EVALUATION OF THE EFFECTIVENESS OF TOOL TIMERS FOR ESTIMATION OF DAILY EXPOSURE TIME TO HAND-ARM VIBRATION

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1 INTRODUCTION

The aim of this work is to evaluate the effectiveness of different types of tool timers for the estimation of daily exposure time for hand-transmitted vibration. The Health and Safety Executive (HSE) previously had little information available to advise on the merits (or otherwise) of tool timers as part of a vibration control program. Duty holders have begun to rely on tool timers to determine their workers' exposure to hand-arm vibration. The results from this study will allow HSE to provide duty holders with better information regarding the use of tool timers in managing employee exposures to hand-arm vibration. This is ongoing work and additional tests are planned to improve the data set.

Tool timers can be strapped directly onto the power tool or worn by the worker. They measure the amount of time a worker is using the power tool by detecting vibration or power flow. Some devices also measure the vibration emitted from the power tool. Using the time and a pre-programmed, or measured, vibration magnitude some devices then calculate HSE exposure points. This is with a view to notifying the user when they reach the Exposure Action Value (EAV) and/or the Exposure Limit Value (ELV) as defined in the Control of Vibration at Work Regulations 2005 (CVWR) [1].

Within this study six different tool timers were evaluated. In brief:

- Two devices were mounted directly onto the power tool ("machine timers" according to BS/PD ISO/TR 19664:2017 [2]).
- Two were wearable devices. One was wrist worn; the other was worn between the fingers of the operator ("exposure timers" according to BS/PD ISO/TR 19664:2017 [2]).
- Two devices were in-line machine timers that monitor the power supply to the power tool (air flow or electric current).

Table 1 describes each tool timer and how it functions in more detail.

2 METHOD

To evaluate the effectiveness of the six tool timers, measurements of the timing accuracy, and where appropriate vibration magnitudes, were carried out at the HSE laboratory and during three site visits. A range of different power tools were used. For all measurements, video footage was recorded to provide a reference measure of the time for which a power tool was in use. Vibration magnitudes were also measured by HSE. During the three site visits a triaxial accelerometer was attached to the handle of the power tool, which was connected to a hand held vibration meter. During the HSE laboratory measurements, three single axis accelerometers fixed to a custom-made aluminium mounting block were rigidly fixed to the handle of the power tool. The transducers were then connected to a Brüel & Kjær Pulse Analysis system.

For measurements during the site visits, power tool operators were instructed to use the power tool as they would under normal working conditions. This included switching the power tool on and off and running it in different modes. The operating time of the power tool varied, depending on its typical use.

For measurements at the HSE laboratory, an initial 30-second continuous measurement was made for each tool, followed by six 5-second 'stop-start' measurements. The 30-second measurement period allowed for the determination of the dominant frequency and the vibration magnitude of the power tool. The 5-second 'stop-start' measurement period, repeated six times, was used to determine the effectiveness of the timing device.

Table 1 Brief description of each tool timer and how each device works

Device	Pre-programmed vibration magnitude	Measures a vibration magnitude	Properties
A	Yes programmed by the manufacturer, the user cannot change it	No	This device is in two parts; one part attaches directly to the machine, stores the vibration information and acts as the holder for the other part which monitors exposure time. The individual monitors are allocated to employees who are responsible for moving them from machine to machine to collect exposure information. The device does not have a display screen but does have a red LED to indicate the exposure limit is reached.
B	No	Yes	Intended to be worn between the fingers of the worker. The device is designed to be small enough to wear under gloves. The device has a visual alarm to indicate the exposure limit has been reached.
C	Yes, the device is synced to tags on tools	Yes	A wrist-worn device that records the time and displays exposure points on a screen. The device calculates exposure points using a predefined vibration magnitude combined with a 'sensed' vibration during use. Sound and vibration indicate the exposure limit has been reached.
D	Yes, manually input by the user	No	The timer is attached directly to the tool using cable ties or a Velcro strap. A screen displays the time that the tool has been running for and calculates exposure points. The device flashes to indicate when the exposure limit has been reached.
E	No	No	The device is connected in-line with pneumatic tools. It measures the time that the tool is switched on by detecting air flow. It does not measure vibration or calculate exposure points. It does not have any alert system.
F	No	No	This device works in the same way as device E but it is designed for mains powered electric tools.

