

PROGRESS IN SOLVING THE PROBLEM OF HAND-ARM VIBRATION FOR CHAIN SAW OPERATORS IN SWEDEN, 1967 TO DATE

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ABSTRACT

When the National Swedish Testing Institute for Agricultural Machinery measured vibration in chain saws in 1974, the average vibration level of the chain saws used in Sweden had been reduced to 30 to 40 Newtons from some 150 Newtons in 1967 as a result of manufacturers' technical improvements.

Since 1973, the National Swedish Board of Occupational Safety and Health has restricted the maximum permissible vibration level of chain saws sold in Sweden to 50 Newtons.

In 1967 and 1974, the National Swedish Institute of Occupational Health and the Forestry Occupational Health Services in Vasterbotten, Ltd., gave forestry workers in northern Sweden medical examinations. The percentage of traumatic vasospastic disease or vibration induced white fingers among chain saw operators in the county of Vasterbotten had decreased from 50% in 1967 to 28% in 1974. Furthermore, of the 28%, 19% had significantly improved; the remaining 9% had not improved or had deteriorated.

INTRODUCTION

When the chain saw was introduced in Swedish forestry at the beginning of the 1950's, no one was concerned about risks of occupational injuries due to vibration in the chain saws. No one was aware of the eventual risks of vibration induced white fingers (VWF) or traumatic vasospastic disease (TVD).

CHAIN SAW WEIGHT AND USE

In 1952, the first chain saws were heavy, two-man machines with an average weight of 18 kilograms (40 pounds). These machines could be used only for felling trees. The cutter still used his handsaw for bucking (crosscutting) the trees into timber and pulpwood and his axe for limbing (branching). The effective working time with the chain saw, i.e., the vibration exposure time, was only about 1 hour per day (Figure 1). The chain saw helped facilitate the cutter's difficult job, and the number of chain saws in use increased steadily. They were technically improved and became lighter and easier to work with. At the end of the 1950's, chain saws were generally used for both felling and bucking. The axe was still used for limbing, and the vibration exposure time was still low: 1 to 2 hours per day.

Technical improvement of chain saws continued, and at the beginning of the 1960's, an important new working technique was developed, namely, limbing with the modern, light, compact chain saw. The axe disappeared from the woods, and consequently the cutter's vibration exposure time while using the chain saw suddenly increased to 5 to 6 hours per day.

The individual Swedish cutter's productivity is today roughly 10 times greater than it was 20 years ago. The increased use of the chain saw plays an important part in this significant achievement.

Today the average age of the professional Swedish chain saw operator is around 46 years. He works 8 hours per day, 5 days per week. The effective working hours are 7.5 hours per day, approximately 220 days per year. During the year, he works about 170 days in ordinary cutting with the chain saw, some 20 days in silviculture work, and the remaining 30 days in other forestry work. In an average day, he fells 1.5 hours, bucks 0.5 hour, limbs 4.0 hours, and drags and walks 1.5 hours. Consequently, the vibration exposure time from chain saw work amounts roughly to 6 hours per day, or approximately 1,000 hours per year.

