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The effect of wear of petrol engine power brush cutters on their vibration exposure

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Summary: The matter of noise and vibration exposure has an accentuated emphasis in the environmental protection policy of the European Union. In practice, the focus is on the evaluation of noise -strain. The evaluation on human beings' vibration-strain is in focus in recent years. At the Technical Department in Corvinus University of Budapest Faculty of Horticultural Sciences we evaluate in PhD training form the possible ways of alleviation and revealance of noise and vibration-strain in gardening devices and machineries. According to the latest development in gardening culture, small gardening machines are more and more widespread. There is a law in Hungary for the compulsory grass-cutting, especially on 'ragweed' (Ambrosia elatior). Along highways, public territories, parks workmen at least six months are in charge to terminate these weed-crops meanwhile they are endangered by serious harmful effects. The operators of hand-held power tools are exposed comprehensive levels of hand-arm vibration at the tool-hand interface. Many studies indicate that extended exposure to mechanical vibration can induce degeneration of the vascular and sensioneural systems in the hand called hand-arm vibration syndrome (HAVS). The precise mechanism for the initiation and development of HAVS is unclear to date. Measurement and risk assessment of hand-transmitted vibration is mostly based on the guidelines and dose-response relationship provided in the ISO-5349 standard. These guidelines suggest that the magnitude, frequency, direction and duration of vibration exposure are the most important variables for the risk assessment of hand-arm vibration. This current study is focusing on brush cutters owned by one of the biggest caretaker company. These machines have similar brand and age but different in usage time. We inquired seven brush cutters through two years. The manufacturer repaid the vibration level of the new machines, but they doesn't examine, whether extent of the vibration emission is changing for the proper use. We wanted to know that are there any differences between the values of vibration specification after certain time of usage. Is it possible to monitor the alternate movements on graphs according to the vibration sciences? By 1/1 octave band frequency and FFT analysis we can point at that these brush cutters can show differences in critical frequencies. These biases can influence the hand-arm system and its vibration-strain burdening.

Key words: brush cutter, frequency analysis, hand-arm vibration

Introduction

The use of hand-held vibrating tools is common in many different professions such as building industry, mining industry, sylviculture, etc. The tools are different type of size, engine capacity, acceleration amplitude and frequency. Low frequency vibrations (1-20 Hz) usually have effects on the whole body (low back pain, sickness, mobile equilibrium, visual disorders), whereas those of a high frequency (20-1000 Hz), which characterize hand-held power tools, generate cumulative trauma disorders on the hand-arm system (*Griffin*, 1990). The hand-arm vibration syndrome (HAVS) is a complex condition associated with vibration exposure and the use of hand-held vibrating machines.

Giovanni Loriga was the first who described the occurrence of tingling, numbness and finger-whiteness in stone and marble cutters who were using air hammers in 1911 (*Loriga*, 1911). Later in 1918, Leake and colleagues described a condition called dead fingers and noted that ``workmen using pneumatic tools were likely to incur vascular disturbances in the form of a limited type of local anaemia of the fingers which were rendered stiff and temporarily unfit for work'' (*Leake*, 1918). Many studies since then have demonstrated an association between occupational exposure to hand-arm vibration and the symptoms of Hand-Arm Vibration Syndrome (HAVS) (*Bovenzi* et al., 1988; *Bovenzi*, 1994, 1998; *Färkkilä* et al., 1979; *Gemne* et al., 1993; *Gemne*, 1997; *Pyykkö* et al., 1986).

Exposure to vibrating tools may cause a variety of symptoms as shown in *Table 1* (*Griffin*, 1990). The most common clinical manifestations of HAVS are the vascular, neural and muscular symptoms may appear as digital vasospasm called vibration induced white finger (VWF). It is frequently used to refer the vibration induced disorders, because cold-induced reductions in blood flow and blanching of the skin, together with tingling and numbness in the fingers and in the hand is a typical symptom of HAVS (*Chetter* et al., 1998; *Gemne*, 1997; *James & Galloway*, 1975). The HAVS diagnosis is usually based on a history of vibration exposure and the presence of symptoms, and it can be supported by a number of laboratory tests. The Stockholm workshop scales are classifications for the sensioneural (neurogical) (*Brammer* et al., 1987) and vasospastic (vascular) (*Gemne* et al., 1987) symptoms in vibration injury.

The scales measure subjectively perceived symptom severity as interpreted by a physician. The scales are well accepted and are widely used in clinical situations.

Table 1 Health effects of vibration

Skin	Digital sclerosis with increase in skin collagen content and loss of elastic fibers
Vascular system	Digital organic microangiopathy Arterial vasospastic phenomenon of the extremities Digital or more extensive forearm arterial thrombosis
Peripheral nervous system	Vibration neuropathy (demyelinating neuropathy with perineurial fibrosis) Carpal tunnel syndrome
Other health effects	Cysts of the wrist and other osteoarticular lesions Hearing deficits caused by an increase in noise susceptibility

Although the dynamic stress and strain in the soft tissues are believed to result in degeneration and dysfunction in the vascular and neural systems in the fingers, it has not been fully determined how the vibration energy causes hand disorders. Several exposure factors seem, individually and collectively, to play a role in the development of HAVS although the precise mechanism of the various physical characteristics in the production of HAVS is unclear to date. The effects of mechanical vibration on the neural and vascular systems depend on the degree of finger deformation in response to vibration frequency (*Bovenzi* et al., 1988; *Bovenzi*, 1998). The risk of developing HAVS has been reported to depend on the magnitude of vibration transmitted to the tool handle, on the cumulative hours of vibration exposure, on mechanical coupling between the hand and the handle, on frequency weighting and frequency range, on vibration direction, and on the use of anti-vibration tools or anti-vibration gloves (*Griffin*, 1990, 1998).

