Reducing Vibration in Armoured Tracked Vehicles

ABSTRACT

The vibration level in an armoured vehicle is an important consideration due to its effects on human health, crew fatigue and system reliability. Reducing vibration in armoured vehicles is necessary to ensure that the crew is safe and efficient. This article highlights how human health is affected by exposure to vibration and the relevant standards to monitor its effects. It also discusses the evaluation and analysis of vibration levels in armoured vehicles, outlines three approaches to reduce vibration, and suggests some practical measures that can be adopted for armoured platforms.

Kaegen Seow Ee Hung
Tan Teck Chuan
Ang Liang Ann

INTRODUCTION

The main design consideration for armoured vehicles is usually to maximise lethality, survivability and mobility. The performance of an armoured platform can also be affected by vehicular vibration. Vibrations generated by armoured vehicles during operations can affect human health and cause components to fail prematurely. Their effects are slow but may lead to dire consequences. Generally powered by a running track system, armoured vehicles generate much higher vibration levels as compared to commercial wheeled vehicles. There is a need to monitor the vibration level closely so that it will not lead to health problems.

The effects of vibration on humans are subjective. An acceptable vibration level for one can be intolerable to another. A credible assessment of vibration in a vehicle must be based on standards and guidelines that are widely recognised. The advancement of technologies has provided innovative solutions that can reduce vibration. With increased emphasis on Human Factor Engineering, the design of many armoured platforms now places greater importance on human factors such as crew safety and comfort. This article outlines the harmful effects of vibration and provides a general guideline for the assessment of vibration levels. It also shares different approaches to reduce vibration for the vehicle crew to function efficiently with minimal health risks.

HARMFUL EFFECTS OF VIBRATION

Vehicle vibration refers to mechanical oscillations of the vehicle body and subsystems, caused mainly by the engine and running gear system. Excessive vibrations in a vehicle are undesirable as they cause considerable crew discomfort and unwanted noise. Technically, there are two main types of vibration that will affect human health: Hand-Arm Vibration and Whole-Body Vibration (WBV).

Hand-Arm Vibration refers to vibrations transmitted from hand-held devices to the hands and arms, which can lead to localised damage such as Raynaud's syndrome. This type of risk is more commonly found in workers using powered hand tools for prolonged periods (Occupational Health Clinics for Ontario Workers Inc, 2005).

WBV refers to vibrations transmitted by the body's supporting surface, such as the legs when standing and the back when sitting. Short-term WBV can cause chest discomfort, nausea, headaches and fatigue, while long-term exposure can lead to serious health problems mainly affecting the lumbar spine and connected nerves systems, such as lumbar scoliosis (Occupational Health Clinics for Ontario Workers Inc, 2005).

Human response to WBV depends on the vibrating frequency and its acceleration, as well as the exposure periods. Low frequency vibrations in the range of 1-80Hz are more harmful to humans. The resonance frequencies of many human organs also lie within this range (CSTI Acoustics, 2006). In particular, studies have shown that WBV in the frequency range of 4-8Hz is most damaging, especially to the lower back region (Occupational Health Clinics for Ontario Workers Inc, 2005). Increased intensity and duration of the exposure to vibrations can lead to greater health risks. However, research on the quantitative relationship between vibration exposure and health risks is inconclusive. Thus, there is no accurate assessment of the probability of risk at various degrees of exposure and durations (ISO 2631-1, 1997).

Vibration can generate excessive noise which may hurt eardrums and aggravate crew discomfort. In general, higher vibration levels lead to greater noise. The noise levels in a vehicle also peak at certain travelling speeds due to air resonance. In an enclosed cabin such as the crew compartment in an armoured vehicle, vibrations from the running gear system or the response to terrain or road conditions (e.g. slopes and rocks) can excite the air to resonance level. This phenomenon is termed acoustic or cabin booming. Cabin booming can cause unacceptable sound pressure levels in the crew cabin (Cherng et al., 2003). Together with WBV, cabin booming intensifies crew discomfort and fatigue. Externally, the loud noise produced by armoured vehicles also allows the enemy to detect them more easily.