MEDICAL COMPLAINTS

In the middle of the 1960's, chain saw operators

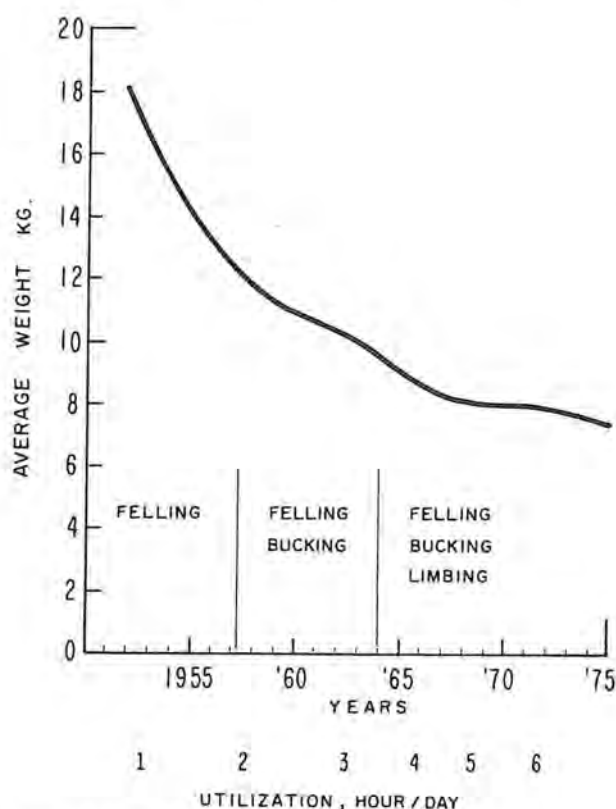


Figure 1. Chain saw use in Sweden.

began to report an increasing amount of complaints and subjective symptoms of circulatory disorders and discomfort in their hands and arms, which was attributed to work with the chain saw. Thus, medical and technical experts and the chain saw manufacturers became aware of the risks and problems of VWF.

At the National Swedish Testing Institute for Agricultural Machinery, we began, in 1965, to develop a technique for measuring vibrations of chain saws. Based on the limited experience at that time, a threshold limit value expressed in amplitude (or displacement) over frequency was proposed: 0.08 mm in the 50 to 500 Hz frequency range.

The report¹ of the preliminary vibration measurements of available chain saws stated:

"With regard to vibration, practically all the chain saws now on the Swedish market have a vibration level in excess of the proposed injury limit. The difference in maximum amplitude between different saws is very slight. Professional use of present-day chain saws in modern logging operations where the tempo is rapid, the daily utilization time long and recuperation breaks few and far between, together with the regular use of the chain 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)."

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

Vibration force, Newton	Subjective effects	Effects on work performance
10	Noticeable, not uncomfortable	No impairment
10-30	Noticeable, but scarcely uncomfortable	No impairment
30-50	Quite noticeable, prolonged exposure uncomfortable but tolerable	Very slight impairment
50-100	Distinctly noticeable, unpleasant after an hour or so; still tolerable	Performance impaired but work still possible
100-150	Uncomfortable, barely tolerable after more than 10 minutes' exposure	Performance heavily impaired; more than 10 minutes' work without a break inadvisable
150-300	Even brief exposure highly uncomfortable	Work difficult to perform
over 300	Extremely uncomfortable	Work impossible

Unfortunately, I would say, this estimation of the risks of contracting TVD when using the chain saws of that time proved to be realistic.

MEDICAL INVESTIGATIONS

In 1967, the National Swedish Institute of Occupational Health (which today forms the Occupational Health Department of the National Board of Occupational Safety and Health) investigated the health of some 450 forestry workers in the northern part of Sweden, in the county of Vasterbotten.² In the medical examinations, particular interest was given to that part of the investigation headed by Dr. Ing-Marie Lidstrom concerning the occurrence of vibration injuries, TVD, among chain saw operators.

The study of TVD occurrence yielded two important results. Firstly, about half of all chain saw operators were found to have vibration injuries. And secondly, a strong significant correlation was found between reported subjective symptoms of TVD and the objective medical findings of clinical provocation tests.

The TVD study included 290 chain saw operators, divided into two age-groups: 136 men between 25 and 34 years and 154 between 45 and 54 years. Of these 290 men, 70% reported they had worked with chain saws for more than 6 years, and 80% reported that they usually worked more than 5 hours per day with the chain saw. In the younger group of men, 36%

had subjective symptoms of TVD; in the older age group, 58%. This corresponds to an average figure of 49% of chain saw operators with subjective TVD symptoms in 1967.

The second important result of the TVD study relates to a specific provocation test made to correlate subjective symptoms and objective medical findings of TVD. Each of the 79 forestry workers investigated was placed, sitting, with both hands in 15° to 17°C water for 10 minutes while his body was being cooled with wet towels. During this cold provocation test, skin temperature measurements and plethysmography were carried out. The results of this provocation test show a strong significant correlation between subjective symptoms of TVD and objective medical findings of TVD.

