REDUCTION OF VIBRATION IN POWER SAWS IN JAPAN

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ABSTRACT

The problem of chain saw induced Raynaud's disease in Japan is presented. Techniques for minimizing vibration and noise emanating from presently manufactured chain saws are discussed. A rotary engine type chain saw has been developed, production prototype units have been constructed, and tests are presently underway in forests in Japan. Performance specifications as well as vibration and noise abatement techniques are compared between the normal reciprocating engine chain saw and the new rotary design.

RAYNAUD'S DISEASE IN POWER SAW OPERATORS

In 1965, the occurrence of Raynaud's disease sufferers among chain saw operators in Japan was first and sensationally reported in a weekly magazine, as mentioned in the Umeaa international meeting. Since then, not only has the protection against Raynaud's disease but also the reduction of vibration in power chain saws themselves become one of the most controversial issues between the Forest Labourers Unions and the Forestry Agency Authority. In 1970, as a preventive measure against Raynaud's disease, the net operating hours for power saw operators was regulated: 2 hours per man-day, 5 days per week, 40 hours per month, and less than 3 days of continuous working days.

The following number of persons were diagnosed as suffering from Raynaud's disease between 1965 and 1974 in Japan.

	National Forest Workers	*Private Forest Workers*
1965	9	37
1966	177	50
1967	126	30
1968	172	20
1969	558	50
1970	125	65
1971	65	39
1972	90	—
1973	436	—
1974	787	—
Total	2,545	424

The number of forestry workers (in 1972, 14,397 for National Forests and 70,220 for Private Forests) using power saws, such as chain saws and brush cutters, has been gradually decreasing every year as mechanization in forestry progresses. The National Forest group represented about 5,000 chain saw operators with the rest being brush cutter operators. The Private Forest group can be further divided into 6,109 fellers, 26,591 chain saw operators, 31,187 log-hauling and transporting workers, and 6,333 miscellaneous workers. Thus, the number of chain saw operators in Private Forests was estimated as above and occasional chain saw users who did other jobs, including cable crane operations and miscellaneous works related to logging and transportation, are included in Table 1.

Table 1. Number of full-time Private Forest workers, 1972

Type of work	No. workers
Loggers	6,109
Chain saw operators (with own chain saws)	16,626
Chain saw operators (with chain saws owned by companies)	9,965
Log hauling workers (man power)	4,800
Log hauling workers (machine power)	23,837
Log hauling workers (animals owned by workers)	2,550
Workers for miscellaneous works of logging	6,333
Total	70,220

It cannot be concluded that the occurrence rate of vibration induced Raynaud's disease sufferers is the same for both National Forest and Private Forest workers, because their working conditions differ. For instance, chain saw operators in National Forests are engaged in the monotonous work of felling or bucking in only tree length, or full tree, logging; in contrast, chain saw operators in Private Forests are engaged in a variety of work that includes not only felling and bucking operations but also hooking, loading, and unloading by hand for cable crane logging operators.

Further, in Private Forests, the average amount of time worked was 59%; 80.3% of the workers traveling to work came from home and 19.7% came from work camps; and 41.6% were fixed-wage workers and 59.4% were piece workers. The age group structure is shown in Table 2.

Table 2. Age group structure of full-time Private Forest workers, 1972

Age group	Number	Percentage
Less than 20	403	0.6
20 to 29	4,757	6.8
30 to 39	19,163	27.2
40 to 49	29,289	41.7
More than 50	16,608	23.7
Total	70,220	100.0

Meetings of the medical examination committee for vibration induced Raynaud's disease were held to establish preventive measures for occupational safety and health. Health check procedures for chain saw and brush cutter operators, health control items, livelihood guidance standards, work control standards, medical care and treatment guidelines, etc., were set for Private Forest workers. In addition, instructions to improve operational motions and to prevent Raynaud's disease have been issued and officially put in force for such operations as the basic motions in felling and bucking, the use and handling of chain saws, the operational standards for felling and bucking, etc.

Other measures for preventing hearing loss and Raynaud's disease are improving and adopting vibration-absorbing gloves and ear protectors, installing rubber mounts to improve the vibration absorbing capability, developing a high frequency (400 Hz) electric chain saw, developing vibration absorbing devices for chain saws not held by the hands, developing a rotary chain saw, and others.

Although almost all chain saws supplied to National Forest workers are antivibration chain saws, only a small number of chain saws supplied to Private Forest workers are of the antivibration type because the price of a chain saw with a shock absorber is more than ¥15,000 ($50) higher than that of a chain saw without a shock absorber. It is therefore assumed that any occurrence of vibration induced Raynaud's disease among National Forest workers may have been caused by the vibration dose accumulated up to nearly 10 years ago from the use of chain saws without shock absorbers, not because of the use of the antivibration chain saw.