Vibration is also known to shorten the service life of electronic and machinery components such as electronic boards and cards, computers, engine, transmission and piping system. When exposed to vibration, machinery components can fracture under repeated loading. The rate of wear and tear will also increase, resulting in premature failure of machine parts. Component breakdown may disrupt vehicle capabilities that are critical for mission success. In order to minimise these harmful effects, vibration in armoured vehicles must be controlled.

RELEVANT STANDARDS AND GUIDELINES

There are several recognised standards and guidelines that can aid in quantifying and evaluating the level of vibration suffered by armoured crew members.

The most widely used international standard for WBV is ISO 2631-1:1997, "Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part 1". This standard defines the methods to quantify WBV in relation to human health, perception and motion sickness. It does not detail the vibration exposure limits but provides a guideline via a health caution zone on vibration exposure for different durations (see Figure 1).

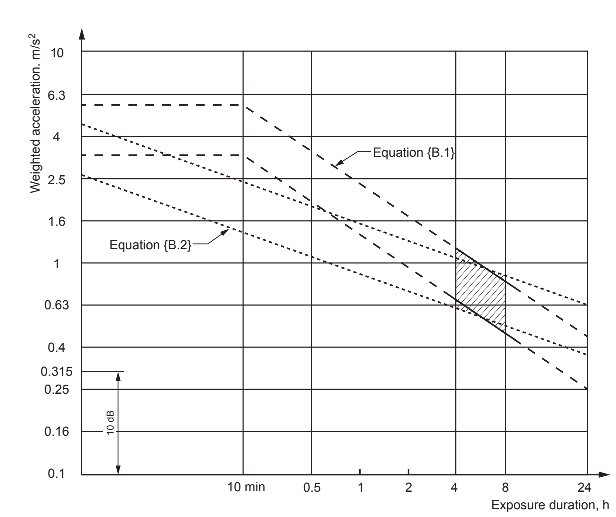


Figure 1. Health caution zone presented in ISO 2631-1:1997, Annex B (Source: Reproduced from ISO 2631-1:1997)

If the measured vibration levels are within the caution zone, there will be potential health risks to the crew. If vibration levels exceed the caution zone, crew members are likely to suffer health problems. There are also various occupational health publications available for practitioners to assess the health risks associated with excessive exposure to vibration. However, most of these publications do not state the acceptable exposure limits.

A directive established in 2002 by the European Communities recommends that the daily vibration exposure should not exceed 1.15m/s^2 for eight-hour durations, and that action should be taken to reduce health risks when the vibration exposure is above 0.5m/s^2. Other health agencies like the Occupational Health Clinics for Ontario (2005) recommend a daily exposure limit of 0.63m/s^2 and suggest keeping vibration below 0.315m/s^2 to maintain proficiency of operators instead.

The recommended exposure limits provide a quantitative means to assess the health risks associated with vibration in armoured vehicles. However, the vibration limit set for every armoured platform may differ according to crew feedback and the expected level of proficiency for the required operation.

ASSESSMENT OF VIBRATION IN ARMOURED VEHICLE

The main source of vibration in tracked armoured vehicles is the running gear system, which includes tracks, sprockets, idler wheels and support rollers (see Figure 2). Most vibrations are generated by the constant impact of the driving sprockets on the moving tracks when the vehicle is in motion. Vibration is also caused by the interactions between the tracks and the ground, the idler wheels, as well as the support rollers. In addition, the running engine and transmission are other sources of vibration in the armoured vehicles.

Vibration generated by the running gear system, engine, and transmission propagates through the vehicle chassis to the floorboard and crew seats. This vibration is eventually transmitted to the human operator, leading to WBV.