3 RESULTS

Devices A to C were evaluated during the three site visits. Devices E to F were evaluated at the HSE laboratory. Device D was evaluated during a site visit and at the HSE laboratory.

3.1 Device A (site visit 1)

It was not possible to make any measurements with this device on site. The host site had several devices set up on different power tools ready for evaluation. However, some of the devices were already indicating that the ELV had been reached when neither the devices nor the power tools had been used that day. As it was unclear what the devices had recorded it was decided to not continue the testing.

The device uses the timer function combined with a pre-programmed vibration magnitude to calculate when the operator has reached the ELV. HSE attempted to explore what vibration magnitude was programmed into the device in order to make some assessment of its functions.The device supplier had not informed the host site what vibration magnitudes had been pre-programmed in to each of the devices. It was not possible to work out what magnitude had been pre-programmed.

3.2 Devices B and C (site visit 2)

Devices B and C were evaluated over six measurements using the power tools and attachments listed in Table 2. The results of the timing measurements are presented in Table 3 and Figure 1. The results of the vibration magnitude measurements for Device C are presented in Table 4.
No vibration magnitude data is reported for Device B. This is because the device constantly logged vibration information including lifting the power tool into and out of position. From the vibration data collected by Device B it was not possible to distinguish between power tool use and other logged activity.
For testing of Device C, the device was worn on the right wrist of the operator for all tests. The vibration magnitude measurement was taken at a position on the handle of the power tool, close to the operator's right hand.

Table 2 Power tools for site measurements with Devices B and C

Test no.	Description	Inserted tool	Dominant frequency (Hz)
1	Trench rammer (new)	11 inch plate	Unknown
2			
3	Trench rammer (used)	6 inch plate	160
4	Trench rammer (recently serviced)	11 inch plate	80
5	Cut-off saw	Abrasive cutting disk	160
6	Plate compactor	12 inch plate	63

Table 3 Timing results for Devices B and C compared to HSE measured time

Test no.	HSE measured time (mm:ss)	Device B time (mm:ss)	% Difference between Device B and HSE	Device C time (mm:ss)	% Difference between Device C and HSE
1	05:53	06:02	+3 %	05:50	-1 %
2	04:27	04:29	+1 %	04:29	+1 %
3	05:45	05:11	-10 %	05:50	+1 %
4	05:19	05:30	+3 %	05:25	+2 %
5	00:26	00:57	+119 %	01:05	+150 %
6	01:52	03:04	+64 %	02:41	+44 %