ANTIVIBRATION CHAIN SAW DEVELOPMENT

About the time of these tests, chain saw manufacturers began attacking the problem of hazardous vibration in saw handles. In developing the modern antivibration chain saw, the main mode has been to insert vibration-damping rubber elements between the body of the saw and the handles. Reducing the vibration level and at the same time reducing the weight of the chain saw and maintaining a high cutting capacity appeared difficult, but it is obvious now that the manufacturers have succeeded (Figure 2). As the result of manufacturers' technical improvements, the average vibration level of chain saws used in Sweden has been reduced from some 150 Newtons (15 kp) in 1967 to 30 to 40 Newtons in 1975. These figures refer to the official vibration measurements carried out by the National Swedish Testing Institute for Agricultural Machinery.

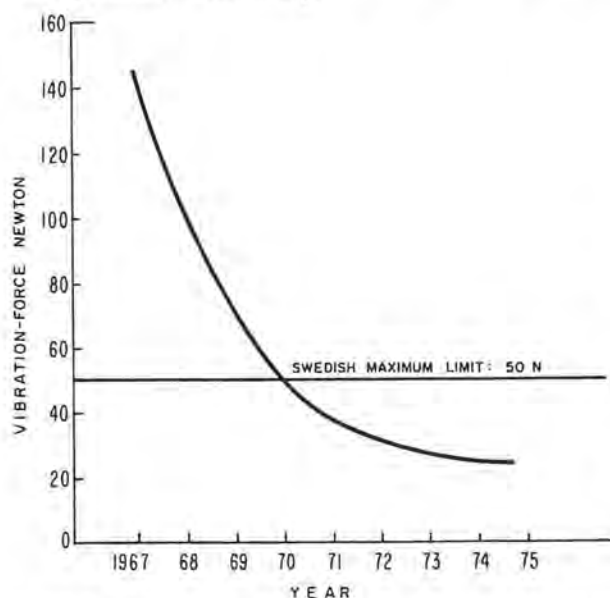


Figure 2. Average vibration level of chain saws used in Sweden.

CHAIN SAW REGULATIONS

Faced with the serious results of the medical investigation in 1967—49% TVD among chain saw operators—the National Swedish Board of Occupational Safety and Health decided to regulate the vibration levels of chain saws. Although no fully accepted threshold limit values for vibrations existed at that time, the National Testing Institute had developed a reliable method for measuring vibrations in chain saws.³ In 1971, the Board of Occupational Safety and Health issued the regulation that chain saws sold in Sweden should be vibration tested by the National Testing Institute. The maximum permissible vibration level of the saw handles was restricted to 80 Newtons in 1971, 60 in 1972, and 50 in 1973.⁴ This Swedish maximum permissible vibration level of 50 Newtons is not a scientific threshold limit value. It is more of a "qualified guess," decided in a serious situation. This "qualified guess" has, however, proved quite realistic (Figure 2).

OCCUPATIONAL HEALTH SERVICES

In 1972, the first Occupational Health Services (OHS) center for forestry employees was established in Sweden. The large forest companies in the county of Vasterbotten joined together to form an independent corporation of some 3,000 employees. The corporation's purpose is to carry out occupational health services in accordance with the basic ILO recommendation number 112, and with Swedish national regulations and agreements. Consequently, the work is directed towards medical and technical preventive measures, such as health service, rehabilitation, medical service, technical safety, industrial hygiene, and ergonomics. In practice, the corporation works on a consulting basis to advise and serve forestry employers and employees. The medical section is mainly concerned with general and specific medical examinations of all employees, and the technical section, with problems related to applied ergonomics. In this work, the occurrence of TVD among chain saw operators naturally plays an important part.

The county of Vasterbotten is in the northern part of Sweden, not far from the Arctic circle. The forest worker's job environment is influenced by the severe winter climate, with 5 months of snow and temperatures down to -20 to -25°C.