To assess vibration levels in a vehicle, physical measurements and computer simulations like the mode-shape modelling technique can be used. For physical measurements, an accelerometer is used to detect the localised vibrating acceleration. The signal is then amplified, processed and displayed for analysis (see Figure 3).

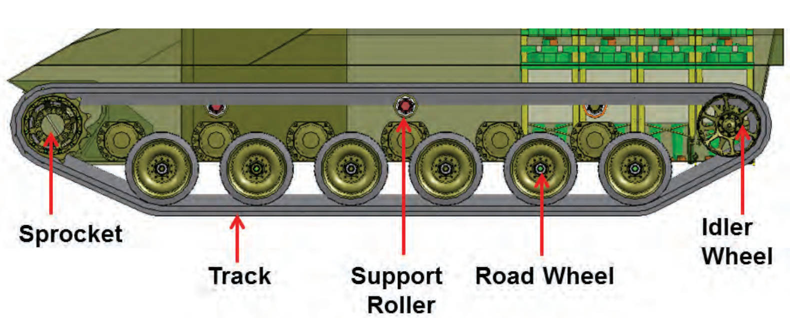


Figure 2. Running track system inclusive of sprocket, road wheels, support rollers, idler wheel and track

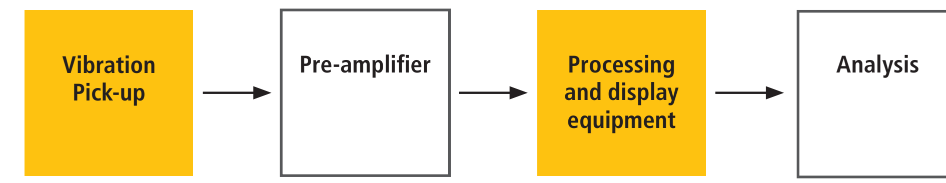


Figure 3. Procedure for physical measurement

The vibration level in a vehicle can also be modelled and simulated using commercial software programs, which is a slightly more complex and time-consuming process as the design model has to be built using these programs. Accuracy of the simulated results depends on parameters such as boundary conditions and load cases in the model. To generate a model with higher accuracy, several iterations and calibrations using actual measured data are required. The calibrated model can then be used for vibration predictions for any future design and load case changes.

It is often complex to assess vehicle vibration, which involves a spectrum of different frequencies (i.e. speed) and accelerating directions. Furthermore, vibration levels are affected by changes in terrain. The evaluation of vibration in armoured vehicles has to take into account these factors, as well as the magnitude and period of exposure. Basic evaluation should be based on the frequency-weighted root-mean-square acceleration. This value gives a quadratic mean of the varying accelerations adjusted according to frequency. The vibration level is then normalised to an eight-hour time frame according to a given operating profile (see Table 1)[1]. The normalised vibration levels for different crew positions can then be compared with the relevant exposure limits (based on eight working hours) stated in various standards to assess the health risks index. A high risk index indicates a need to reduce vibration to acceptable levels.

Exposure period (hours)	Vibration level in frequency-weighted root-mean-square acceleration (m/s^2)
4	0.8
2	0.1
5	0.9

When the vibration exposure consists of two or more periods of exposure to different magnitudes and durations, the equivalent vibration magnitude corresponding to a reference duration of 8 hours can be evaluated according to the formula below:

Normalised vibration level for an <u>8 hour</u> duration

$= [(\sum a_i^2 \times T_i) / T_r]^{0.5}$

$= [(0.8^2 \times 4 + 0.1^2 \times 2 + 0.9^2 \times 5) / 8]^{0.5}$

$= 0.91$ m/s^2

Where:

a_i is the frequency-weighted root-mean-square acceleration

T_i is the exposure duration of each vibration profile

T_r is the reference time frame (8 hours)

Table 1. An example of normalised vibration level for an eight-hour exposure

APPROACH TO REDUCE VIBRATION

Ideally, the vibration levels in a vehicle should be as low as possible for maximum crew comfort. However, reducing vibration is labour and technology intensive, leading to high costs and extensive man-hours. The focus should be on reducing vibration to an acceptable level such that crew safety and efficiency are not compromised.