It is well known that the effects of mechanical vibration on the finger-hand-arm system are strongly frequency-dependent: low frequency vibration can transmit from hand to arm, while high frequency vibration absorbed in the local tissue of fingers. (*Pyykkö* et al., 1976; *Reynolds & Angevine*, 1977; *Sorensson & Lundstrom*, 1992). Dong et al. concluded, that high frequency vibration energy (>100 Hz) is absorbed in fingers (results indicate that, at very high frequencies (>1000 Hz), the vibration induced dynamic strain is concentrated at a tissue depth less than 1 mm, and the vibration energy dissipates at the skin surface layer) while the low frequency vibration (<40 Hz) is transmitted from palm into arm (*Dong* et al., 2005a, 2005b). The examinations showed that the major resonance of the finger is around 100–125 Hz that is independent of the direction of activations and there is a second resonance around 250 Hz. This second resonance of the fingertip is independent of the pre-compression, and the dynamic strain values in the soft tissues reach peak around this frequency. They set it out based on their model that the vibration around a frequency of 250 Hz may likely cause damage to the neural and vascular system (*Wu* et al., 2007). This concerns the workers use brush cutters greatly, because our examinations show that at many machines the vibration emission is higher around in this frequency, although the totally emission was not beyond the limit value.

There is an association with vibration acceleration, latency and prevalence of HAVS (*Färkkilä* et al., 1985). The duration of exposure to vibration needed to produce HAVS cannot be readily defined. This is not only due to different individual susceptibilities to vibration, but also to the different physical characteristics of the vibration exposure (*Pelmear & Leong*, 2000). The prevalence of vascular symptoms in workers using vibrating tools can be as high as 70%, depending on the type and duration of exposure (*Letz* et al., 1992). The period of latency before the appearance of the first symptoms can be as short as 1 year. In a study of 89 platers using vibrating machinery, Nilsson et al. have shown that the prevalence of Raynaud's phenomenon was 8% after 4 years of exposure, 84% after 5 to 9 years and 94% after 10 years. An 11% increase in the odds ratio was observed for each year of vibration exposure (*Nilsson* et al., 1989). Characteristically, there is a latency period, with symptoms typically not appearing until after 2000 hours of vibration exposure (*Miyashita* et al., 1983). The latency periods ranges from 6 weeks to 14 years, which makes it extremely difficult to predict the likely time of onset of the symptoms and their progression (*Gemne*, 1997). Acute sensory impairment was recently demonstrated after an exposure of only 30 min to vibration, in that the vibration perception thresholds increased and numbness developed (*Malchaire* et al., 1998). After 8000 hours of exposure Miyashita et al. reported the presence of symptoms in more than 50% of the forestry workers. The period between the initial exposure to vibration and the onset of symptoms, the latency period, varies considerably between individuals due to differences in the type of exposure and individual susceptibility. However, a higher risk of HAVS is generally expected in a work environment where there is a short mean latency period.

Other variables of importance for the exposure dose (*Griffin*, 1997). In Annex D, ISO 5349-1 states that the effects of hand-transmitted vibration can be influenced by factors such as force and contact area, wrist, elbow and shoulder posture, grip and push forces, body and hand temperature and the users sensitivity to hand-arm vibrations (*ISO 5349*, 2001). There is also evidence that both the vibratory force and the impulse type transmitted from the hand-held tool to the hand affect the manifestation of HAVS.

European Directive 2002/44/EC considers it necessary to introduce measures to protect workers from the risks arising from vibrations. In the Human Vibration Directive 2002/44/EC of the European Parliament and of the Council of June 2002 (*EU*, 2002) new standards are enforced. The daily exposure action value standardized to an 8-h reference period was set at 2.5 m/s^2. The corresponding daily exposure limit value standardized to an 8-h reference period was set at 5 m/s^2 (*Directive 2002/44/EC*, 2002). The International Standard ISO 5349-1 presents the guidelines to evaluate these vibrations, but nevertheless recognises the need to continue investigations in this field (*ISO 5349*, 2001).

The intention of the research was to define the vibration exposure level of the hand-arm-transmitted vibration from the brush cutter's handle to the user's hands'. The aim of this study is to reveal if there is a relationship between the rise of pertaining to vibration charging and the time of use of the brush cutter. We would have liked to know, whether the vibration's frequency characteristic curve is changing during the use. We examined, that on which frequency can be experienced rise and how is having an affect of the workers. Based on suited to valuables we tried to plot a graph and to appreciate growing of the vibration emission.

