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# APPLICATION OF 3×3 MATRIX METHOD IN THE ESTIMATING OF RISK OF VIBRATIONS GENERATED DURING THE USE OF AGRICULTURE TRACTORS

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**Abstract**. Agriculture tractor drivers are exposed during their work to various negative influences including vibrations. They are vibrations generated in engines, which are transmitted to the driver body (whole body vibrations) through the seat, floor and controls of a vehicle. The exposure to these vibrations over a long period of time can lead to serious health problems. Therefore, it is important to estimate risk to the health that comes from whole body vibrations in order to develop mechanisms of protection. Although standard procedure assumes studying all risks and harms that may occur at one workplace, only estimation of risk to tractor drivers health from vibrations was presented in this paper. During the estimating of the vibrations 3 × 3 risk matrix was used. The estimation showed that the drivers and operators of heavy-duty machinery work in high risk working conditions. Therefore, some organisational and technical measures were proposed to be taken by employers so as either to reduce or eliminate the risk completely.

*Keywords*: risk estimation, whole body vibrations, agricultural tractors, 3×3 matrix method, drivers.

## AIMS AND BACKGROUND

During their activities, the drivers and operators of heavy construction, agriculture or mining machinery (bulldozers, dumpers, excavators, tractors, compactors, fork lift trucks, scrapers, graders, trucks…) are exposed to many negative influences that have complex effect on man. Besides physical strain, precipitation, unfavourable micro-climate, temperature, various pollutions and noise, vibrations are also important factor[1–4].

They are whole body vibrations (WBV) generated in the interaction between the uneveness of the ground and the work of engine, as well as the work of implements and aggregates. Whole machine or a vehicle is exposed to complex oscillatory processes that are transmitted to the driver body during the work. Vibration

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level depends, apart from the condition of the ground (terrain), on the tire type, vehicle velocity, seat type, etc.

A correlation between the impact of mechanical vibrations, generated in heavy-duty machinery, and some occupational illnesses in drivers and operators was observed as early as in the 60' in the last century, but it became especially obvious over the last 20 years. That is when the occupational medicine started to study the correlation between the short-and long-term exposure to vibration and some illnesses[5–7].

According to Workplace exposure to vibrations in Europe, an expert review[8], the highest exposure is in the construction sector, where 63% of workers are exposed to vibrations, 44% – in mining and heavy industry, 38% – in agriculture and commercial fishing, 23% – in transport, etc. In all these sectors heavy machinery is used and it is main generator of vibrations.

Although well-known world manufacturers of agriculture and construction machinery (Case, Caterpillar, John Deere, JCB…) are dedicated to solving this problem it must be said that the protection of workers or operators from these vibrations is still insufficient in comparison to the development of vehicles performances (power, transmission, velocity, electronic controls…). In older generations of machinery, the impact from vibrations is more evident.

Harmful effects of vibrations are especially obvious in agricultural tractors, considering the implements they use, surfaces they work on and their life. There are more than 27 million tractors worldwide, that are older more than 20 years, so they can be generally considered outdated. Regardless of the fact that they still can work, their harmful effects remain, because of WBV especially.

Some studies show that about 10% of all tractor drivers, during their working time, are exposed to vibration levels above exposure limit value (ELV), while in case of longer working time the percentage is 27%. Even 95% of all tractor drivers, during their 8-hour working time, are exposed to vibration levels higher than exposure action value (EAV), in case of which the employers are obliged to control vibration risks[1].

Although standard procedure assumes studying all risks and harms that may occur at one workplace, this paper presents only estimation of risk from vibrations as one of the most harmful influences to drivers health. This paper elaborates the most important steps that must be taken in order to determine the danger caused by vibrations. Subsequently, assessment of the real risk to health is carried out using a 3×3 matrix method. On the basis of these data it is possible to develop protection mechanisms (technical and organisational) that can reduce negative impact from vibrations. At the end of the paper, some measures will be proposed to reduce vibration levels in tractors.

## HARMFUL EFFECTS OF WHOLE BODY VIBRATIONS ON THE HEALTH OF DRIVERS AND OPERATORS OF HEAVY-DUTY MACHINERY

In professional working conditions, there are many effects to human health from the impact of mechanical vibrations. Namely, the human body is a complex system whose parts have, with appropriate approximations, their own vertical oscillations frequencies. When a machine oscillation frequency matches the natural frequency of tissue of a driver organ resonance occurs. In these cases, vibrations with even small amplitude can lead to huge displacements in internal organs.

Disorders that occur in human body depend on physical features of vibrations (frequencies, amplitude, velocity, acceleration), the direction of vibration spreading (vertical, horizontal, rotational), the point of contact and spreading through the tissue (local and whole body vibrations) and, on the other hand, on the individual features of an organism.