There are three approaches that can be used to reduce vibration (see Figure 4):

a) Source approach to reduce vibration at source

b) Path approach to cut down on transmission of vibration

c) Receiver approach to minimise vibration experienced by crew members

Regardless of the approach taken, the basic way to reduce vibration is to dampen or stiffen the vibrating element.

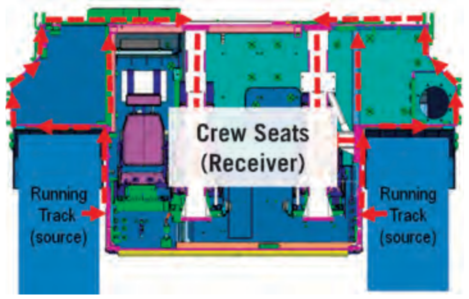


Figure 4. Vibration transmission path from source to receiver in an armoured vehicle

Source approach

The main source of vibration in armoured vehicles is the running gear system. One way to reduce vehicular vibration is to dampen the various running gear components, so that less vibration will be transmitted through the vehicle chassis.

Several designs can be explored, such as coating the idler wheels and sprockets with a layer of rubber material (see Figure 5). This method helps to absorb and dampen the impact of the tracks against these rubberised running gear components during movement. In addition, the support rollers can be isolated from the hull using spring dampers, which reduces the transmission of vibration to the vehicle chassis (see Figure 6). Based on trials, these methods can lower the vibration level by up to 40%. However, results vary according to the crew location. It is worth noting that heavy cyclic loading on rubber material may pose potential durability issues, thus generating a high life cycle cost. With the rapid advancement of rubber technology, rubberised running gears may prove to be more viable in the future.

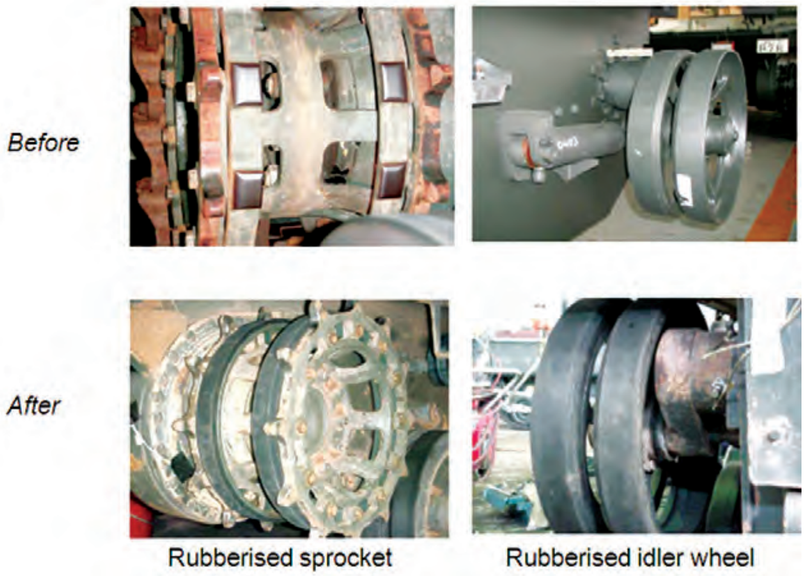


Figure 5. Rubberised sprocket and idler wheel

Figure 6. Isolated support roller

Other alternatives for reducing vibration at source include using a double-pin track or rubber band track. A double-pin track is able to ‘wrap’ more snugly around the driving sprocket, reducing the impact between the track and the sprockets (see Figure 7). As compared to a single-pin rubber bushed track, most double-pin tracks possess twice the amount of rubber bushing to support the vehicle load. Thus, there is further reduction of noise and vibration. Unfortunately, the double-pin track is generally heavier and more costly than the single-pin track.