Although the cause of vibration induced diseases could not be definitely related to the use of chain saws without shock absorbers, the use of antivibration chain saws should be promoted for Private Forest workers by subsidizing its purchase.

In addition to the above diseases, other hazards requiring preventive measures are noise problems, saw chain rupture, kickback, etc. These latter problems, however, occur mostly from careless operation and are not yet considered serious in Japan.

MEASUREMENT METHOD OF VIBRATION IN POWER SAWS

Since 1965, we have conducted vibration tests on chain saws, brush cutters, etc., using the original measuring method, at the Government Forest Experiment Station (as reported at the Umeaa international meeting). In 1974, we began using a frequency analyzer and engine tachometer in our vibration testing.

Equipment Used for Measuring and Analyzing Vibration

Frequency Analyzer

A B&K real-time ⅓-octave analyzer equipped with frequency analyzer 2130; real panel control and display unit 4710; JT0997-type 12.5 Hz filter; JT0998-type 16 Hz filter; JT0999-type 20 Hz filter; J10010-type linear filter; and 2305-type level recorder.

Accelerometer

B&K 4344-type three dimensional pickups (compression type, frequency range: 1 to 14,000 Hz; weight for one dimension, 2 grams; total weight, 15 grams).

Engine Tachometer

An ONO SOKKI CT 542-type rpm digital counter; SE11R-type rpm indicator; and PA100-type rpm amplifier.

Charge Amplifier

B&K 2626-type conditioning amplifiers.

Electrodynamic Calibrator

An NF Block SL136A-type exciter; 514A-type power amplifier (frequency range 5 to 5,000 Hz); and a SHINNIHON SOKKI 360A-type power amplifier.

Measurement Method

Mounting Method

The three-dimensional pickup screwed to a small steel plate (4 mm thick, 15 mm wide, and 30 mm long, with a curvature around the round section of the aluminum pipe handle [14 grams]) is clamped to the upper side of front and rear handles by the use of small steel bands to reliably measure the vibroacceleration transmitted to handles in three directions, (up and down, right and left, forward and backward, at the same time under no load and load). The relation between the clamping pressure of pickup on handle and the vibroacceleration was reported in the Umeaa international meeting.

Measurement of Engine Speed

Since engine speed is one of the most important test conditions, it is reliably measured at 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, 10, 000 rpm with a deviation of ± 50 rpm under no load, and at available speed (mostly 7,000 ± 50 rpm) under load.

Method of Holding Chain Saw Under Test

A chain saw under no load test is suspended horizontally with the front handle held by a cotton rope (two pieces, each 5 mm in diameter and 1,700 mm in length) that hangs down from the ceiling of the test room. The throttle trigger is controlled by the operator's right fingers that softly touch the rear handle sideward; this yields the required engine speed.

The operator, using both hands but not using the back grips, holds the chain saw being tested horizontally and controls the engine at a speed of 7,000 ± 50 rpm. The wood is a 20-cm cube of Japanese beech with a 13% to 15% moisture content.

In all our tests for the past 10 years, we have used the same test operator and the same test wood from the same forest.

OFFICIAL PUBLICATION OF TEST RESULTS

Results of tests conducted at the Government Forest Experiment Station on vibration transmitted to power saw handles have been published by the Forestry Agency. The test results for chain saws and brush cutters have been published using a table format incorporating the test parameters listed above.

SAFETY AND PUBLIC HAZARD CONTROL FOR POWER SAWS

The Subcommittee for Forestry and Hand-Held Machines, under the supervision of the Ministry of International Trade and Industry (Chairman: S. Yamawaki), has discussed the reduction of vibration, noise, and other hazards of power saws and their operation. Recommendations on the safety and public hazard control for chain saws were reported in March 1974, and those for brush cutters, in March 1975. The outline of the former report follows.

Vibration Abating Measures

This working group strongly recommended the use of an acceleration pickup clamped to the rubber covered handle as a measure of the acceleration level. This can be subsequently processed by a ⅓-octave frequency analyzer.

The target of these efforts was the reduction of vibration transmitted to handles in chain saws. The agreed upon level was about 3 g, at less than 500 Hz, in the three orthogonal directions. This target level will be the most stringent one to date that must be met by manufacturers of chain saws and is expected to prevent the occurrence of vibration induced Raynaud's diseases.