Materials and methods

Machines used in the experiments

Almost any operator of forestry and agricultural machinery is exposed to whole-body and/or hand transmitted vibration. With improvement of horticulture, the horticultural machinery also getting more and more widespread not only between the park landscaping but in home gardening. These machines make the job easier, they speed it up and they adapted to different jobs such as grass-cutting, hedge-cutting, wood-cutting, spraying, irrigation, etc. The most common job is grass-cutting. This can be finished with two type of tool: with lawnmower or with trimmer or brush cutter. Either sort is obtainable electric and in variant with petrol. The first type is used mostly in gardens and the second mainly in parks, in large areas, along roads.

Trimmers and brush cutters are small machines that use a rapidly spinning plastic line or a metal knife to break off or cut the plants. Trimmers are used for trimming, edging and scalping. Brush cutters have higher mechanical power and used for cutting particularly weeds and high grass. There are several variations of the tool, different in engine size and location, straight or curved shaft and handle shape and location. Therefore, levels of hand-arm vibration exposures vary among models. The tested Husqvarna 343R brush cutter is equipped with a vibration damping system that is designed to minimize vibration and make operation easier. The machines vibration damping system reduces the transfer of vibration between the engine unit/cutting equipment and the machines' handle unit with a spring, or with a rubber blotting-pad. These tools were bought in august 2005 and they used those for various length of time. The company recorded the exact time of use in the tools' register-book (*Table 2*).

Table 2 Machines usage time

Machine serial number	Usage time (hour) until 2006	Usage time (hour) 2006-2007	Total usage time (hour)
52600117	463	637	1100
52600116	274	454	728
52600113	172	302	474
52600115	103	228	331
52600104	120	245	365
52600114	100	331	431
52600118	163	290	453

Methods

At present, risk assessment of hand-transmitted vibration syndrome is based on the international standard (*ISO 5349*, 2001). According to the standard, the risk is proportional to the total vibration energy, i.e. magnitude and duration of exposure. The risk depends also on the frequency of the vibration. ISO 5349 annex A limits the harmful frequencies to 8–1,000 Hz. The standard specifies general methods for measuring and reporting hand-transmitted vibration exposure. In the standard recommendations, the most important quantity used to describe the magnitude of the vibration transmitted to the users' hands is root-mean square frequency-weighted acceleration (SI unit: m/s^2). According to the standard, measurements of the vibration should be done as close as possible to the surface which is in contact with the hand. The vibration levels transmitted to the users' hands were measured under the operating conditions at cutting in the three mutually orthogonal directions. The Svantek product SV 3023M2 triaxial accelerometer hold in SV 50 hand-arm measurements set was matched with an SV 06A four channel input module and a Svan 912AE Sound and Vibration Meter and Analyser. The accelerometer was mounted on an aluminium mounting block, and the block was held into the user's palm and finger as shown in *Figure 1*. The cable was taped along the user's hand to prevent movement. A 1,8 m high, average build male performed the actual running of the machine. We repeated the measurements for three times on each hand. Because we found so, that without exception higner vibration exposure had been worth the right hand, therefore we took this into consideration at appreciation. Preliminary testing established the general characteristics of the acceleration waveform with respect to amplitude and stability of the signal with machine speed. We decided upon measurement time based on the tests to two minutes. Grass cutting operations were done under the same circumstances. We processed the results with the analyser's own software.

Figure 1 The accelerometer's position

Results

We examined seven same aged, but dissimilar usage time Husqvarna 343R type brush cutter. Because we were not interested in vibration effect on human exposure, but inherence between the vibration and the machines' usage time, we didn't use hand-arm weighting filter.

First we studied, whether there is a difference between the exposure on the left and right hand. We found so, that values of the vector acceleration had been almost same (*Table 3*), but the difference was significant between the channels. Turned out from the 1/1 octave-band frequency analysis, the acceleration values of the different frequencies are attaining on the two arms (*Figure 2 and 3*). Because for establishment of the machine the right hand feels better exposing to the exposure, we carried out the comparative examinations with results suited to on the right hand.

Table 3 Acceleration levels on the three axis (right and left hand)

Chan	Fun	Filter	Time	I unitsI	Result	Peak	Min	Max
#1	Val	Lin	00:02'00	I m/s2 I	2.40	14.62	1.84	2.88
#2	Val	Lin	00:02'00	I m/s2 I	2.92	16.41	2.43	3.47
#3	Val	Lin	00:02'00	I m/s2 I	2.54	13.18	1.66	2.85
Vect	Val	MODULE	00:02'00	I m/s2 I	4.57	22.65	3.51	5.19

Chan	Fun	Filter	Time	I units I	Result	Peak	Min	Max
#1	Val	Lin	00:02'00	I m/s2 I	1.14	19.05	0.90	1.36
#2	Val	Lin	00:02'00	I m/s2 I	2.92	16.98	2.32	3.72
#3	Val	Lin	00:02'00	I m/s2 I	2.92	18.41	2.37	3.63
Vect	Val	MODULE	00:02'00	I m/s2 I	4.27	22.91	3.51	5.25

Table 4 shows the two year's measurement results in three axis and vector. It can be seen that on the occasion of the first examination among the seven brush cutter just two had a higher vibration emission than daily exposure action value (2,5 m/s^2), but not reach the corresponding daily exposure limit value (5

