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VIBRATION TRANSMISSION BY COMBINE HARVESTER TO THE DRIVER AT DIFFERENT OPERATIVE CONDITIONS DURING PADDY HARVEST

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ABSTRACT

This research was conducted to evaluate WBV that harvester driver was exposed to it at different working conditions during paddy crop harvesting. The research involved three different investigations, the first to investigate the operations that the combine must do to achieve a paddy crop harvesting, while the second was to investigate the vibration emitted by different units of combine harvester and the third was the effect of threshing cylinder speed with three levels (800, 1000, 1200) rpm. The effect of the vibration at three orthogonal axes (X,Y,Z) and total equivalent vibration Av were tested .The vibration measured and defined according to the European Union guide (2002/44/EC Directive) as well as the organization of ISO (ISO 2631-1-1997). The RBCD with three replications was used .Each investigation considered as a single experiment and carried out individually. the results indicated that the vibration which the harvester driver exposed to it during paddy crop harvesting higher than the rest operations tested such as driving the harvester on the agricultural roads, or on the rice field or when operated while the harvester at parking position. However, the value of that vibration exceeded the levels of ELV and EAV. Another wise that vibration value recorded 1.97 m/s² Av which was considered very uncomfortable vibration level. The Y axis was the highest in vibration followed by the X axis, while the least value noted at the Z axis. Changing the number of harvester operating units led to clear changes in vibration generated in the three orthogonal axes, as well as Av value. However, these changes associated with the effect of road surface conditions. Increasing the threshing cylinder speed during paddy harvesting caused increasing vibration significantly at the X axis only while the Z and Y axes remained close to the safe levels of EAV and ELV respectively. The Av value was increased with increasing threshing cylinder speed.

KEY WORDS: threshing, comfortable, road, operation, ELV, EAV, Av.

INTRODUCTION

WBV is the vibration and shock a combine harvester driver feels when he sit on the driver seat during operating, the engine and other combine units for the daily check or travelling over rough ground or crop harvesting . Passes of vehicles over irregularities of the road surface and presence of offset mass on rotating axes of these machines, cause mechanical vibrations. (Hostens and Ramon 2003 and Nguyen and Inaba, 2011). Exposure to this vibration brings a driver problem, a machine problems and harvesting losses. Several studies recognized that the WBVas an influential source of discomfort for agricultural machinery drivers (Stayner and Bean, 1975; Bovenzi and Beta, 1994; and Lines *et al.*, 1995 ; and Ahmadi, 2013). The directive 2oo2/44/EC assumed that the vertical axis vibration frequencies of some human bodies parts with appropriate approximation, for example: abdomen = 4 – 8 Hz, eye socket = 80 Hz, chest = 60 Hz, head = 25 Hz, hips =50– 200 Hz, elbows = 16–30 Hz, *etc*., when these natural frequency (driver organ tissue frequency) match with forced vibration frequency of the machine lead to significant disorder in the internal organ of the driver body. To evaluate the degree of risk caused by the exposure to the whole body combine vibration two interval time values reported in the ISO 2631 –1: 1997standard, these are the effective action value (EAV)

and the effective limit value (ELV). The control of vibration at work Regulation 2005 (the vibration Regulation) set an EAV is equal to 0.5 m.s⁻² A(8) more than this value require to take action to reduce the exposure time. However; the ELV is equal to 1.15 m. s⁻² A (8) and must not be more. Solecki (2007) investigated several agriculture machines in general he stated that the highest value of RMS occur in the vertical plane (Z) and followed by RMS of the longitudinal direction (X) and the RMS in transverse direction (Y). Harvesting is one of most important operation in production of paddy crop, it must be done at a short time, therefore the driver of harvester need to work along time during the day in order to complete this operation at proper time. The aim of this research was to investigate the effect of operation conditions of paddy harvesting on the harvester driver WBV at different work circumstances.