Noise Abating Measures

It was also agreed that a noise level of 100 dB(A) or lower (as measured near the ear, over the safety helmet of the operator) is a desirable target. This has also been adopted in the Scandinavian countries.

This requires chain saw operators to wear ear protectors such as ear plugs and ear muffs as tightly as possible. If the volume of the silencer is insufficient, the effect must be increased by using a baffle plate. The engine cover, centrifugal clutch, and sprocket cover and section port must be redesigned to reduce the mechanical and suction sound.

Kickback Prevention

To protect the operator from injuries, the centrifugal clutch should be improved so that an optional kickback prevention device can be mounted on the chainsaw.

Chain Saw Safety

For all types of chain saws, improved design should include a provision for mounting handle guards on both front and rear handles. Although kickback injuries are not frequent in Japan, developing and improving the quality of chains not manufactured in Japan are necessary.

Improvement of Guide Bar

The development of a guide bar incorporating a small roller or sprocket nose with low frictional resistance and high wear resistance is necessary to facilitate plunge-cutting and thereby increase the safety of wood-sawing works.

Additional Safety Precautions

After the deliberations on the safety and public hazard control of hand-held forestry machines and equipment (especially chain saws), this working group has reached some conclusions that are to be reflected in the manufacture of chain saws, saw chains, and related equipment.

Items for Further Research and Investigation by This Working Group

- research and development for safety and public hazard control of brush cutters,
- improvement and standardization of shock-absorbing gloves, ear protectors, safety helmets, etc.

Items for Research and Development by Manufacturers

- improved shock-absorbing rubber and anti-vibration structures,
- silencers to reduce exhaust and suction noises and other mechanical noise,
- exhaust port, fuel and lubricating oil mixing ratio, a mini exhaust-gas purifying unit, etc., as exhaust-gas measures,
- saw kickback and saw chain safety devices,
- a domestic safety chain and improved saw chain quality,
- a domestic guide bar with a sprocket or roller nose, and
- a domestic diaphragm type carburetor.

Items for Research and Development Requiring Cooperation of Manufacturers

- a tractor-mounted felling and prehauling machine,
- automatic bucking and sorting equipment, and
- a pruning, felling, and bucking machine using a laser apparatus.

It goes without saying that the observance of operation control, operational standards, operators' manuals for chain saws, and education for training health control, etc., are needed for the safety and hazard control in chain saw operations.