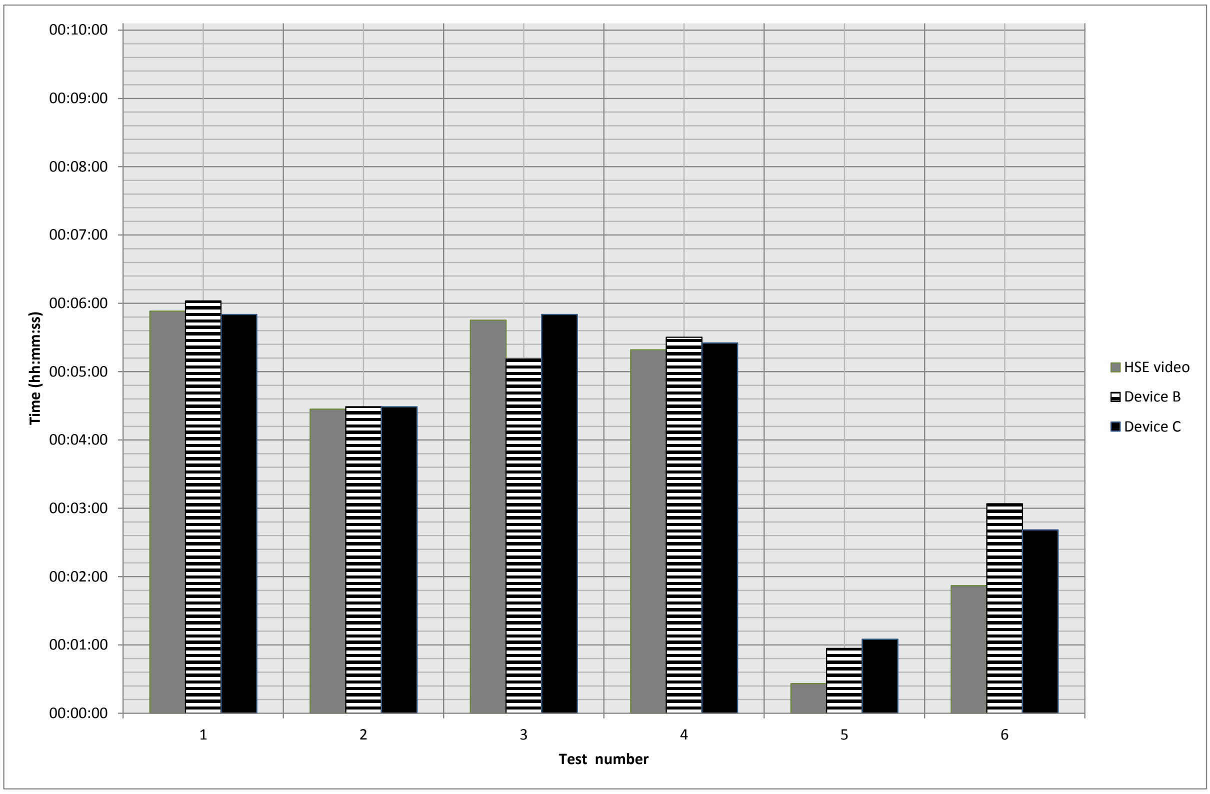

Figure 1 Timing data for Devices B and C plotted with the HSE measured time

Table 4 Vibration magnitude results for Device C compared to HSE measured vibration magnitude. HSE measured the vibration on the handle of the power tool that corresponded to the same wrist that the operator wore the device.

Test no.	HSE measured vibration magnitude (m/s²)	Device C measured vibration magnitude (m/s²)	% Difference between Device C and HSE
1	6.8	9.6	+41 %
2	18.0	17.7	-2 %
3	8.6	12.2	+42 %
4	15.0	14.9	-1 %
5	4.5	11.8	+162 %
6	8.1	9.4	+16 %

3.3 Device D (site visit 3)

Device D was attached to a professional contract mower. Device D was pre-programmed with a vibration magnitude of 2.6 m/s². Two test runs were carried out. The results for the timing parameter are shown in Table 5.

Table 5 Timing results for Device D compared to HSE measured time

Test no.	HSE measured time (mm:ss)	Device D time (mm:ss)	% Difference between Device D and HSE
1	08:52	07:39	-14 %
2	04:37	03:55	-15 %

3.4 Devices D, E and F (HSE laboratory)

Devices D, E (for pneumatic tools) and F (for electric tools) were evaluated over six measurements using the power tools, attachments and work pieces described in Table 6. The results of the timing measurements are presented in Table 7.

Table 6 Power tools for laboratory measurements on Devices D, E and F

Test no.	Description	Inserted tool	Dominant frequency (Hz)
1	Pneumatic random orbital sander	125 mm 2000 grit, sanding steel block	125
2	Electric orbital sander	Used without sand paper on steel block	160
3	Pneumatic polisher	200 mm polishing mop on steel block	31.5
4	Electric nibbler	2 mm	31.5
5	Pneumatic stone hammer	100 mm test bit in rigid test fixture	63
6	Electric rotary hammer drill	150 mm test bit in rigid test fixture	20

Table 7 Timing results for Devices D, E and F compared to HSE laboratory measured time

Test no.	HSE measured time (mm:ss)	Device D (mm:ss)	% Difference between Device D and HSE	Device E/F (mm:ss)	% Difference between Device E/F and HSE
1	05:08	06:11	+20 %	05:07	0 % (E)
2	06:11	06:42	+8 %		
	05:09*			05:37*	+9 % (F)
3	05:05	06:05	+20 %	05:09	+1 % (E)
4	08:51	08:11	-8 %	06:22	-28 % (F)
5	05:50	06:33	+12 %	05:47	-1 % (E)
6	07:01	06:24	-9 %	06:40	-5 % (F)
*Based on 5 tests rather than 6					

4 DISCUSSION

4.1 Laboratory and site measurements of timing and vibration magnitudes: Devices A to F

The requirements of the evaluation process and the availability of the devices, power tools and sites, meant it was not possible to evaluate all devices in exactly the same way.