MATERIALS & METHODS

This research was carried out in an identified and well controlled paddy crop field in the area of the Abbasia city, province of Najaf (160 km south of Baghdad) to evaluate the value of vibration that Combine driver was exposed to it in different working conditions, the research involved three different investigations:

A: Investigate the routine operations that the combine

must do in order to achieve a paddy crop harvesting these are: (operate the engine and other harvester units for daily check, travel on a agricultural road, travel in the paddy field and harvesting operation)

B: Investigate the source of vibration emitted by different units of the combine harvester, these units and the investigation details are shown in the table 1.

C: Investigate the effect of threshing cylinder speed during harvesting with three levels (800, 1000, 1200) rpm at the same harvesting speed. Three investigations were considered as simple experiments having a single-factor with several levels and carried out according to the RCBD statistical design and each treatment was replicated three times in each test condition.

TABLE 1: The second Investigation treatments by different units of Combine harvester and the Investigation details
The differences between the means were tested by using Duncan test

Test condition	Source of vibration tested
Parking	Engine
	Engine + processing units except platform
	Engine+ all processing units
Travelling on agricultural road	Engine + transmission
	Engine+ transmission + processing units except platform
	Engine + transmission + all processing units
travelling on paddy field	Engine + transmission
Harvesting	Engine + transmission + all processing units

Determining the whole body vibration influence requires defining three orthogonal measuring directions (figure 2), these are the vertical direction that is marked as Z direction, which indicates the up and down motion (vertical), while the other directions are called the lateral directions marked as X and Y directions , where X refer to the longitudinal direction which indicates the forward and backward motion and Y refer to the transverse direction which indicate sideward motion (left and right). Mechanical vibration was measured by using ERBESSD Instruments Ei-Calic. The specifications of this instrument are shown in Figure 1. This Instrument was linked to a personal laptop during the measurement, the degree of changeability of vibration measured was based on registration within the given time interval. Therefore, the register person was sitting beside the driver's seat to get readings and saved it to the laptop for each treatment. The Supplement Program Installed with measurement of vibration on the laptop to meet the work requirements. The single treatment was 50 m in length and the acquisition time was sixty seconds. The accelerometer has been attached to the driver's seat and oriented to the direction of one of the axes (X, Y, Z) under vibration test. The accelerometer connected to one side of the optical sensor by cord and the other side was joined to the outlet of the lab top figure 1. The capture parameters for the entire study were set prior to the beginning of the study through the offered option data acquisition menu (capture preference). However, the level of combine vibration expressed as rms was extracted from the captured image and then the daily exposure of vibration levels of A (8) m. s^{-2} was calculated according to 2002/44/guide EC Directive regulation, considering 8-hour working time (Cvetanovic and Zlatkovic, 2013). A Class Dominator combine harvester was used in the implementation of the experiments of this study (Figure 1).

- Sensitivity 330 mV/g.
- Weight 45 grams.
- Dimensions 0.625" diameter 1.625" long.
- Neodymium magnetic base.
- Frequency range: 1Hz-8kHz.
- Amplitude range: 6g Peak to peak.
- Aluminum design.
- 5 Pin connector.

FIGURE 1: Ei-Calic ERBESSD Instruments to measure the WBV

The daily exposure levels in the three orthogonal axes were calculated as follow:

$$A_x (8) = 1.4\ w_x \sqrt{(T/T_o)} \text{----------------------} (1)$$
$$A_y (8) = 1.4\ w_y \sqrt{(T/T_o)} \text{--------------------} (2)$$
$$A_z (8) = 1.0\ w_z \sqrt{(T/T_o)} \text{----------------------} (3)$$