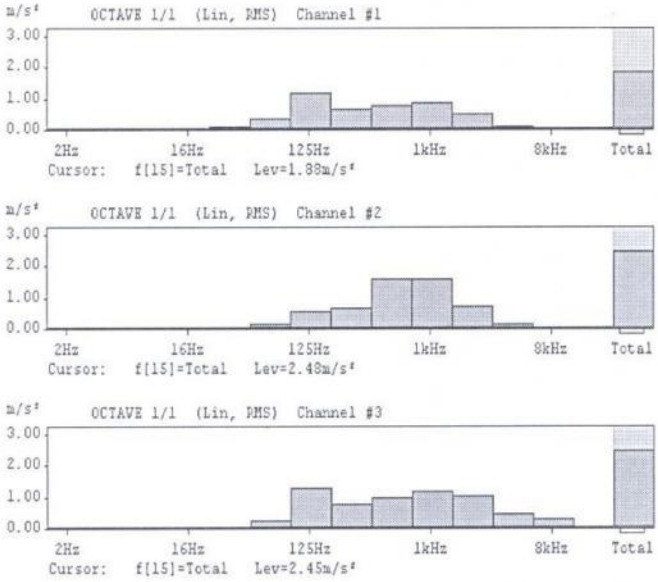

Figure 2 1/1 octave band frequency analysis on the right hand

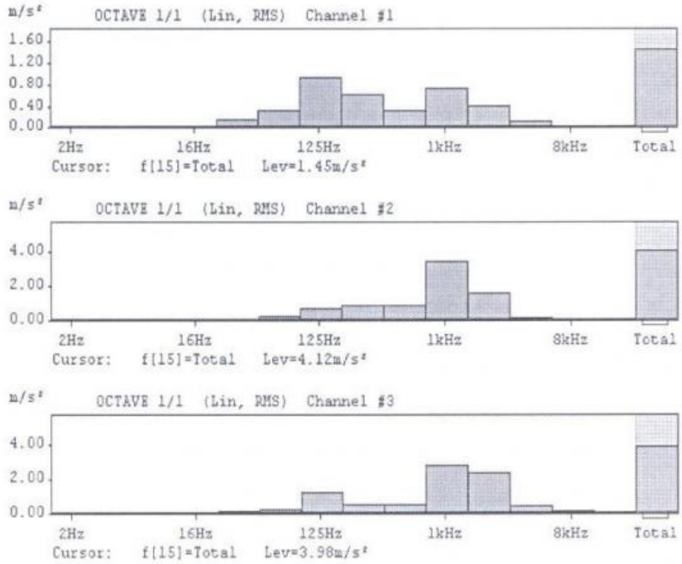

Figure 3 1/1 octave band frequency analysis on the left hand

m/s^2). Because these two brush cutters are used only 4-5 hours a day, the vibration emission counted on eight hours work time is less than the limit value. After a year-old use the vibration level has not rise as high that would have made the user unsafe. The results have been showing already different picture after the second year: there were only two machines where we found lower vibration acceleration than the limit value. These two brush cutters were used the less. The data show that the accelerometer values of the vectors increase with their increase of use. We examined, whether there is a function connection between temporal change of the vibration emission and the time of usage. *Figure 4* shows that a regression analysis was applied to evaluate the relationship between these values. Model fits was checked by means of residual analysis (*Altmann,* 1991). The analyse was performed with the Statistical Package for the Social Sciences. (At evaluation of the data we didn't consider the two lowest acceleration values in the second year examination because these results were unintelligibly dissimilar from the remainder.) It can be seen from the diagram, that there is a relationship between the time of usage and the increase of acceleration value. The spreading of the relationship is 92%. The power function adjusted onto the points shows, that the vibration emission value is higher after about 250 hours use, as the daily exposure action value

Table 4 The brush cutters' acceleration level on three axis and their vector

Machine serial number	Result (m/s^2)							
	x	y	z	vector	x	y	z	vector
52600117	1,95	2,26	1,6	3,39	2,65	3,2	2,2	4,7
52600116	1,06	1,74	1,66	2,63	2,4	2,92	2,54	4,57
52600113	1,26	1,06	1,14	2,00	3,05	1,95	1,84	4,07
52600115	0,85	0,93	1,2	1,74	1,08	0,55	0,57	1,33
52600104	1,01	0,98	0,93	1,69	1,08	1,2	0,56	1,7
52600114	1,24	1,06	1,24	2,05	2,11	1,84	1,36	3,13
52600118	1,95	0,99	0,88	2,36	1,55	2,14	1,8	3,2

(2,5 m/s²). After 1000 hour use the acceleration value have already gained on the corresponding daily exposure limit value (5 m/s²). The results show that in spite of the fact, that into the use at receiving the brush cutter suited the prescriptions, during the use the vibration emission is altering remarkably. This means serious risk regarding the user.