4.1.1 Device A

Despite not being able to collect any results for this device, the concept of how the device works can be discussed. The programmed vibration magnitude data for the device under test was unavailable; however, the device can be either be supplied with a specific value or a generic vibration value. Once the device is programmed by the manufacturer it is not possible to change it.

The manufacturer also does not appear to keep records of what vibration magnitude has been programmed. The device sends the time data it collects back to a computer software system where, together with the programmed vibration magnitude, HSE exposure points are calculated. The generalisation and lack of flexibility in the programming of the vibration magnitude could foreseeably lead to a points total which over- or under-estimates actual exposure.

4.1.2 Device B

This device measures vibration magnitude as well as time and from this calculates HSE exposure points. The device flashes different colours to indicate when the EAV and the ELV have been reached. This device works with software that allows the user to see a time history which can help to identify periods of time with high or low vibration magnitudes.
Due to the fact this device is constantly measuring the vibration magnitude; it picks up extraneous information; for example, when the trench rammer was moved into and out of position before and after actual operation. This can lead to false information within the time history making the device over cautious. This is reflected in the range of timing results for this device which were found to be inconsistent. When the measurement time was greater than 4½ minutes the range was -10 % to +3 %; less than 4½ minutes and the range was +64 % to +119 %.
The vibration magnitude data measured by this device are not included in the results presented here. This is because the device constantly logged vibration information including lifting the power tool into and out position. From the data collected it was not possible to distinguish between power tool use and other logged activity.
During the testing process the operator complained that the device was painful and uncomfortable to wear when using the power tools. This raises concerns as to whether the operators would wear and use this device as intended. The device is designed to be worn between the fingers and fits well under gloves. However it is unclear how workers are supposed to see the visual alarms when they are wearing gloves.
This device's software produced a lot of data and graphs. Whilst this information was useful in HSE's analysis of this device, it was questioned whether duty holders would make use of this feature, or just wait until the device flashes to indicate when the exposure action and limit values have been reached.

4.1.3 Device C

This device is in two parts. The wrist-worn element has to be synchronised with magnetic tags on the power tool before use. These tags contain a pre-programmed vibration magnitude for the power tool. The wrist worn device measures the time and also a 'sensed' vibration. During testing there were difficulties syncing the device to the power tool. The device relies on syncing the two elements to carry out its exposure points calculation.
The device's timing ability was found to be accurate to within 3 % of HSE's measured time for durations greater than 4½ minutes. During test 1 the power tool was switched on and off several times. It was found that the device did not register the switching and continued to log time.
This device uses the pre-programmed vibration magnitude to calculate exposure points. Additionally it uses a magnitude based on its built-in vibration sensor, which is measuring at the wrist, to calculate 'sensed' exposure points. The vibration information was found to be inconsistent, ranging from -2 % to +162 % difference compared to the HSE measured vibration magnitude. It was within 2 % of HSE's measured vibration when the vibration magnitude was greater than 15 m/s^2.

4.1.4 Device D

The device records time and clearly displays this on its screen. It requires re-programming with a vibration magnitude for each power tool used. The programming is straightforward to do. Using the time information and the pre-programmed vibration magnitudes the device calculates exposure points. The device was evaluated in the HSE laboratory and on site.
Site testing timing results showed a -14 % to -15 % difference compared to the HSE measured time. The test on site involved two long periods of mowing with a break in between. The area that was mowed was flat and unremarkable. It was anticipated that there would not be a large

percentage difference. A -14 % to -15 % difference underestimates the actual running time of the mower and therefore underestimates exposure points.
Laboratory results showed a -9 % to +20 % difference compared to the HSE measured time. This can be broken down further to -9 % to +8 % for electric power tools and +12 % to +20 % for pneumatic power tools. In both cases compared to the HSE measured time, this device is under- and over-estimating time.
As this device requires the user to input the vibration magnitude for each different power tool they use, it was questioned whether workers would use the device as intended, or opt to use a single vibration magnitude for the duration of work, regardless of the power tool in use.