Whereas:
AX (8) :- is the daily exposure to combine vibration

(m. s⁻²) in the longitudinal axis (lengthwise vibration), the motion of the driver forward and backward.
AY (8): the daily exposure to combine vibration (m.s⁻²) in the transverse axis (the driver's motion is to the left and right)
AZ (8): the daily exposure to combine vibration (m. s⁻²) in the vertical axis (the driver's motion is upward and downward), Figure 2
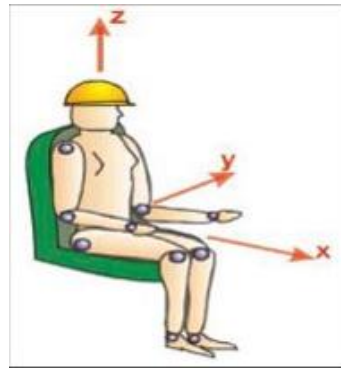

Figure 2 the orthogonal measuring directions that effect on driver wbv

1.4 :- is the coefficient of the longitudinal axes X and Y .
1.0:- is the coefficient of the vertical axis Z
WX, WY and WZ:-are the values of vibration emitted by the combine simultaneously on the longitudinal and transverse and vertical axes respectively (m. s⁻²) figure 2,
T: - time of daily exposure to combine vibration in hour,
T_o:- time interval of daily 8-hour work. (2002/44 / EC Directive)
 A computer program prepared by the British Health and Safety (HSE) known as WBV Calculator was used to

calculate the amount of daily exposure to vibration, and the time required to get to the specific values of the vibration EAV and ELV, Figure 3 shows the model of the readings of this program.
Overall vibration equivalent Av is the outcome of a vibration caused by the vibration in the three orthogonal axes (X, Y, Z)
 It was estimated by adopting the recommended way in the Organization ISO guide (ISO 2631-1-1997) and using the following equation: -

$$A_v \ (m .s^{-2}) = \sqrt{w_x^2\ +\ w_y^2\ +\ w_z^2} \qquad \text{----------} (4)$$
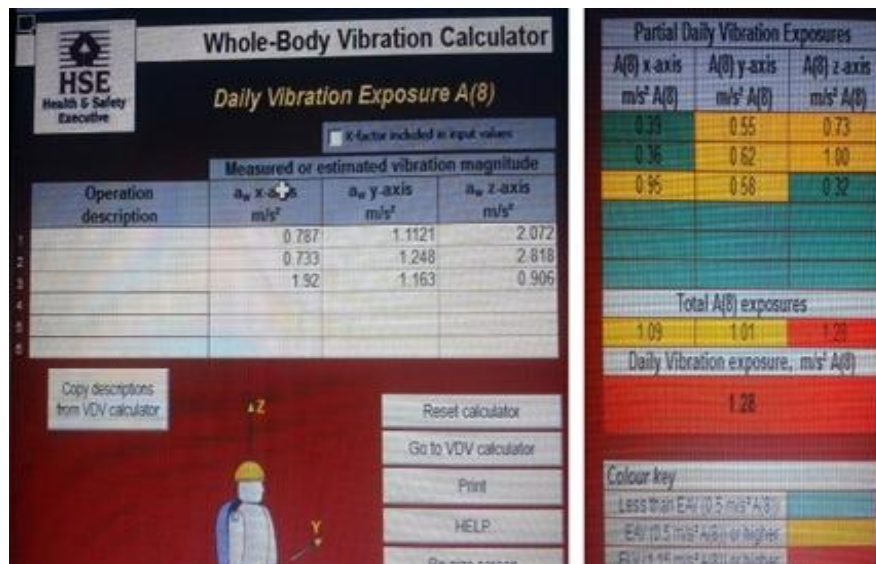
HSE to determine Daily Vibration Exposures A (8)   Figure 3 WBV Calculator

RESULTS & DISCUSSION

Figure 4, indicates that the type of operation performed by the Combine clearly affects the vibration value suffered by the combines driver at all positions tested of the three orthogonal axes (X, Y, Z), as well as the overall vibration equivalent Av . Results also indicates that the difference in the type of operation led to change in which of the axes has the most influential vibration. However; when operating the Combine in the parking position showed a vibration value in the vertical axis equal to (0.73 m.s^{-2}) which is the largest of the rest of the axes and this value exceeds the affecting exposure action value EAV. Whilst the vibration value in both the longitudinal and transverse is little less or close to the acceptable and non-influential vibration value compared to driver safety values.