To reduce vibration at source, the most promising approach is to make use of the rubber band track. A rubber band track consists of rubber track that is moulded into a central core made of steel or composite materials.

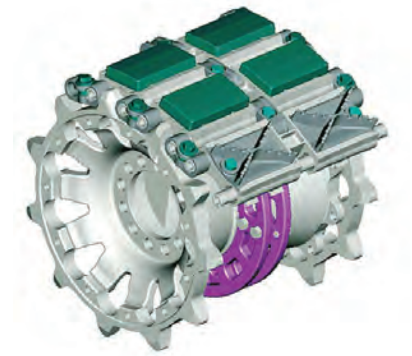


Figure 7. Double pin track around sprocket (Source: Astrum)

The main challenge involved in using the rubber band track is the weight of the vehicle. Originally, the rubber band track was designed mostly for lightweight vehicles such as snow automobiles. Breakthroughs in rubber technology and manufacturing methods have allowed rubber band tracks to be used on heavier armoured vehicles.

Some well-known examples of armoured vehicles using rubber band tracks include the BV206 and BV206S tracked articulated, all-terrain carriers developed by BAE Systems. In Singapore, rubber band track technology was implemented successfully on the 18-tonne Bronco (see Figure 8) and later employed in the UK’s Warthog vehicles. The latest development involves the use of rubber band tracks on a 28-tonne Combat Vehicle 90.

Figure 8. Rubber band track on Bronco

One major advantage of using rubber band tracks is the significant reduction of vibration and noise caused by the interaction between the tracks and drive sprockets. Compared to conventional metal tracks, rubber band tracks can potentially reduce vibration by 65% and noise by 10 decibels (BAE Systems, 2011). Since rubber band tracks are about 30% lighter than metal tracks, weight can also be reduced significantly by more than 0.5 tonne for a 30-tonne vehicle.

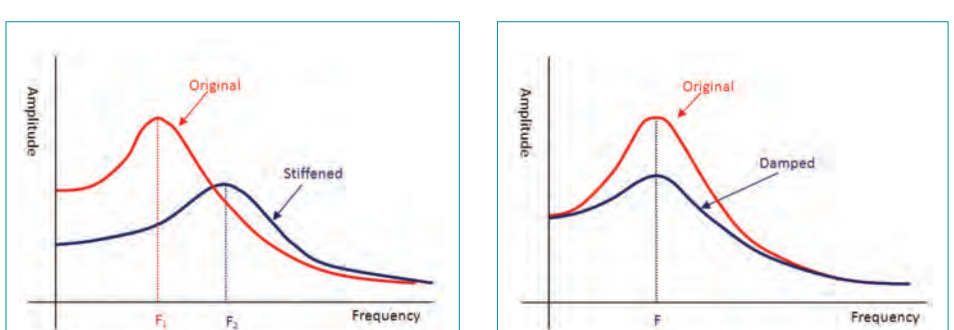
Due to the unique design of the rubber band track, its requirements for field support logistics (i.e. methodology for storage, repair and maintenance) may differ significantly from that of conventional metal tracks. Unlike the metal track, the rubber band track cannot be broken down into smaller sections. Hence, logistics requirements to support their repair and maintenance may involve more equipment such as cranes and recovery vehicles.

Path approach

The path approach explores methods to reduce transmission of vibration within the vehicle body. For armoured vehicles, this usually involves stiffening or damping the vehicle hull and supporting structures, especially those directly connected to the crew station. The methods of stiffening a structure include increasing the structure thickness, and adding metal strips or plates to existing components. Stiffening can also be achieved by providing more support for overhanging components.

Structure stiffening has the effect of shifting the natural resonance frequency to occur at higher speed ranges, ideally beyond common operating speeds. This can be observed from Figure 9 (a). As the stiffness of the structure increases, resonance (peak vibration) occurs at higher frequency, which corresponds to a higher vehicle speed. It is theoretically possible to avoid the resonant vibration completely by shifting the natural frequency of the structure beyond the operating speed range.