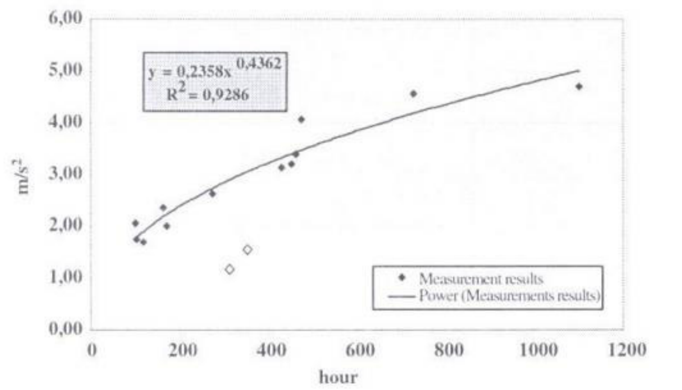

Figure 4 The relationship between the me of usage and acceleration value

Completing the 1/1 octave band frequency analysis it turned out, that at some frequencies there are significant differences in acceleration value with increase of use. The analyser did not make the possible to 1/3 octave band frequency analysis, but we carried out an FFT analysis to identify the critical frequencies which make a contribution to the growing vibration emission of the brush cutter. Based on the analytical outcomes it is not possible to choose only one dominating direction: *Table 5* shows, that around 125 Hz the x direction's acceleration value is the highest, but above this the y and z directions acceleration values become dominant. This cause, that in more occurrences the total value of these two directions is higher than the x direction's (*Figure 5*). It would be a large mistake, if according to practical habits, without finishing frequency analyse we would calculate the acceleration value onto only one direction. Based on our examination results it can be seen, that if we had carried the measurements out in only one direction according to the ISO-3549 standard prescription, the total value of acceleration would have become deformed remarkably. The 1/1 octave band frequency analysis point out, that among these brush cutters the highest vibration exposure can be experienced around two frequency range: 63–125 Hz and 1 kHz. We measured outlier valuables in this lower frequency range in the x directions, while in y and z directions the maximum values were arising in 1 kHz.

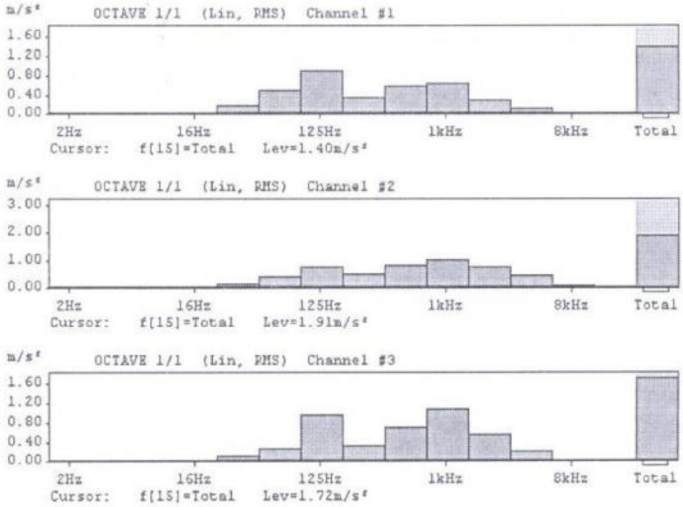

Figure 5 1/1 octave band frequency analysis on 52600118 serial number brush cutter. Channel 2-3 are y and z axis

So that we can determine the critical frequencies more exact, we executed FFT analysis too. (*Table 6*). It turned out from the detailed FFT analysis, that the first and second highest values can be measured mainly between 64,3–152,3 Hz. At the 1/1 octave band frequency analysis fully visible peaks at 1 kHz here not so visible already, rather higher values measurable in this 1/1 octave band medium frequency. We examined, whether there is a difference between acceleration values suited on different frequencies plotted against time of use. Although

Table 5 Acceleration values in 1/1 octave band frequency analysis (results nominated with light-grey colour are the highest values on each axis and the dark grey ones are the second highest)

Machine serial number		Acceler ation value in 1/1 octave band frequencies (mm/s²)													
		2 Hz	4 Hz	8 Hz	16 Hz	31,5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	TOTAL m/s²
52600117															
directions	x	58,9	51,3	53,1	56,9	143	569	**1640**	759	468	313	263	114	49	1,95
	y	20,9	30,2	28,5	50,7	150	335	1020	661	**1170**	**1230**	794	417	166	2,26
	z	20,9	33,9	32,4	42,2	107	266	813	372	**861**	**923**	442	197	100	1,6
52600116															
directions	x	7,08	14,3	22,4	27,2	122	372	**1200**	668	804	**881**	537	120	61,7	1,88
	y	9,66	17,8	27,5	29,5	61,7	162	562	684	**1620**	**1580**	724	200	95,5	2,48
	z	7,24	11,5	16,4	24,3	85,1	302	**1320**	785	1010	**1170**	1060	490	327	2,45
52600113															
directions	x	716	16,2	30,5	24,8	155	912	427	168	**1020**	**1740**	537	130	63,8	2,29
	y	9,12	12,7	16,2	21,4	123	**861**	309	288	700	**1740**	661	184	178	2,19
	z	8,91	21,4	32,4	30,9	302	**1570**	**631**	248	285	367	186	94,4	46,8	1,76
52600115															
directions	x	7,24	13,8	18,2	21,4	56,2	204	**676**	**237**	51,9	31,6	34,3	22,4	37,2	0,733
	y	8,81	13,3	18,6	33,9	71,6	155	**292**	87,1	106	**166**	141	51,9	129	0,437
	z	8,13	17,8	19,7	25,4	43,2	120	**700**	**216**	66,1	80,4	83,2	27,5	60,3	0,741
52600104															
directions	x	14,3	33,5	55	155	351	**891**	**462**	186	248	305	279	107	41,7	1,16
	y	14	23,4	34,3	97,7	355	**966**	**525**	153	385	473	507	257	43,7	1,41
	z	13,8	33,1	71,6	84,1	232	**473**	260	81,3	243	**447**	295	120	65,3	0,832
52600114															
directions	x	18,2	40,3	30,9	49	174	610	**1160**	519	537	**1160**	490	172	65,3	1,93
	y	8,41	23,4	58,9	76,7	263	617	596	407	**724**	**1430**	716	313	70	2
	z	20,7	45,2	45,7	58,2	145	537	**776**	468	403	**700**	389	155	71,6	1,36
52600118															
directions	x	29,2	43,2	41,7	49	195	513	**902**	351	589	**646**	288	129	38,5	1,4
	y	37,6	49	44,2	63,1	193	412	776	531	**832**	**1060**	804	468	132	1,91
	z	20,9	36,3	42,7	50,7	124	272	**955**	327	700	**1070**	569	207	53,7	1,72