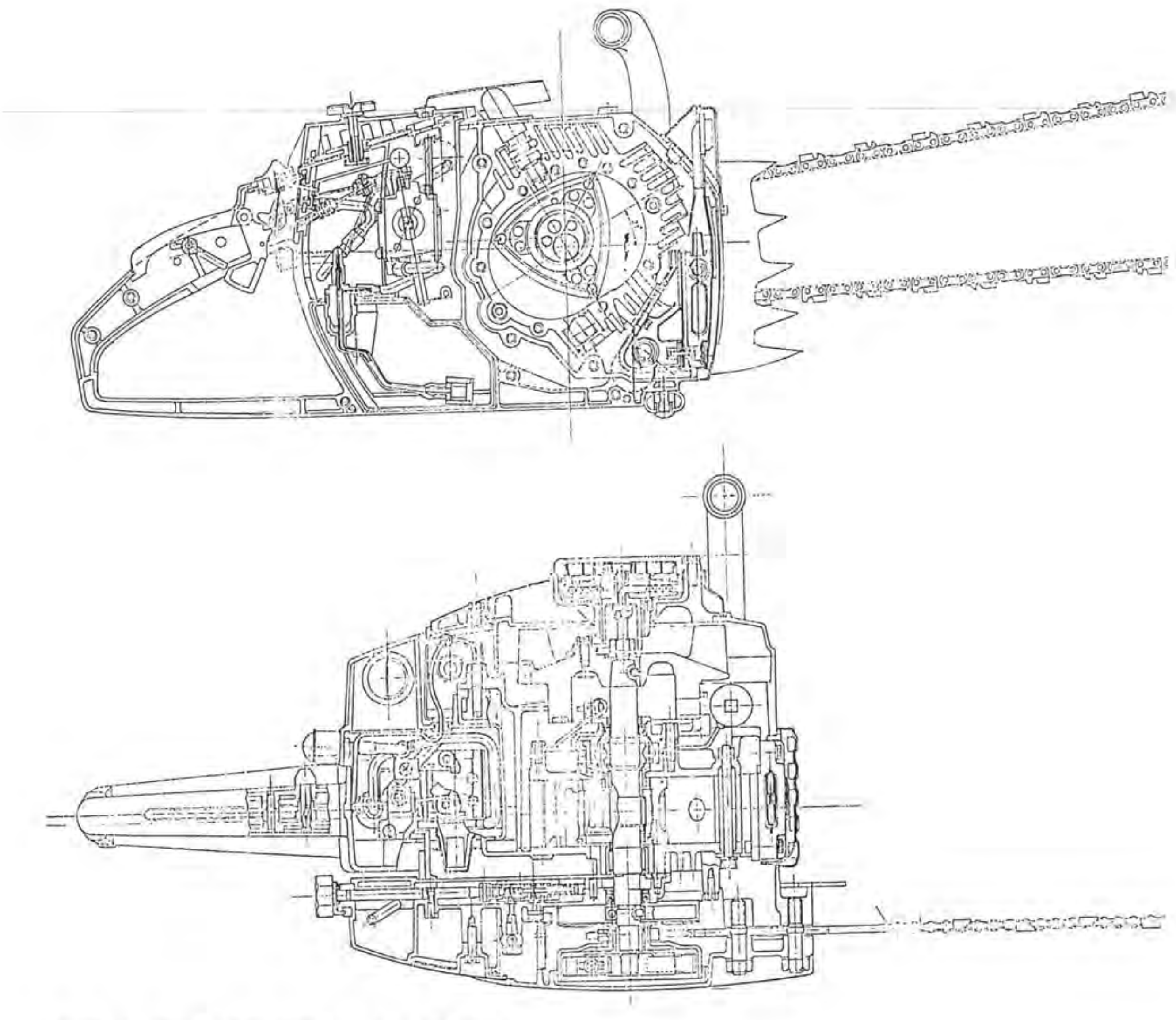

Figure 1. Profile and plan of rotary chain saw.

TEST RESULTS OF A ROTARY CHAIN SAW

Die-cast rotary chain saws have just been test manufactured early this year under the supervision of the author. About 150 rotary chain saws are now being field tested in National Forests. By the end of this year, about 1,000 rotary chain saws will be tested in National Forests—from the northern parts (subfrigid forests) to the southern parts (warm, temperate forests) of Japan.

Rotary Chain Saw Specifications

Specifications for this die-cast rotary chain saw are listed in Table 3 (see, also, Figure 1).

Rotary Chain Saw Operational Efficiency

Field tests of the rotary chain saws have been made not only in National Forests but also in Private Forests. The operational efficiency in felling, limbing, and bucking operations using rotary chain saws is shown in Table 4.

From these test results, it may be said that the operational efficiency is nearly equal to that of the reciprocating chain saws with almost the same piston displacement.

Vibration Transmitted on Handle of Rotary Chain Saw

The vibration transmitted to the front and rear handles of the rotary chain saw under no load and load conditions using a ⅓-octave real-time analyzer is shown in Figures 2 and 3.

From results of test conditions at the Government Forest Experiment Station, the maximum values of vibroacceleration (at less than 500 Hz) transmitted to the front and rear handles of the rotary chain saw can be compared with those transmitted to one of many kinds of reciprocating chain saws equipped with various shock absorbers (Figure 4).

Table 3. Specification of the rotary chain saw

Engine	Air-cooled WANKEL-type rotary engine
Piston displacement	56.5 cc
Number of rotors	1
Width of rotor	38 mm
Major and minor diameters of trochoid	101 mm/75 mm
Generating radius	42 mm
Eccentric length	6.5 mm
Dried total weight (with 16-in. guide bar)	8.7 kg
Wet total weight (with 16-in. guide bar)	10.7 kg
Overall length, width, and height (with 16-in. bar)	440 mm × 288 mm × 253.5 mm
Ignition system	C.D.I. ignition system
Starter	Rewind
Shock absorber	4 rubber mountings
Lubricating oil feeding system for saw chain	Automatic
Fuel tank capacity	0.7 liter
Oil tank capacity	0.3 liter
Fuel-oil mixture	40:1
Clutch	Centrifugal clutch
Type of carburetor	Diaphragm
Type of sprocket	Rim
Pitch of saw chain	⅜ in.
Guide bar length	16 in., 20 in.
Maximum horsepower	3.7 PS / 8,000 rpm
Maximum torque	0.38 m-kg / 6,000 rpm

Table 4. Operational efficiency of felling, limbing, and bucking operations with rotary chain saws