Because of the combination of vibrations and other occupational harmful effects it is impossible to correlate the negative influences from vibrations and drivers health deterioration. However, many studies[9–11], biodynamic models and understanding of human body indicate following effects of whole body vibration to health:

- spinal column disease and complaints are perhaps the most common diseases associated with the long-term exposure to whole-body vibration, where the back is especially sensitive to the 4–12 Hz vibration range;
- digestive system diseases are often observed in persons exposed to whole-body vibration over a long period of time. This is associated with the resonance movement of the stomach at frequencies between 4 and 5 Hz;
- cardiovascular system effects resulting from prolonged exposure to whole-body vibration at frequencies below 20 Hz. These result in hyperventilation, increased heart rate, oxygen intake, pulmonary ventilation and respiratory rate.

## ESTIMATION OF RISK FROM WHOLE BODY VIBRATION

The risk estimation is a research process that aims to increase the safety level at a workplace. The law or standards do not prescribe any universal or specific risk estimation method. Practically, it is a licensed institution that determines which method will be applied (Kinney, Pilz, Guardmaster, 5×5 or 3×3 risk matrix, etc.)

When estimating the risk one should consider the fact that a driver health risk depends on the vibration level and frequency, as well as on the length of exposure and the working practice. It is important to know that an individual sensation, during the period of exposure to vibrations, depends on the health of an operator and working practice.

With appropriate risk estimation it is possible to identify and reduce exposure in the early stages. The understanding of the way workers are exposed to vibrations can help adopting methods of reducing or eliminating the exposure.

Risk at a workplace can be estimated in 3 simple steps (Table 1).

**Table 1**. Stages of risk estimation

| | |
|---|---|
| Step I | Collection of information and risk identification |
| Step II | Risk estimation and evaluation |
| Step III | Activities for risk elimination or reduction |

The beginning of the process is the collection of real information of a workplace and identification of harm. After that, the risk is estimated with the use of a method that can estimate and control occupational health and safety risks. Necessary measures for risk reduction are taken only in case the estimation indicates increased risk.

## COLLECTION OF INFORMATION AND IDENTIFICATION OF RISK-HARM FROM WHOLE BODY VIBRATION

For risk estimation at a workplace it is important to collect as much information as possible about where the workplace is and who the worker is, what equipment and materials are used, what activities are performed, what protection measures are taken, etc. The information is collected from the technical features of the equipment, manuals, legal documents, etc. Manufactures of equipment must provide vibration level generated by the equipment in the form of test results.

One of the most relevant indicators of harmful effect of vibration to the drivers health is obtained with appropriate measuring during working activities. In measuring and evaluating the impact of vibrations on operators, relevant standards define acceleration as a measurement and evaluation parameter. The measuring of vibration level is carried out in 3 orthogonal measuring directions, where the longitudinal direction is marked as *z*-direction (vertical). Lateral directions are marked *x* and *y*, where *x*-direction (afterward) indicates forward-backward motions, and *y*-direction (sideward) indicates leftward-rightward motions (Fig. 1).

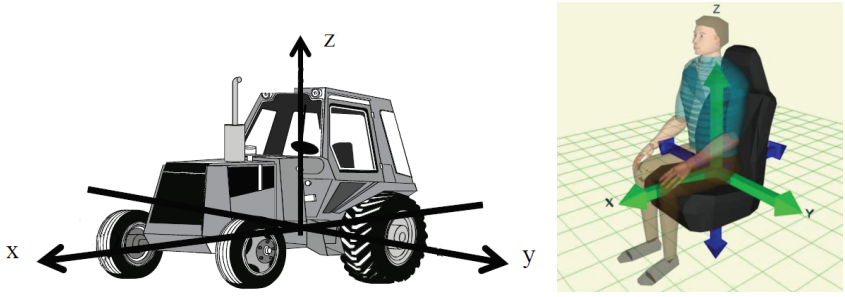


**Fig. 1**. Defining of orthogonal measuring directions in the vehicle and the driver

The measurements of vibration levels in all 3 orthogonal directions can be carried out at the seat of the driver and (or) at the floor of the vehicle.

Apart from vibration level, the period of exposure is also important for estimation and identification of vibration harmfulness. According to these two parameters, the level of daily exposure A(8) is determined-continuous equivalent acceleration regulated on the basis of 8-hour working time.

## RESULTS AND DISCUSSION

### WHOLE-BODY VIBRATION RISK ESTIMATION USING 3×3 MATRIX

One of the methods that enables occupational health and safety risk estimation and management is a 3×3 matrix method. According to it, the risk (R) is expressed as a product of possibility for occupational injury, health damage and work-related injuries (V) and the level of injuries, health damage and occupational illnesses (T).

$$R = V \times T.$$

The possibility of occurring and the effects of injuries is the matter of subjective assessment of person estimating the risk. The estimation of possibility is carried out according to the information the estimator acquired during measuring of vibration levels and calculating of the exposure levels in a number of vehicles or using such data from books, catalogues, manuals, etc. The statistics related to occupational illnesses, injuries, damages are important as well.