Table 6 First and second highest acceleration values on each directions

Machin e serial number		First highest acceleration value		Second highest acceleration value	
		frequency (Hz)	acceleration value (m/s^2)	frequency (Hz)	acceleration value (m/s^2)
52600117					
directions	x	146,5	1,01	152,3	0,966
	y	146,5	0,531	105,5	0,49
	z	146,5	0,475	152,3	0,403
52600116					
directions	x	111,3	0,596	152,3	0,462
	y	726,6	0,55	720,7	0,543
	z	111,3	0,603	158,2	0,49
52600113					
directions	x	64,5	0,75	1130,9	0,596
	y	64,5	0,733	1136,7	0,525
	z	64,5	1,2	70,3	1,07
52600115					
directions	x	146,5	0,403	152,3	0,316
	y	105,5	0,193	99,6	0,166
	z	140,6	0,452	146,5	0,447
52600104					
directions	x	70,3	0,624	46,9	0,473
	y	70,3	0,832	87,9	0,741
	z	46,9	0,313	93,8	0,292
52600114					
directions	x	111,3	0,902	117,2	0,692
	y	111,3	0,403	76,2	0,316
	z	111,3	0,708	117,2	0,569
52600118					
directions	x	87,9	0,437	93,8	0,417
	y	134,8	0,32	87,9	0,305
	z	134,8	0,462	128,9	0,442

the vector' acceleration level increased during the use, the highest values fell into the same frequency range. One difference appears: parallel to increase time of use, a second peaks appear around other frequencies at y and z axis (*Figure 6*).

Discussion and Conclusion

The term 'hand-arm vibration syndrome' (HAVS) is used collectively for the different symptoms associated with manual work involving vibration power tools. These symptoms, which include vascular, bone, musculoskeletal and neurogical disorders have also been recognised as an important preventable occupational disease (*Gemne*, 1997). The examinations pointed out that there is a cumulative effect of vibration on both the vascular and sensorineural components of the HAVS (*Bovenzi*, 1990; *Färkkilä* et al., 1982; *Lundström* et al., 1995). However, the different components appear to occur and progress independently of each other (*Pelmear & Leong*, 2000).

Our examinations finished with Husqvarna 343R type brush cutter brought the following results:

- We received almost the same total acceleration value on left and right hand, but the results were dissimilar in the three axis and depend on frequency range.
- It was found, that the dependents of acceleration values vs. usage time can be approximated by a power function. Because we carried out the measurements from statistic angle on few machines it is necessary to do more examinations on other machines, not just on other pieces, but on other types to definition the more exact connection. After definition the connection there will be a possibility to appreciate, when reach the machine to the limit value of acceleration. This might be a good prime data for safety use and for the maintenance.
- Risk of the damage is increases with acceleration value. It has to examine with use of human filters, what is the connection between the time of usage and the