4.1.5 Device E

Device E is designed for pneumatic power tools. It is connected to the air line between the power tool and the air supply, such that the air going to the power tool must pass through the timer first. It only recorded time when the power tool was drawing air through the line.
The timing results were within 2% of the HSE measured time. An observation during testing was that the device did not account for the period in which the power tool was running down after the trigger was released. This could lead to a small under estimate of exposure time. The run down time for the power tools used was a handful of seconds.
The device worked like a stopwatch; it is not designed to record any form of vibration or calculate exposure points.

4.1.6 Device F

Device F is connected in line with electric power tools. The device measures only time and works by detecting current drawn through the power cable.
The timing results ranged from -28 % to +9 % difference compared to the HSE measured time, a range of 37 %. This could lead to an over-estimate of exposure time. As with Device E, this device does not account for any run down time of the power tool.
Whilst the device is easy to use, it is quite large and because it has to be connected in line with the power tool, manoeuvrability of the power tool is reduced. It may not be practical in a workplace.

4.2 Supplementary test: transportation of Device D in a vehicle

The aim of this test was to determine if a device picked up any 'tool use' whilst being transported. It is possible that the travelling motion could activate the device, leading to inaccurate timing information. Timer D was attached to a power tool (with the power tool's vibration magnitude programmed into the device) and placed unsecured in the back of a van. The van was driven around a series of tarmac roads and rougher tracks. During these tests this device did not record any 'use'.

4.3 Possible causes for variations in timing measurements

Devices intended to be worn on the body, such as Devices B and C, may detect 'use' on power tools with internal combustion engines that use a draw cord for starting. The sudden and sharp motion of drawing the cord could be enough to activate the timing functionality of the device. In test 5 using Devices B and C, it took 5 pulls on the draw cord to start the cut-off saw. During this test percentage differences can be seen of +119 % and +150 %, for Devices B and C respectively, Also, the measured vibration magnitude from Device C was +162 % different from the HSE magnitude.
For devices fixed directly to a power tool when left idling, it is possible that the device will continue to log time (and measure vibration magnitude if it has this functionality). The worker may not have their hands on the power tool and hence not be exposed to any vibration. The power tool used in test 6 on site visit 2 was turned on and left idling. The worker repeatedly took their hands on and off the power tool whilst preparing the work activity. This possibly contributed to the timing difference, which was +64% for Device C and +44% for Device D.

4.4 Comment on vibration magnitudes

4.4.1 Devices with a pre-programmed vibration magnitude

Devices that calculate exposure points from time and pre-programmed vibration magnitude information are reliant on those vibration magnitudes being representative of the power tool's use, operation, maintenance and age. Whilst independent of a device's timing functionality, there is a risk that over- or underestimation of exposure points will occur should non-representative vibration magnitudes be used.

4.4.2 Devices measuring vibration magnitude

Devices calculating exposure points from time and a measured vibration magnitude are reliant on those vibration magnitudes being representative of the power tool's use and operation. BS EN ISO 5349-1:2001 [3] and BS EN ISO 5349-2:2002 [4] clearly state the requirements for the measurement and evaluation of human exposure to hand-transmitted vibration. The two devices evaluated in this study that measure vibration magnitude - B worn between the fingers and C worn on the wrist - do not meet the requirements of these standards.

5 CONCLUSIONS

Tool timers should be used with caution. With the exception of Device E (in-line pneumatic timer), none of the devices evaluated were consistent or reliable in their timing functionality when compared to the HSE measured time. Over the 25 time measurements across the six devices, the percentage difference range was -28 % (Device F) to +150 % (Device C). For 15 of these measurements the percentage difference was -10 % to +10 %. Users need to be aware of the pitfalls of their chosen device. This is ongoing work and additional tests are planned to improve the data set.

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6 REFERENCES

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4. BS EN ISO 5349-2:2002 Mechanical Vibration – Measurement and evaluation of human exposure to hand-transmitted vibration. Part 2: Practical guidance for measurement at the workplace