Test field	OKUTAMA	OKUTAMA	NUMATA	SHINSHIRO
Test period	2/12-15/1975	2/12-15/1975	3/23-26/1975	7/28-30/1975
Kind of tree	Japanese cedar	Japanese fir (Momi fir)	Hardwood	Japanese cypress
Forest type	Artificial	Natural	Natural	Artificial
Stand age, years	50	70 to 200	60	60
D.B.H.	20 cm / 10 to 32 cm	76 cm / 53 to 100 cm	23 cm / 5 to 40 cm	19 cm / 8 to 30 cm
Slope gradient, degrees	30 to 40	35 to 45	10 to 20	
Logging method	Tree length logging: felling and limbing	Short wood logging: felling, limbing, and bucking	Short wood logging: felling, limbing, and bucking	Tree length logging: felling and limbing
Fuel consumption, liter/day	4.9	3.5	2.1	1.4
Oil consumption, liter/day	2.1	1.5	0.9	0.6
Operational efficiency, m³/man-day	30.1	11.6	4.9	11.7

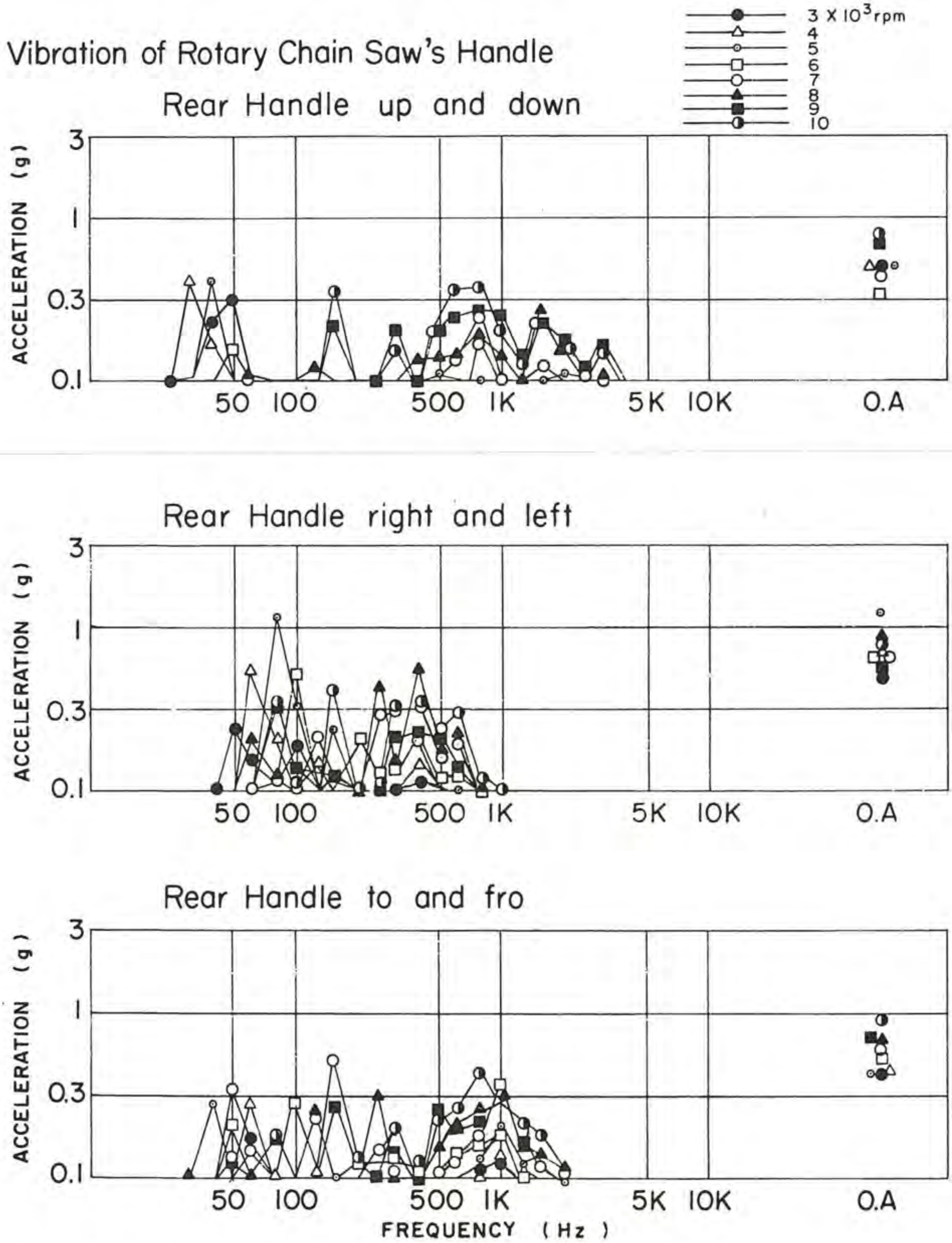

Figure 2. Vibration transmitted to front handle of rotary chain saw.