Damping will not shift the natural frequency of structure. Instead, damping aims to reduce the vibration amplitude (see Figure 9 (b)) by absorbing vibration energy and dissipating it as heat. It usually involves the use of rubber mounts at strategic positions to interrupt the transmission path. Vibration isolation is achieved when a system has zero or minimal response to the vibrating element.



(a) (b)

Figure 9. Graphs showing how damping/stiffening can affect the amplitude of vibration

Damping or isolation is one of the most common and economical methods to resolve vibration issues. However, the effectiveness of damping and stiffening on complex structures such as an armoured vehicle would have to be validated through trials. Damping and stiffening can have varying effects on vibration magnitude at different frequency ranges. For example, damping the vibrating roof panel of a vehicle may only be effective for vibration above 200Hz while improvements for frequencies from 1-100Hz may be negligible. Therefore, these measures tend to be useful only at certain speed ranges which would have to be identified through field and laboratory tests.

Receiver approach

The most basic method to reduce vibration experienced by the crew is to damp the transmission path to the direct supporting structures (e.g. seat and floor). This usually takes the form of enhanced seat and floorboard design.

Generally, there are two types of seats in the armoured vehicle: the cushion seat and the canvas seat. The right density and material of the cushion seat (see Figure 10) can improve crew comfort significantly, as tests conducted have shown vibration reduction of up to 40%. Specially designed cushions such as air cushions can potentially reduce the vibration level by 50%. However, there is a need to balance vibration absorption with durability, cost, and ease of maintenance to find the ideal seat for an armoured platform.

Figure 10. Different types of cushion foam

Canvas seats which are suspended by straps anchored to certain points of the vehicle are gaining popularity in the market (see Figure 11). Some hybrid designs also include a hard base frame for a firmer support. Canvas design allows the seat to be isolated from the main body of the vehicle, thereby reducing transmission of vibration to the crew. Other advantages include a lightweight and enhanced protection from mine and improvised explosive device blasts. Examples of armoured vehicles with canvas seats are the Leopard 2 Main Battle Tank and Puma Armoured Personnel Carrier (Autoflug GmbH, 2006).

Figure 11. Canvas seats suspended by straps

The vehicle floorboard also acts as a receiver component when the floor surface starts to vibrate and transmits vibrations to the crew. To reduce such direct transmissions, some armoured platforms are laid with an isolation floor mat (see Figure 12). Alternatively, a suspended foot rest can be used for the individually seated crew. A spring-loaded or suspended floorboard can also be deployed. Both methods can also be designed to double as a mine protection system for the crew on board.

Figure 12. Isolation floor mat
(Source: Mackay Consolidated Industries Pte Ltd)

CONCLUSION

Tracked vehicles generally experience a higher level of vibration as compared to wheeled vehicles. These vibrations are inevitable and unavoidable. Design engineers not only have to improve the components that generate the vibrations, but also consider the subsystems at the transmitting path and receiver ends.

Apart from affecting component reliability, vehicle vibration also influences the health and efficiency of crew members. Research has shown that short-term exposure to WBV can diminish crew performance through ailments like nausea and fatigue, while prolonged exposure can lead to lower back injuries. Thus, it is necessary to monitor vibration levels carefully.

The most essential and relevant standard for measuring and assessing health risks posed by WBV is ISO 2631-1:1997. Several occupational health agencies also offer recommendations for daily exposure limits. Although vibration levels in armoured vehicles can be benchmarked against these limits, crew feedback should also be taken into consideration.

To reduce the vibration effects, there are three approaches that can be used: the source approach, path approach and receiver approach. These approaches have their merits and limitations in terms of feasibility, cost, reliability, ease of deployment and maintenance. Much effort is required to reduce vibration in armoured vehicles, given the adverse operating environment and inherent shortcomings in the conventional metal track running gear system. Breakthrough technologies such as the rubber band track system can be explored, but there are logistic and maintenance implications to be addressed.

