the formula

$$A = \sqrt{A_V^2 + A_H^2 + A_A^2}$$

where $|A|$ = amplitude vector value

A_V = measured vertical amplitude

A_H = measured horizontal amplitude

and A_A = measured axial amplitude

The amplitude vector value computed in this way shall be expressed in millimetres to two decimal places, and the appropriate frequency octave band shall also be stated.

B. Vibration Force in Kiloponds

Vibration force is defined as the force generated by the weight and vibrations of the power saw that acts between the saw handgrip and the hand. Measurement shall be made at the front handgrip of the saw, and the measuring instrument, normally a wire elongation indicator, shall be attached to the handgrip at the point where it is held in the hand during cross-cutting. The vibration force measured in this manner shall be expressed in kiloponds to one decimal place.

Example of Expression of Vibration Load

	Vector amplitude mm	Corresponding frequency octave band cps	Vibration force kp
Cross-cutting:			
front handgrip	0.15	125	6.5
rear handgrip	0.18	125	—

N.B.: Use of this power saw as an occupational tool for more than about four hours daily, especially if it is used for limbing, involves appreciable risk of vibration injury (vasoconstriction) to the fingers and hands of the operator.

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Sammanfattning

Analys av motorsågars vibrationer

Avsikten med undersökningen har varit att:

1. På medicinska grunder uppställa kriterier på risken för uppkomst av vibrationsskador vid arbete med motorsåg.
2. Vetenskapligt studera och analysera motorsågars vibrationer ur teknisk och fysikalisk synpunkt.
3. Utreda orsakerna till motorsågars vibrationer.
4. Redovisa praktiskt genomförbara åtgärder för reducering av skaderiskerna.
5. Framlägga en objektiv och såvitt möjligt enkel mätmetod för bestämmande av olika motorsågars vibrationsnivå.
6. Ur vibrationssynpunkt granska motorsågar på den svenska marknaden.

Flertalet på den svenska marknaden förekommande motorsågar medför påtagliga risker för uppkomst av vibrationsrubbningar i fingrar och händer (kärlkramp eller TVD) då de användes för fällning, kapning och framförallt kvistning i högt uppdrivet tempo och med få inslag av återhämtningspauser. Vibrationerna medför dessutom en fysiologisk belastning, som hindrar arbetet. Vid uppmätning av vibrationer på ett tjugotal i Sverige vanligen förekommande motorsågar låg endast två under skadegränsen. En av dessa sågar var försedd med motverkande kolv. Den andra sågen hade en konventionell encylindrisk tvåtaktsmotor. Anledningen till dessa sågars låga vibrationer synes vara en väl utförd balansering av motorn. Över hälften av de undersökta sågarna hade vibrationer som verkade så starkt hindrande, att arbete mer än 10 minuter i sträck ej kunde anses tillrådligt. Stora variationer i den personliga dispositionen föreligger dock, varför ovan angivna uppgifter närmast avser »normalmänniskan».

Motorsågarnas vibrationer är sålunda lika allvarliga som deras buller. Ur arbetshygienisk synpunkt synes därför väl motiverat att förutom bullernivån även undersöka vibrationsnivån.

Sammanfattningsvis kan noteras att riskerna för vibrationsskador är stora vid

- Felaktig eller dålig arbetsteknik (t. ex. hårt statiskt grepp om handtagen, onödig rusning av motorn vid kvistning).
- Långvarig intensiv användning av motorsågen.
- Utnyttjande av motorsågen för kvistning.
- Ensidigt arbete med motorsågen.
- Avsaknad av återhämtningspauser (10 minuter vila eller arbete av ej vibrerande karaktär är tillräckligt för att påtagligt minska risken för vibrationsskador).
- Användning av motorsåg som är dåligt balanserad eller försedd med illa eller felaktigt filad kedja eller med slitet kedjehjul och svärd.
- Avkylning av fingrar och händer under arbete.
- Tobaksrökning.

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