Of the 3,000 forestry workers involved with the OHS center, about 1,600 are chain saw operators; 500, logging machine operators; 300, supervisors; and 600, other categories. The results of 1,605 medical examinations of chain saw operators made at the OHS center in Lycksele⁵ are given in Table 2. Examinations of the occurrence of TVD are performed as a part of the regular health service examinations. At present, there are no simple objective clinical tests for identifying TVD-VWF available in Sweden (or, apparently, anywhere else). However, as mentioned earlier, a strong significant correlation has been established between reported subjective symptoms of

Table 2. Medical examinations in 1973-1974 of 1,605 chain saw operators

Pathological findings	%	
Heart and blood vessels	15	
Eyes	12	
Gastritis — ulcer	10	
Hearing losses		
Noise injuries	55	64
Others	9	
Back		
Neck	10	43
Lumbar	33	
TVD		
Not improved	9	28
Improved	19	
Other diagnosis	47	
Overweight	13	
Admission notes	12	

TVD and objective medical findings of clinical cold provocation tests.

TVD-VWF EXAMINATIONS

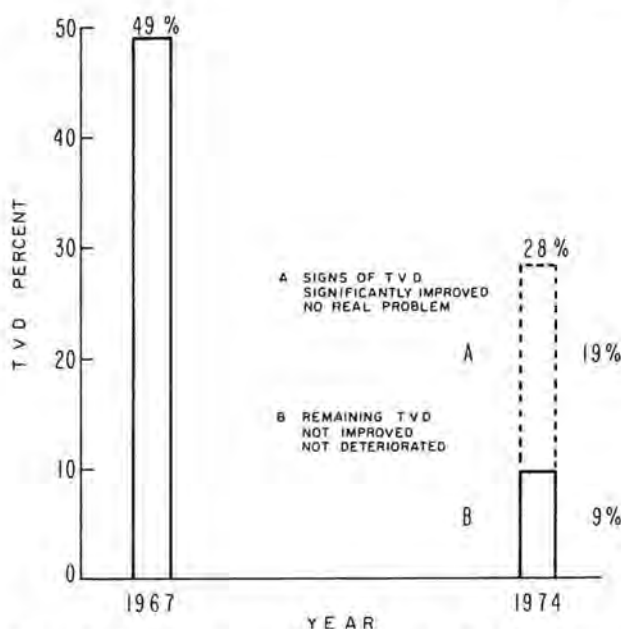
For the medical examinations of TVD at the OHS center, each employee is interviewed by the industrial physician according to a comprehensive medical questionnaire and is given a medical examination; no cold provocation tests are performed.

Among the 1,605 chain saw operators, 28% were found to have indications of TVD-VWF. Of the 28%, however, 19% were classified as "improved," i.e., showing a significant improvement from earlier TVD symptoms, with only slight remaining indications. According to the opinion of the chain saw operators themselves, these remaining indications of TVD are almost negligible from a practical point of view. The remainder, 9%, were classified as "not improved," i.e., with clearly remaining symptoms of TVD (Table 3).

The results of this medical examination can be directly compared with the results of the TVD investigation in 1967 (Figure 3). Both investigations were

Table 3. Results of TVD examinations, 1973-1974.

Number	Category	TVD-symptoms, %		Total
		Not improved	Improved	
1,605	Chain saw operators	8.7	19.3	28.0
507	Logging machine operators	2.0	3.9	5.9
307	Supervisors	3.6	2.0	5.6
561	Others	0.7	0.4	1.1

**Figure 3. Results of medical findings of TVD among chain saw operators, 1967 and 1974.**

carried out in the same geographical area, during similar conditions, and with similar methods. Such a comparison shows that the percentage of TVD injuries among chain saw operators in northern Sweden has been reduced from 49% in 1967 to 28% in 1974. Of the 28% in 1974, 19% have significantly improved and 9% have not improved or have deteriorated. The main reason for this satisfying development seems to be the considerable reduction of the vibration level in the chain saws during the same time period.