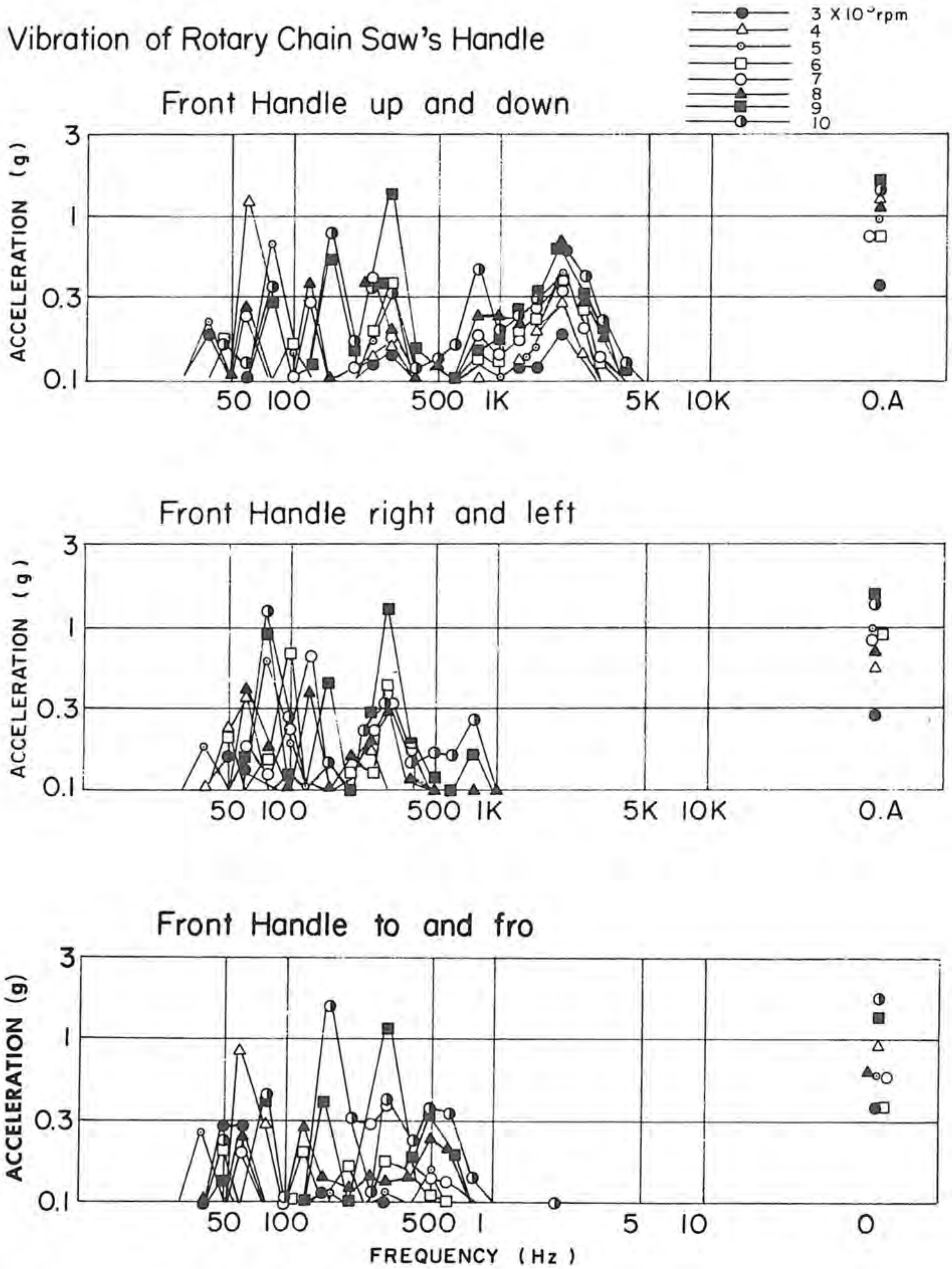

Figure 3. Vibration transmitted to rear handle of rotary chain saw.