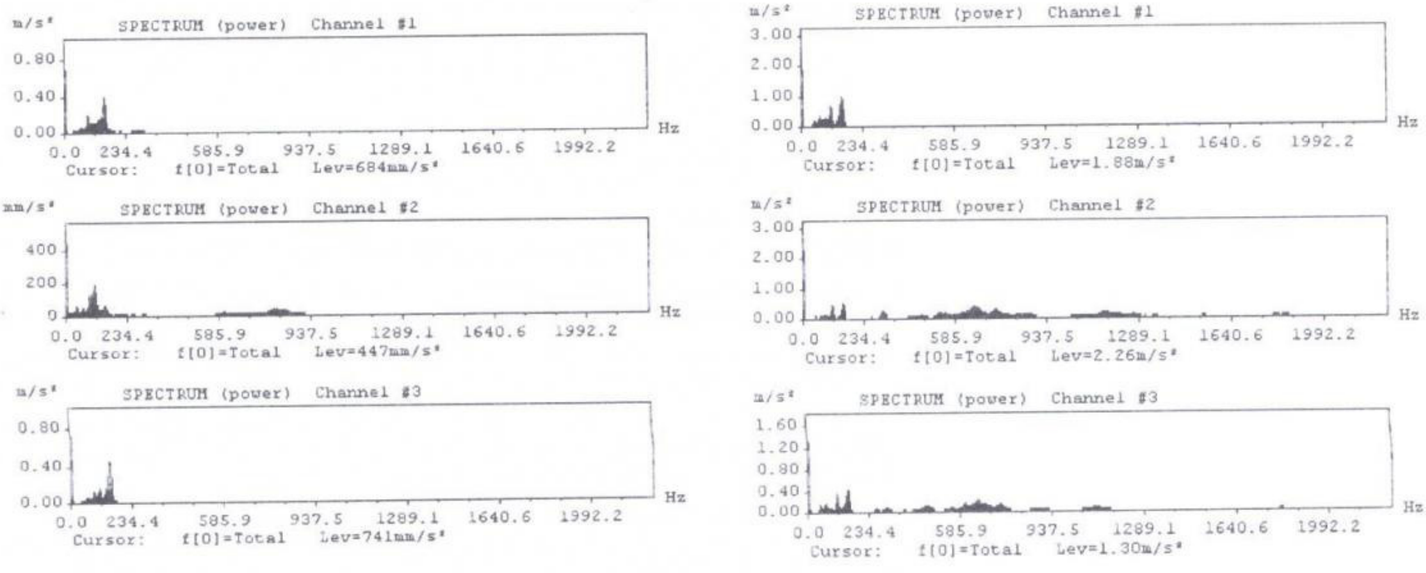

Figure 6 Spectrum analysis of the fewest and the more used brush cutter

acceleration values. Based on the results must defined, when will the machine reach the limit acceleration value. After this it is necessary to protect the workers for example with reduction of work time (*Table 7*) (*Lin* et al., 2005).

Table 7 Limited values of exposure to hand-transmitted vibration

Frequency weighted acceleration m/s	Exposed time per day h
5,00	4,0
6,00	2,8
7,00	2,0
8,00	1,6
9,00	1,2
10,00	1,0
> 10	<0,5

- It can be seen from the 1/1 octave band frequency analysis and from FFT analysis, that it is not a good practice to define the total accelerometer value in one dominating direction, because acceleration values of all three axis are significant at these results. The largest acceleration values decreased among 64,3-152,3 Hz and according to the 1/1 octave band frequency analysis, there were second peaks around 1 kHz. The analysis pointed out that the highest acceleration values can be measured on that frequencies (around 125 Hz), which are the most harmful onto the human hand. With increase of use second peaks appear around other frequencies at y and z axis. In the future, during the drafting the factory must intend to remove this.

Any vibrating tool in contact with the hand with a different frequency range may inflict adverse effects after exposure for a critical period of time. HAVS can be reversible, at least in the earlier stages (*Färkkilä* et al., 1986). Appearance of the symptoms continued use of vibrating tools should be avoided (*Ogasawara* et al., 1997). If the same level of vibration exposure continues, severe disability will inevitably occur. If vibration exposed workers will receive appropriate information and training to prevent the development of HAVS, the illness will be avoided. Safe working practices to minimize the exposure to mechanical vibration should be undertaken. Objective measurements of the vibration exposure and estimations of the vibration dose will facilitate risk assessment and increase the possibilities for preventive actions. Other factors of importance are the risk of underestimating the effect due to diagnostic uncertainties, the biological variation and the healthy worker effect (*Gemne*, 1997). They should pay more attention to the design and use of ergonomic tools, the use of gloves, reduction in the intensity of vibration transmitted to the hand by the use of damping techniques and, probably most importantly, reduction of vibration exposure by the correct organization of work and enrolment of breaks.

References

Altman, D.G. (1991): Practical Statistics for Medical Research. London. Chapman & Hall

Bovenzi M. (1990): Medical aspects of the hand-arm vibration syndrome. International Journal of Industrial Ergonomics 6: 61-73.

Bovenzi M. (1994): Hand-arm vibration syndrome and dose-response relation for vibration induced white finger among quarry drillers and stone-carvers. Italian Study Group on Physical Hazards in the Stone Industry. Occupational and Environmental Medicine 51: 603–611.

Bovenzi M. (1998): Exposure-response relationship in the hand-arm vibration syndrome: an overview of current epidemiology research. International Archives of Occupational and Environmental Health 71 (8): 509–519.

Bovenzi M., Franzinelli A., Strambi F. (1988): Prevalence of vibration-induced white finger and assessment of vibration exposure among travertine workers in Italy. International Archives of Occupational and Environmental Health 61 (1–2): 25–34.

Bovenzi, M. (1998): Exposure–response relationship in the hand-arm vibration syndrome: an overview of current epidemiology research. International Archives of Occupational Environmental Health 71: 509–519.

Brammer A., Taylor W., Lundborg G. (1987): Sensioneural stages of the hand-arm vibration syndrome. Scandinavian Journal of Work, Environment and Health 13: 279–283.

Chetter I.C., Kent P.J., Kester R.C. (1998): The hand-arm vibration syndrome: a review. Cardiovascular Surgery 6 (1): 1–9.

Directive 2002/44/EC, of 25 june 2002: On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration), Official Journal of the European Communities. 13–17.

Dong R.G., Wu J.Z., Welcome D.E., McDowell T.W. (2005a): Estimation of vibration power absorption density in human fingers. Journal of Biomechanical Engineering 127 (5): 849–856.

Dong R.G., Wu J.Z, McDowell T.W, Welcome D.E., Schopper A.V. (2005b): Distribution of mechanical impedance at the fingers and the palm of the human hand. Journal of Biomechanical Engineering 38 (5):1165–1175.

Färkkilä M., Aatola S., Starck J., Pyykkö I., Korhonen O. (1985): Vibration induced neuropathy among forest workers. Acta Neurologica Scandinavica 71:221–225.