In case of agricultural tractor drivers, according to many studies[12–14], a correlation between whole body vibration and health damage was determined, and for 8-hour working time the possibility of work-related injury (Table 2) and the effects of severity of work-related injury (Table 3) are medium.

**Table 2**. Possibility levels and their description

| Possibility of work-related injury, health damage and work-related illness (V) | | Description |
|---|---|---|
| Low possibility | 1 | work-related injury, health damage and work-related illness is not likely to occur |
| Medium possibility | 2 | work-related injury, health damage and work-related illness is likely to occur |
| High possibility | 3 | work-related injury, health damage and work-related illness occurs frequently or repeats |

**Table 3.** Effects of the severity of work-related injury, health damage and work-related illness

| Effect of severity of work-related injury, health damage and work-related illness (T) | | Description |
|---|---|---|
| Minor effects | 1 | effect of severity of work-related injury, health damage and work-related illness requires first aid only |
| Medium effects | 2 | effect of severity of work-related injury, health damage and work-related illness requires hospital treatment, the illness causes temporary weakness or disability |
| Serious effects | 3 | effect of severity of work-related injury, health damage and work-related illness is considered serious and as an occupational illness |

After adopting numeric values from Tables 2 and 3, the risk can be calculated. In case of agricultural tractor drivers, medium risk from whole body vibrations was classified (Table 4).

**Table 4**. Matrix model for risk estimation

| Effect of severity of work-related injury, health damage and work-related illness (T) | | Possibility of work-related injury, health damage and work-related illness (V) | | |
|---|---|---|---|---|
| | | low | medium | high |
| | | 1 | 2 | 3 |
| Minor effects | 1 | negligible risk (1) | slight risk (2) | low risk (3) |
| Medium effects | 2 | slight risk (2) | medium risk (4) | high risk (6) |
| Serious effects | 3 | low risk (3) | high risk (6) | extreme risk (9) |

Classified medium risk is increased risk, i.e. a risk that is assumed to be the cause of work-related illnesses or workplace injuries and can exceede the legal limits (Table 5).

**Table 5**. Risk classification and description

| Risk (R) | Risk classification | Risk description |
|---|---|---|
| 1 | negligible risk | acceptable risk |
| 2 | slight risk | |
| 3 | low risk | |
| 4 | medium risk | increased risk |

After determining the increased (or unacceptable) risk to health, it is important to take adequate measures so as to eliminate vibrations or decrease their levels under legaly regulated limits.

In case of increased or unacceptable risk, an employer is obliged to take some corrective measures-methods for risk control, so as to reduce it or eliminate it completely[15]. An important part in the process is the understanding of work processes that generate vibrations, i.e. understanding how the workers are exposed to vibrations. When taking corrective measures, achievable objective should be set, priorities should be determined, plan of activities should be made and duties should be assigned adequately.

The principle method in vibration control is tractor maintenance. Primarily, this refers to suspension system (pressure in tires, suspension of cab and seat, etc.). One of the solutions is the use of air seats instead of mechanical ones, taking care that the seats conform to the vehicles, which will prevent higher vibration levels.

Drivers should operate the machines with low velocity, since it contributes to vibration levels significantly.

Activities should be planned carefully, so that the periods of exposure to vibrations are as little and short as possible, and in cases when it is impossible to avoid high vibration levels, drivers shoud be changed frequently. Also, an important measure is a proper training of drivers as well as consulting workers and their colaboration in risk reduction. It is necessary to inform them about health risks that come from the equipment they use, about exposure, action and limit values, risk estimation results, their rights to medical care, etc. Consulting the workers can provide better and understandable solutions to them, because the efficiency of the measures depends on them, too.

## CONCLUSIONS

Detrimental effects of vibrations from heavy-duty vehicles and machines to workers and drivers are known, but are still not taken seriously. Comprehensive correlation between vibration effects and health damage can not be determined because of combined effects of vibrations and other occupational risks and damages. Exposure to vibration can affect drivers and operaters in various ways, from minor disorders and low efficiency of workers to serious health deterioration, depending on the length of exposure and vibration levels.

As a result of risk estimation, an increased tractor drivers health risk was classified, therefore, employers are obliged to take appropriate measures and activities so as to reduce or eliminate whole-body vibrations completely. The effects of measures taken should be analysed occassionally in order to assess their adequacy and efficiency.

Risk estimation must be carried out each time new vehicles are used, when working practice or working hours spent in vehicles causing vibrations are changed.

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