A similar case was found when the Combine was travelling on an agricultural road, the vibration is paved with relatively high-vibration for the three axes and the reasons for the two cases are that the only source of vibration in the case of parking Combine is the vibration coming out of the engine, which clearly shows in the vertical Z-axis, however, when the Combine travelling on agricultural road a noticeable increase in the vibration was caused by the uneven road conditions. With respect to the combine travelling on the paddy field on the lines harvested earlier (mulches) with loaded tank, fig revealed a remarkable increase in vibration values in the three axes tested with the notice that the most effective axis was differ from the two earlier cases. However; in this case the vibration values increased at the longitudinal axis X by relatively large margin followed by the transverse axis Y while the vertical
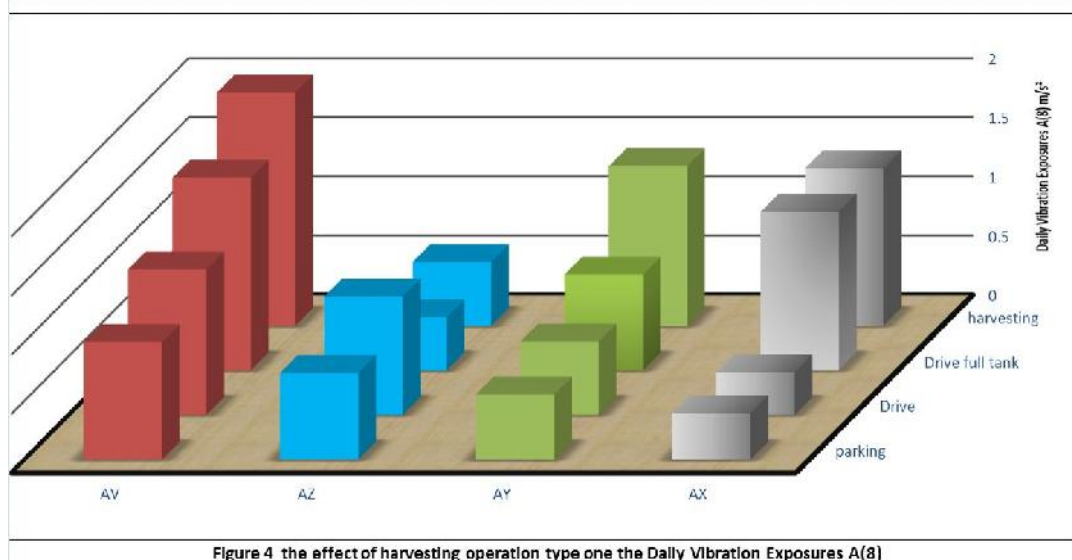

Figure 4 the effect of harvesting operation type one the Daily Vibration Exposures A(8)

axis Z was the least in vibration. The highest vibration value in the longitudinal axis X was (1.15 m.s^{-2}) which exceeded the exposure limit value (ELV). Considering, the reason that the vertical axis. Z has the least vibration value compared to other axes as mentioned above may be caused by the very wet soil in the paddy field with presence of plant residue may absorb part of the vertical vibration and damping it , therefore; the vibration in Z axis was reduced when harvesting paddy field. This phenomenon was true by the presence of long and wide crawler that gives bigger area of contact with soil which reduces the effect of uneven soil surface in the vertical direction. Whilst the wet soil and the residue was the reason for the increase in vibration at the longitudinal and transverse axes because of adding them wobble movement forward and backward as well as to both sides of the combine. It was also noticed that the harvesting process were similar with the process of the Combine travelling at harvested paddy field in terms of reduced vertical vibration in comparison with the rest of the axes tested. The same thing was also noticed during the processes of travelling at agricultural road and operating the combine for daily check , that is the two axes (longitudinal and transverse) have higher vibration values than the vertical axis, and the reason for that is the reciprocating motion of

the combine cutting unit especially being the cause of a lateral movement of the whole combine while the other combine units such as conveying, threshing, screening and cleaning increased vibration in the vertical axis compared with the process of travelling at the harvested paddy field with a loaded tank.