Other factors contributing to the reduction (with regard to the apparent connection between TVD symptoms and cooling of the hands and body) seem to be the continuous improvements of the workers' cabins and shelters, the better heating, the better possibilities for drying clothes, and the development of new, appropriate working clothes made of nylon fiber-fur.

OTHER PROBLEM AREAS

The remaining problem of chain saw vibration, as we see it today in Sweden, refers to the durability of the vibration damping system of the chain saw. We have found that in many cases the vibration damping capacity deteriorates when the chain saw has been in normal use for some time. A number of vibration measurements of chain saws in use have shown that, for approximately 1 chain saw in 10, the vibration level has increased considerably since the saw was new and will exceed the maximum permissible level of 50 Newtons. When this happens, chain saw operators for whom the earlier TVD symptoms have almost disappeared, obviously run the risk of having the symptoms return. We have had indications of this in several cases. Consequently, it is important that

the manufacturers improve the durability of the vibration dampers so that a low vibration level is ensured and maintained during the technical life of the chain saw. In the meantime, the vibration level of chain saws in use must be regularly checked and vibration dampers replaced as soon as the vibration level has increased.

The Swedish National Board of Occupational Safety and Health issued new regulations on January 1, 1975, demanding that the control intervals of chain saws in regular use should not exceed 2 months.⁶ We have developed a simple method for measuring vibration of chain saws in the field. Although the method is accurate enough for practical purposes—checking that the vibration level has not increased above 50 Newtons—I want to emphasize that this method is not appropriate for scientific measurements.

FIELD MEASUREMENT METHOD⁷

For the measurements, Brüel and Kjaer equipment is used: precision sound level meter; integrator (ZR 0020); accelerometer (4332/4335); dB-vibration-converter ([slide rule] QH 0001).

The measurement is done during the normal cutting of discs (bucking) of a log. The accelerometer is firmly attached to the front and rear saw handle. It is normally enough to measure vibration only in vertical direction. The sound level meter gives the result in dB. This value is converted into acceleration, m/s^2 , with the slide rule (knowing the accelerometer sensitivity in mV/g). Next, the acceleration value is converted into vibration force in Newtons, which is the vibration unit used by the Testing Institute in the measurement of new chain saws. This is done with help of the relation (shown in Figure 4) between the acceleration value of the field testing method and the corresponding vibration force value, in Newtons, according to the method used by the Testing Institute. The relation is established through a series of comparative measurements and regression analysis. The relation is approximate but, according to our experience,⁵ accurate enough for practical purposes. Figure 4 shows that an acceleration value of 90 to 100 m/s^2 corresponds to the maximum permissible value of 50 Newtons. If we come across a chain saw in use with a vibration level of over 100 m/s^2 , the saw is taken to the service station for replacement of its vibration dampers.

SUMMARY

We have reason to believe that the problem of TVD-VWF among chain saw operators is under adequate control today in Sweden. The vibration level has been reduced from 150 to 30 to 40 Newtons during the last 7 years. During the same period of time, the percentage of TVD among chain saw operators has dropped from 49% to 28%. Furthermore, of the 28%, 19% have significantly improved; the remaining 9% have not improved or have deteriorated. We expect this favorable trend to continue. This develop-

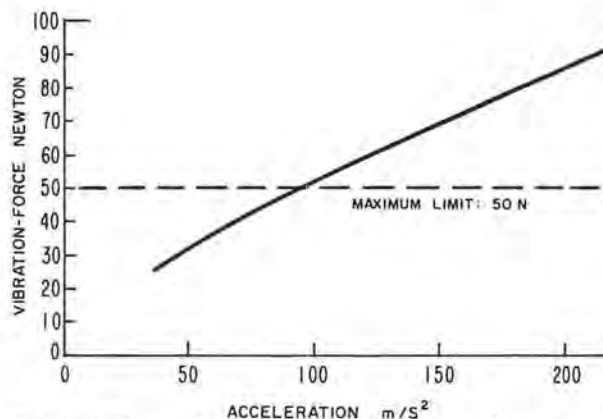


Figure 4. Approximate relation between acceleration and vibration force.

ment indicates that the risk of contracting TVD is insignificant for an "average" chain saw operator using a modern antivibration chain saw with a vibration level not exceeding 50 Newtons, or its equivalent in other measuring units.