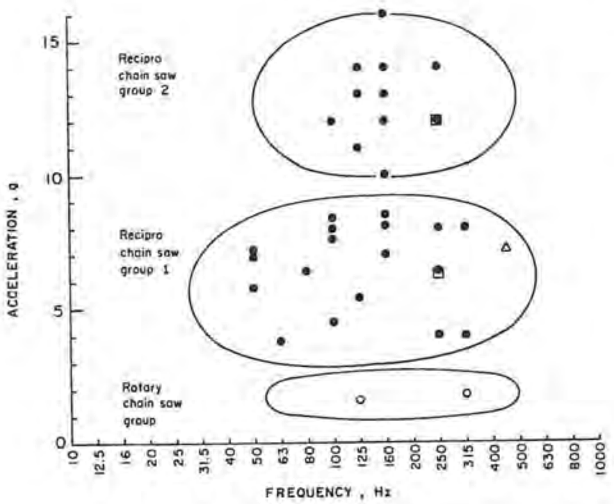

Figure 4. Comparison between the maximum values of acceleration at less than 500 Hz of rotary chain saw and a reciprocal chain saw.

From these results, it can be said that the rotary chain saw equipped with a WANKEL-type light rotary engine with rubber mountings as a shock absorber has excellent vibration-abating characteristics as compared with antivibration reciprocating chain saws.

Noise Level of Rotary Chain Saw

The noise level of the rotary chain saw under no load and load conditions, measured at the operator's ear, as analyzed is shown in Figure 5.

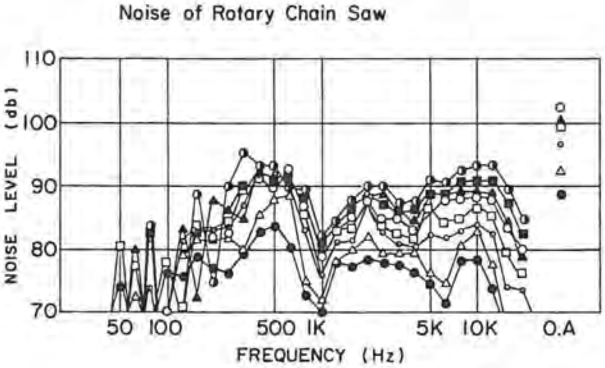

Figure 5. Noise level of a rotary chain saw.

Because the exhaust temperature of the rotary engine becomes higher than that of a two-cycle reciprocating engine (reaching several hundred degrees centigrade because of the characteristics of the special exhausting), the exhaust silencer of the rotary chain saw should be equipped with a type of duplicate structure in which the inner case of the muffler should be air cooled by a cooling fan from the engine, under the outer case of the muffler. This is necessary to lower the temperature of not only the exhaust fumes but also the muffler case itself.

From this test result, it may be said that the noise level of the rotary chain saw is markedly lower than that of reciprocating chain saws.

Correlation Between Engine Torque and Handle

The correlation between engine torque and handle vibration (both front and rear and under no load and load conditions) can be measured by using a rotary chain saw specially equipped with strain gauges pasted on the rotor shaft between the sprocket and the main bearing, and with a slip ring. This measuring method is similar to that of reciprocating chain saws (reported at the Umeaa meeting in December 1973). The test results obtained from this method are shown in Figure 6.

From these results, it may be said that the variation of engine torque and the variation of vibration transmitted on front and rear handles of the rotary chain saw have a distinct cross correlation with each other.

QUESTIONS, ANSWERS, AND COMMENTARY

Question (D. Wasserman, NIOSH): I would guess that the higher the moisture content in wood, the harder it is to cut. I don't know if that is correct, but if it is correct, why aren't tests on chain saws performed on wood that has been immersed in water or saturated rather than on wood with a 13% or a 30% moisture content?

Answer: Natural seasoning of wood leads to about 13% moisture content. Dry timber is harder to cut than green timber.

Question (D. Wasserman): Then if dry timber is harder to cut than green timber, why didn't you use dry timber for your tests?

Answer (G. Keighley, British Forestry Commission): In the plans for our chain saw group, we look at the work situation for the majority of operators. Because most operators are dealing with felling live trees and immediately branching and, also, cross cutting the green timber, this is the most common work situation. If there was some special factor—if we knew that there was a difference with dry timber, perhaps we might have to apply that. For example, I believe in parts of Canada, a chain saw is used in house building. I was told of cutting seasoned timber with chain saws. But for our purposes, it's green timber.

Question (D. Wasserman): How do you get consistency of tests from one laboratory to the next if, in various testing laboratories, not only is the wood different, but the moisture content in that wood is different as well as the wood cut?

Answer (G. Keighley): The answer to that is that we have just agreed on a basic moisture content, and we are in the process of developing uniform testing methodology. But, clearly, it is a problem.