In terms of overall vibration equivalent Av, it may change depending on the type of operation performed by the Combine. It had an overall vibration equivalent Av values of the all operations tested within the range of uncomfortable (0.8 _1.6 m.s^{-2}) and very uncomfortable t$_o$ work (1.25_2.5 m.s^{-2}) ISO 1997. The harvesting process has the most effective of overall vibration equivalents VALUE that is (1.97 m.s^{-2}) followed by the process of travelling on harvested field, and then travelling on the agricultural road and finally the operated engine only when the Combine was parked, and the reason for this is that the overall vibration equivalent Av represents the resultant of the vibration of all orthogonal axes (X, Y, Z). However, in the harvest process these values of all three axes are high too especially X and Y, while the rest of the total vibration equivalent Av values for the rest operations changed gradually depending on the vibration at the three axes for each operation and according to the mathematical relationship values .

Effect of harvester operating units on harvester vibration

In general the results shown in the table -2 set out that each of the harvester operating units add a considerable amount of vibration emission to the total whole body vibration values of the combine. However; in most events the added vibration recognized to be associated with the most effective axis , therefore , the following is to discuss the vibration at realistic work conditions that harvester deal with in order to distinguish which of its units is the most effective in vibration and the effect of its all units collectively .

Vibration of harvester engine alone

The results in the table 2 indicate that operating the harvester engine alone while the harvester was parking a remarkable level of vibration value in all axes and also a remarkable Av value were detected with the fact that the Z axis had the highest vibration values. The reason for that remarkable vibration was operating the engine alone that mean the engine work without any load which make it free to vibrate. However; when the threshing , separation and cleaning units allowed to be operated all together with the harvester engine as a source of power ,a decrease in vibration was found and the highest vibration level stays at the Z axis which was considered within the ranges of the harmless vibration , the reason for that decrease in the vibration mentioned above is the restriction exerted by the harvester units loads on the harvester engine in addition to overlapping effect of forces in different directions ,which reduced the resultant of generating the final strength of the vibration in each direction too .On the other hand, adding the operated cutting units to the tested units of the harvester increased the vibration values more than the two cases mentioned above in all axes with the Z axis stay with highest vibration values . The results also showed that the Av is the other parameter had risen to 1.03 m.s^{-2} which make the vibration condition become almost uncomfortable, due to the addition of the cutting units.

TABLE 2 the effect of harvester units and operation type on the daily vibration exposures A (8)

Test condition	Source of vibration tested	Daily Vibration Exposures			Highest Axis	Av A(8) m/s²	Time to reach EAV m/s² hh:mm	Time to reach ELV m/s² hh:mm
		Ax A(8) m/s²	Ay A(8) m/s²	Az A(8) m/s²				
Parking	Engine	0.39 cb	0.55 b	0.73 c	Z	0.99 b	0:27	2:27
	E + pro U except plat	0.31 a	0.48 a	0.50 a	Z	0.76 a	0:59	5:14
	E + all pro U	0.33 ab	0.60 c	0.77 c	Z	1.03 c	0:25	2:14
Travelling on agricultural road	E + tran	0.36 b	0.62 c	1.00 f	Z	1.23 d	0:15	1:19
	E+ tran + pro U except plat	0.46 d	0.60 c	0.84 d	Z	1.13 c	0:21	1:53
	E + tran + all pro U	0.60 e	0.71 d	0.84 d	Z	1.25 d	0:21	1:51
travelling on paddy field	E + tran	1.90 g	1.15 e	0.64 b	X	1.63 e	0:16	1:27
Harvesting	E + tran + all pro U	1.33 f	1.35 f	0.54 a	Y , x	1.97 f	1:06	5:06