Further medical monitoring is definitely required. In particular, young chain saw operators, who start their work using modern antivibration chain saws, must be followed. We know also that chain saws with a vibration level below 50 Newtons might cause discomfort and fatigue in hands and arms. Consequently, it is desirable that chain saw manufacturers continue their present work to reduce the vibration further and, in particular, to improve the durability of the vibration damping system.

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QUESTIONS, ANSWERS, AND COMMENTARY

Question (G. Keighley, British Forestry Commission): You say 100 m/s² acceleration has a relationship to 50 Newtons of force?

Answer: The relationship is only true for the conditions I have described, namely, the acceleration measured according to our field test method and the vibration forcing measured according to the technique used by the Testing Institute. This is not uniformly applicable, I would say; it is just for our own use in order to check the source.

Question (D. Wasserman, NIOSH): I'd like to know whether, to your knowledge, your country has required other types of tool manufacturers to install antivibration mounts on tools such as pneumatic tools and rotating electrical tools?

Answer: This has been discussed, but chain saws are the only tool to date with regulations involving vibration levels.

Question (C. Wilson, New Jersey Institute of Technology): Could you briefly note or describe the Testing Institute method of measuring?

Answer: The Swedish testing method used by the Testing Institute is a laboratory method. Basically, the chain saw is fixed in a test stand and vibration is measured in three directions. One measures the force instead of acceleration or amplitude. Force is just convenient; it's not necessarily that vibration force would be a better measure than acceleration (from the medical point of view). Rather, it seems easier to measure the force than the acceleration. When the saw is fitted into the test stand, the measurement is done with ordinary equipment without a load. The saw just hangs suspended and is not cutting during the measurement. The measurement is done at two specific values; the first at the rpm of the maximum power of the saw, and then at the higher value—I think it's 1.33 times the rpm at maximum power. We are thinking of carrying out these measurements not only at these two rpm's but also during the whole segment from idling up to the highest value. That won't change the measurement method, however.

Question (H. Von Gierke, Aerospace Medical Research Laboratory): Your curve for reduction in vibration level is pretty much parallel to the curve in weight of the chain saw. Measuring the force and not acceleration at the handle is, I guess, related to the weight of the chain saw. I would guess that the improvement in the worker's hand is not solely due to a reduction in vibration levels; rather, some improvement is due to the reduced saw weight. My question is, would less force be required if you had a heavy chain saw with the same reduced vibration level?

Answer: You are right; the curves appear to be similar, but, of course, the similarity depends on the scale used. I believe we would have the other relationship; also, a heavier chain saw would show a higher vibration force.

Comment (H. Von Gierke): It depends on what hand impedance you test it against. Or do you use the handle impedance?

Answer: As I said—the saw is not fixed in a fixture. It is just suspended in a stand with some rubber elements.

Question (H. Von Gierke): If you measure force at a handle, you have to measure it against a reference. If you have a hand of infinite mass, you will measure a large force. If you have a hand without any mass, you measure a very small force.

Answer: I agree that the method used by the Testing Institute is good from one point of view—that is, you can get the same results every time using the same saw. And you can compare chain saws. That is just for type testing. But, certainly, it is not the same if you take the saw out and use it while working. This is only a laboratory method.

Question (G. Keighley): We have been told that this method will develop the means of comparing saws from all over the world of similar weight or engine capacity, and the inventors or designers of the equipment never thought of standards or anything like that being applied to this equipment. In fact, they have admitted (Professor Moberg in December of 1973) that this method was not suitable for medicine or design and has been applied in a sense not originally envisioned. If a better method could be found, he would welcome this and do his utmost to get his colleagues to have it implemented and used as a new test method of chain saw measurement in Sweden.