The reduction of vibration levels typically uses a combination of approaches. Laboratory and field tests are conducted to validate the outcome of these approaches. Most measures lead to certain trade-offs in the vehicle design (e.g. weight, cost, and ease of maintenance) which must be considered holistically before implementation. Based on a tracked armoured platform study, the methodology is able to reduce the normalised vibration level systematically at all crew stations to less than 0.63m/s^2, a typical benchmark used in assessing health risks. This design approach can be employed in the development of future tracked armoured platforms.

REFERENCES

Cherng, J.G., Gang, Y., Bonhard, R.B., and French, M. 2003. Characterization and Validation of Acoustic Cavities of Automotive Vehicles. Proceedings of the 21st International Modal Analysis Conference, Orlando, 3-6 February.

CSTI Acoustics. 2006. Low-Frequency Vibration. http://www.cstiacoustics.com/vibhumanlimits.php (accessed on 22 September 2011)

BAE Systems. 2011. Defence Talk. Norway Buys Rubber Tracks for CV90 Afghan Operations. http://www.defencetalk.com/norway-buys-rubber-tracks-for-cv90-afghan-operations-31973/ (accessed on 24 September 2011)

Autoflug GmbH. 2006. Safety Seat System. Defense update, Issue 2. http://defense-update.com/products/a/autoflug.htm (accessed on 20 September 2011)

Directive 2002/44/EC of the European Parliament and of the Council. 25 June 2002. Official Journal of the European Communities. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:177:0013:0019:EN:PDF (accessed 24 September 2011)

International Organisation for Standardisation. ISO 2631-1:1997. Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part 1: General Requirements.

Occupational Health Clinics for Ontario Workers Inc. 2005. Whole Body Vibration. http://www.ohcow.on.ca/resources/handbooks/whole_body_vibration/WBV.pdf (accessed 24 September 2011)

ACKNOWLEDGEMENTS

The authors wish to acknowledge Tao Jin Sheng and Kiew Woon Hwee from Singapore Technologies Kinetics for their contributions to this article.

ENDNOTES

[1] See ISO 2631-1:1997 for more details on evaluation and calculation methods.

BIOGRAPHY

Kaegen Seow Ee Hung is an Engineer (Land Systems). He is involved in the development and integration of crew systems for the next-generation armoured fighting vehicle for the Army. He managed the acquisition of medical container systems previously. Kaegen obtained a Bachelor of Engineering (Mechanical Engineering) degree with Honours from Nanyang Technological University (NTU) in 2010.

Tan Teck Chuan is a Principal Engineer (Land Systems). He manages the project to deliver the next-generation armoured fighting vehicle for the Army. He has extensive experience in the development of combat fighting vehicles, system integration and aerial delivery systems. He was a member of the Countermine Vehicle Team which won the Defence Technology Prize (Engineering) Award in 1999. Teck Chuan obtained a Bachelor of Engineering (Mechanical Engineering) degree with First Class Honours from Cardiff University, UK, and was awarded as the best graduate of the department in 1996. His academic excellence also attained awards from the Institution of Mechanical Engineers, UK. As a recipient of the DSTA Postgraduate Scholarship, he further obtained a Master of Science (Weapon and Vehicle System) degree from Cranfield University, UK in 2001.

Ang Liang Ann is a Senior Programme Manager (Land Systems). He leads the development of the next-generation network-enabled fighting vehicles. He has extensive experience in the development of combat vehicles, tactical vehicles, support equipment and military bridges. From 2001 to 2003, he worked on the systems management of military vehicles and equipment. Liang Ann graduated with a Bachelor of Engineering (Mechanical Engineering) degree from the National University of Singapore with Honours in 1985. He is a co-author of the paper 'A Computer Model for Vibrating Conveyors', which was published in the Proceedings of the Institution of Mechanical Engineers, UK in 1986, and awarded the Edwin Walker prize for the best paper.