E: engine, pro: processing, U: units, plat: platform, tran: transmission

Driving harvester on the agricultural road

Driving the harvester on the agriculture road accompanied with the increase in vibration values in all axes as well as the value of Av compared with the vibration emitted by the operated parked harvester. The reason for that is due to the influence of transmitting motion from the engine to the crawler as well as the effect of irregular agricultural road conditions. Driving the harvester on the farm road causing the total equivalent vibration value Av within the extreme end of the acceptable limits that remains almost within uncomfortable term with the fact Z and Y axes as the highest parameters value and their values exceed the value of EAV and lower than the level of ELV. However, when the threshing, separating, cleaning and elevating units were operated during the harvester driving on agricultural road caused a significant decrease in the vibration at the Y and Z axes as well as in Av while reached the lowest of its level (0.75 m.s^{-2}), that was due to increase in the source of vibration forces influencing in opposite directions, resulting in low resultant of the vibration power of the three orthogonal axes. The table (2) shows that addition of operating cutting unit to the harvester working units while driving on agricultural road led to the increase in vibration in the X and Y axes as well as Av. This increase reached the uncomfortable level, while the vertical Z axis was not effected and its value remained the same.

Driving harvester on paddy field

Figure 4 shows that driving the harvester on paddy field have brought about a clear change in the vibration level at the various positions that the harvester driver exposed to it. The results showed that the highest axis in vibration is the X axis not the Z axis as appeared in the previous tests with a value equal to 1.34 m.s^{-2} which exceeds the ELV value. This was the highest value for this axis during the entire of this experiment. The Y axis is the other axis that showed significant increase compared to its value during driving the harvester on agricultural road, while the Z axis was found to be reduced the lowest of its value in the experiment (0.45 m.s^{-2}). However when all units of harvester were operated during paddy crop harvest may double the Y and X axes vibration to become highest axis in vibration with value equal to 1.35, 1.33 m.s^{-2} respectively, which was the highest vibration value during the entire of the experiment of Y axis. Slight increase in the vibration was detected at the Z axis with value of 0.54 m.s^{-2}. The Av is the other parameter has recorded the highest value in the experiment with value equal to (1.97

m.s^{-2}), which was considered as very uncomfortable driver work conditions. However, when comparing the harvester vibration that all harvester units operate on agricultural road test(no crop harvest) with the harvester vibration during harvesting paddy crop , we find that processing the passing rice crop through the harvester units share in doubling vibration in the lateral and longitudinal axes Y and X on the other hand lowering vibration in the vertical axis Z .The reduction in vibration at the Z axis was due to the vertical damping caused by the crop specially at the threshing unit which was working as cushion between the concave and the rotating cylinder . However, the reduction in the vertical direction forces caused increased forces in longitudinal and transverse direction.

The effect of the threshing cylinder speed
The results in the figure 5 showed that no significant effect in all axes when the cylinder speed increased from 800 to 1000 rpm. on the other hand , increasing rotation speed to

1200 rpm during paddy crop harvest caused a significant increase in vibration at the X axis as well as Av until the vibration range reached to very high values equal to 2.65 m.s^{-2} which was classified as extremely difficult circumstances to work with . The results also showed that no significant effect at Z and Y axes. However the vibration value at the X and Y axes exceeds the ELV while the vibration values remain close to the EAV ranges at the Z axis. It is very interesting to mention that the increase in vibration at the X axis as the cylinder speed increase was due to increase the impact forces at the longitudinal direction of the harvester especially during the work of the threshing cylinder. Another reason for that were the interface between the cylinder bar and the rice crop in addition to the impact of walkers and the other working parts and units of the harvester, as well as absence of any way in working conditions that reduces the vibration at the longitudinal axis.