Comment (H. Von Gierke): Yes, I agree if you compare saws of the same weight, it's fine. We have seen a dramatic decrease in weight, and unless you test the saw against the proper impedance of the hand-arm, the results are questionable.

Comment (G. Keighley): I think it's fair to say they never intended it to compare a 100 cc saw to a 40 cc saw.

Answer (U. Naeslund, Husqvarna AB): I agree this method isn't perfect. But it isn't correct to believe that it's only the weight of the chain saw that has reduced the vibration forces. For instance, we have two different chain saws with about exactly the same weight, exactly the same crank shaft, and exactly the same fly wheel. If we put the older chain saw into the testing equipment, we'll have a difficult time getting down to the 50 Newton level, whereas the new chain saw with a good antivibration system is down to 15 to 20 Newtons.

This test really shows which chain saw is the better of the two.

From this Swedish method, we can correlate our old findings on acceleration to these findings and to those of other testing institutes. For example, the test rig used in Finland and Japan is now being used in Sweden. It is also being used by Swedish chain saw manufacturers and by the Stihl Company in Germany. As I said before, it's not a perfect method, but I think it's the best available method today. As

you've heard at this meeting, everybody seems to have rediscovered the problems created by differences in the size of the men holding the saw, grip forces, etc., which we discovered in 1964 and 1965 when we started with the problems of vibration measurements.

Comment (R. Bailey, McCullough Corporation): I was recently in Sweden and talked to Professor Moberg who developed this test. In the test, the two suspension arms are supposed to simulate the mass of the hand-arm system, and the big rubber pad is supposed to simulate damping and the spring characteristics of the hand. So this test wasn't just an arbitrary thing. Also this arm is cut back to have some sort of tube that has three strain gauges in it. The strain gauges simultaneously measure the XYZ axes and resolve them into one vector force using a computer. So it's not as arbitrary as you might think. I'd like also to speak to what Mr. Naeslund has said. We have a light weight chain saw that just went through testing in Sweden and Japan. We find a great similarity when comparing these with some heavier saws that we tested prior to that time.

Question (W. Taylor, University of Dundee): I'm sorry to raise this point, but I thought at one stage we had a standard method for testing saws? This worries me to find yet another method! My question is, how are we going to use these data with the medical data or is that impossible?

Comment (S. Axelsson): I think it is very important to make clear from the beginning the actual purpose of this measuring method, and I don't think we have done this here. We are talking about different goals in the measurement. For example, the goal of the field method is very simple—just to check the chain saw. And the goal of the measurement made at the Testing Institute has nothing to do with the medical point of view. The only goal is to compare chain saws and objectively find their vibration levels. And then we have another goal, of course. This is the

optimum method whereby we can take into account the medical points of view together with the best technique for measuring. But we haven't gone this far as yet.

Question (G. Laroche, Quebec Workmen's Compensation Commission): I'm very interested in the persons you observed in your study who were not improved. Did you check to see if this group is made up of older or younger lumberjacks and which group had been exposed for a longer period of time? And did you check to see if they had vasospastic diseases or organic diseases?

Answer: Of the 1,605 persons, 9% were found to have remaining indications of TVD or had deteriorated. As far as I know, included in this group of 9% are people with Raynaud's disease (according to Dr. Taylor's terminology, of having white fingers) for reasons other than vibration. That's all I can say, not being a medical man.

Comment (W. Taylor, University of Dundee): I'm very impressed with two things. The first is the Occupational Health Service. The second is that the improvement in the antivibration saw is terrific. I'm very impressed, indeed, with it.

What bothers me is that if we're going to get anywhere, we'll have to correlate this vibration energy with the medical findings and relate this back to what Dr. Von Gierke called "preventive medicine guidelines." How can we do this if we don't all measure in the same way?

Answer (Mr. Keighley): I think we should let this answer go until Mr. Naeslund's presentation. He may first develop the measurement problem and the frustrations, if you like, from a designer's point of view. I think it's going to be especially interesting to designers of all other tools to know which way to go with a particular tool they're dealing with. We've gone so far with chain saws; where do we go next? We will try to answer this in his presentation.

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