Färkkilä M., Aatola S., Starck J., Korhonen O., Pyykkö I. (1986): Hand-grip force in lumberjacks: two-year follow-up. International Archives of Occupational and Environmental Health 58: 203–208.

Färkkilä M., Pyykkö I., Korhonen O., Starck J. (1979): Hand grip forces during chain saw operation and vibration white finger in lumberjacks. British Journal of Industrial Medicine 36: 336–341.

Färkkilä M., Pyykkö I., Starck J., Korhonen O. (1982): Hand grip force and muscle fatigue in the etiology of the vibration syndrome. In: Brammer A, Taylor W (Eds) Vibration Effects on the Hand and Arm in Industry. New York. John Wiley & Sons.

Gemne, G., (1997): Diagnostics of hand–arm system disorders in workers who use vibrating tools. Occupational and Environmental Medicine 54: 90–95.

Gemne G., Lundström R., Hansson J.E. (1993): Disorders induced by work with handle-hand vibrating tools. A review of current knowledge for criteria documentation. Arbete och Hälsa 6.

Gemne G., Pyykkö I., Taylor W., Pelmear P. (1987): The Stockholm Workshop scale for the classification of cold-induced raynaud's phenomenon in the hand-arm vibration syndrome (revision of the Taylor-Pelmear scale). Scandinavian Journal of Work, Environment and Health 13: 275–278.

Griffin, M.J. (1990): Handbook of Human Vibration. London. Academic Press

Griffin, M.J. (1997): Measurement, evaluation, and assessment of occupational exposures to hand-transmitted vibration. Occupational Environmental Medicine 54: 73–89.

Griffin, M.J. (1998): Evaluation of the effectiveness of gloves in reducing the hazards of hand-transmitted vibration. Occupational Environmental Medicine 55: 340–348.

ISO 5349 (2001): Mechanical Vibration. Measurement and Evaluation of Human Exposure to Hand-transmitted Vibration, International Organization for Standardization, Geneva, Switzerland

James P., Galloway R. (1975): Arteriography of the hand in men exposed to vibration. In: Taylor W., Pelmear P. (Eds): Vibration white finger in industry 4: 31–41 London. Academic Press

Leake J. (1918): Health hazards from the use of the air hammer in cutting indiana limestone. Bulletin U.S. Bureau of Labor Statistics 236: 100–113.

Letz R., Cherniack M.G., Gerr F., Hershman D., Pace P. (1992): A cross sectional epidemiological survey of shipyard workers exposed to hand-arm vibration. British Journal of Industrial Medicine 49: 53–62.

Lin W., Chunzhi Z., Qiang Z., Kai Z., Xiaoli Z. (2005): The study on hand-arm vibration syndrome in China. Industrial Health 43:480–483

Loriga G. (1911): Il lavoro con i martelli pneumatici. Bolletino dell' Ispettorato del Lavoro 2: 35–60.

Lundström R., Nilsson T., Burström L., Hagberg M. (1995): Vibrotactile perception sensitivity and its relation to hand-arm vibration exposure. Central European Journal of Public Health 3: 62–65.

Malchaire J., Rodriguez Diaz L., Piette A., Goncalves Amaral F., de Schaetzen D. (1998): Neurological and functional effects of short-term exposure to hand-arm vibration. International Archives of Occupational and Environmental Health 71: 270–276.

Miyashita K., Shiomi S., Itoh N., et al. (1983): Epidemiological study of vibration syndrome in response to total hand-tool operating time. British Journal of Industrial Medicine 40: 92–98.

Nilsson T., Burstrom L., Hagberg M. (1989): Risk assessment of vibration exposure and white fingers among platers. International Archives of Environmental Health 61: 473–481.

Ogasawara C., Sakakibara H., Kondo T., Miyao M., Yamada S., Toyoshima H. (1997): Longitudinal study on factors related to the course of vibration-induced white finger. International Archives of Occupational and Environmental Health 69: 180–184.

Pelmear P.L., Leong D. (2000): Review of occupational standards and guidelines for hand-arm (segmental) vibration syndrome (HAVS). Applied Occupational and Environmental Hygiene 15: 291–302.

Pyykkö I., Farkilla M., Toivanen J., Korhonen O., Hyvarinen J. (1976): Transmission of vibration in the hand-arm system with special reference to changes in compression force and acceleration. Scandinavian Journal of Work, Environment and Health 2: 87–95.

Pyykkö I., Korhonen O., Färkkilä M., Starck J., Aatola S., Jantti V. (1986): Vibration syndrome among Finnish forest workers, a follow-up from 1972 to 1983. Scandinavian Journal of Work, Environment and Health 12: 307–312.

Reynolds D., Angevine E.N. (1977): Hand-arm vibration, part II: Vibration transmission characteristics of the hand and arm. Journal of Sound and Vibration 51: 255–265.

Sorensson A., Lundstrom R. (1992): Transmission of vibration to the hand. Journal of Low Frequency Noise and Vibration 11: 14–22.

Wu J.Z., Welcome D.E., Krajnak K., Dong R.G. (2007): Finite elements analysis of the penetrations of shear and normal vibrations into a soft tissues in a fingertip. Medical Engineering and Physics 29 (6): 718–727.