FIGURE 5: the effect of cylinder rpm on the Daily Vibration Exposures A(8)
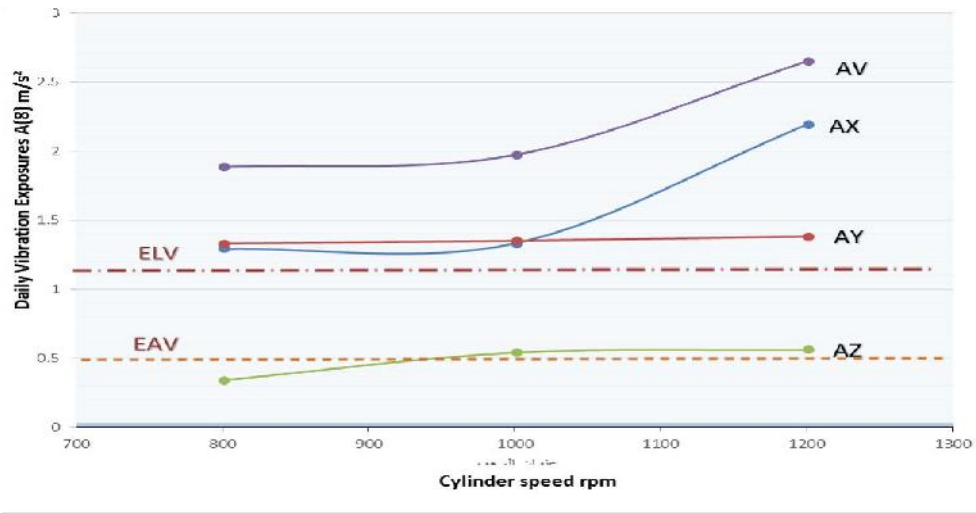
CONCLUSION
Vibration in the three orthogonal axes of the harvester is affected by the resultant forces in their directions (X, Y, Z). These forces is due to the operation of the various harvester units and they have been affected by the nature of the soil surface that harvester move on it and it's characteristics as well as the number of harvester operating units. However drive in most of his work conditions exposed to harmful levels of vibration resulting from operating the harvester at different conditions. The harvester working conditions diversity affect significantly the overall vibration values and independent values of vibration at the three orthogonal axes (X,Y,Z) as well as any of the three axes is the most productive in vibration .
The harvest process recorded the highest equivalents value of the vibration compared to the rest of the combine operations with value equal to 1.97 m.s^{-2}, this value represent very uncomfortable level of vibration, which do not permit the conditions of work for a long periods of time in contrast to the required period the combine harvester driver should give during the paddy harvest seasons. The Y axis show higher vibration values during the rice harvesting process with exceeded the exposer

limit value of vibration ELV followed by the X axis with very close results , while the wet nature of the paddy field, wet soil and plant residue of paddy crop work on damping vibration in the vertical axis and downgrades the vibration level to its lowest level in the experiment with values lower than EAV. The nature of the soil surface that the harvester always deal with showed a very big impact on overall vibration results and the independent vibration values at perpendicular axes . However the effect of soil surface in term of vibration exceeded the effect of the harvester units during traditional work. More over; the paddy field soil was the highest in vibration generation at the longitudinal (X) and transverse (Y) axes, while the Z axis was the most in vibration when the harvester moving on the agricultural road or when treated during parking tested. The results also showed that increasing the threshing cylinder speed up to 1200 rpm increased vibration value of the X axis to very high level at paddy harvest followed by the Y axis , while the Z axis has not affected and its vibration values stayed closed to EAV. Meanwhile; the Av values rise up 2.65 m.s^{-2} which was considered as extremely uncomfortable operating conditions.

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