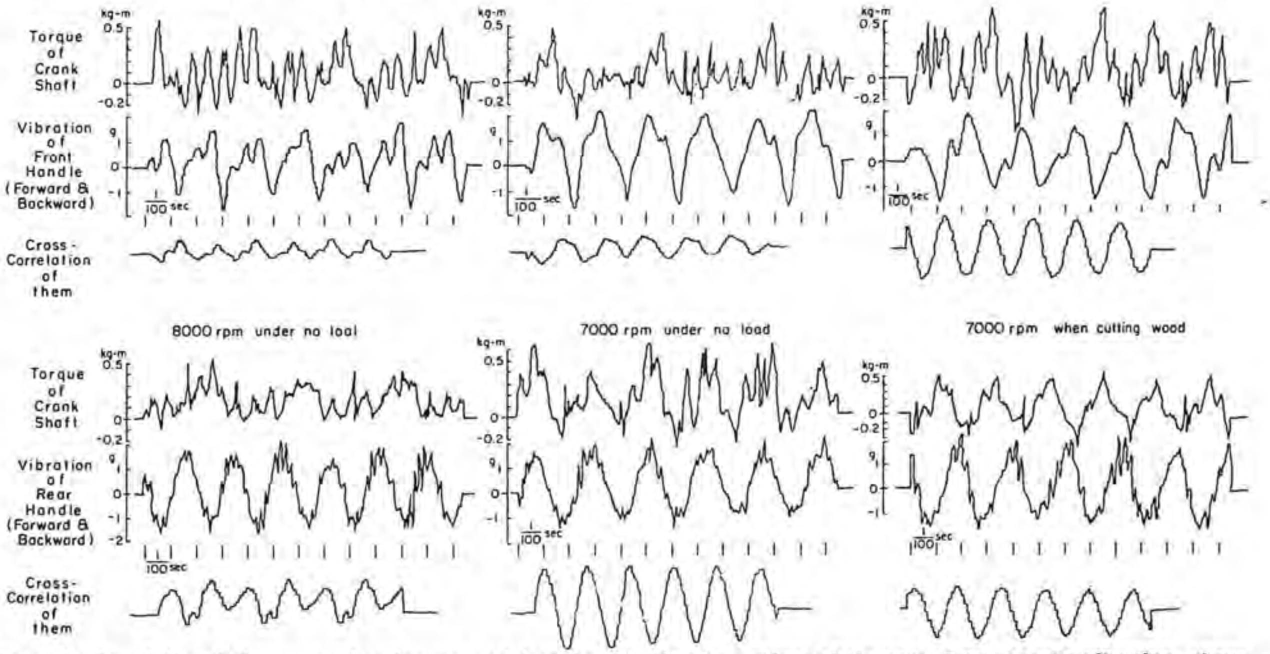

Figure 6. Correlation between engine torque and handle vibration in a rotary chain saw. Front handle vibration, above; rear handle vibration, below.

Comment and Question (J. Bailey, McCulloch Corporation): Our testing experience indicates that other variables appear important in addition to the differences of wood: the position of cutting, grasp, position of the saw, etc. I have a question for Dr. Yamawaki. You say the temperature of the exhaust gases of the rotary saw is higher than that of the reciprocating saw. Is it hotter or cooler than the reciprocating engine exhaust?

Answer: Hotter by several hundred degrees.

Question (J. Bailey): When you measure vibration using your new standard, what speeds will you use for cutting.

Answer: 8,000 rpm.

Question (J. Bailey): Some saws have their best cutting or best power at other speeds?

Answer: Perhaps.

Question (J. Bailey): Then will you have a test requirement at no load as well as for cutting? And what speed will that be?

Answer: 7,000 for cutting. For no load, from 2,000 to 10,000, in thousand increments.

Question (J. Bailey): And there will be a 3 g maximum for any of those conditions?

Answer: Yes.

Question (J. Bailey): When you say no load, is that when you support the front handle and then just lightly grasp the saw with the rear handle?

Answer: Yes.

Question (G. Keighley): Have you performed any tests so far?

Answer: Yes. With rotary chain saws equipped with a special muffler whose exhaust temperature is about 260°C. Without the special muffler, the temperature would be much higher.

Comment (R. Larsen, Outboard Marine Corporation): There seems to be some question about Dr. Yamawaki's discussion of the temperature of the exhaust on the rotary combustion powered saw. Those of us who test them find that, indeed, the exhaust temperatures on the rotary systems are considerably higher than they are on the reciprocating engine. That's because of the nature of the combustion chamber, namely, if you clean out a lot of unburned hydrocarbons, you get a very high temperature exhaust.

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