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Research on the Distribution of Axial Excitation of Positive Pressure Ventilators in the Aspect of Stability Safety of the Load-Bearing Frame

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ABSTRACT

Positive pressure ventilators are exposed to self-shifting during their operation. The aim of the article was to perform research analysing dynamic excitations resulting from vibrations caused by the operation of the drive system. The tests included four different fans, including one with an electric drive. The tests carried out made it possible to determine the effective *RMS R* value of vibrations, which is a maximum of 0.970 G, and the direction of the excitation relative to the vertical and horizontal axes. In addition, the values of vibration amplitudes on individual axes of the adopted reference system were determined. In this case, the highest values were measured on the vertical axes for combustion-powered ventilators (vibration value from 20 to 35 m/s^2) and in the axis along the fan rotor for electric-powered ventilators (vibration value from 1.1 m/s^2).

Keywords: positive pressure ventilators, rescue operation, machine vibration, vibration of internal combustion engine, vibration of electric drive, occupational safety.

INTRODUCTION

Equipment used to carry out rescue operations, depending on the requirements of a particular country, may be subject to special testing and certification procedures [1–3]. One such device is positive pressure ventilators, which are an important tool used during the implementation of rescue operations by fire protection units [4–6]. For these devices, requirements related to the need for testing and verification of essential technical and performance characteristics have not been implemented in Poland at this time. Describing the most important features that determine the effectiveness of the use of mobile ventilators, it is necessary to point out: the volumetric flow rate, the characteristics of the air stream velocity profile, the operating time of the ventilator, noise, and the mass and size of the ventilator unit [1]. Since mobile ventilators operate in extreme operating conditions (fire environment), and the lives of people evacuated from a building may depend on their effectiveness, it is important to strive for a comprehensive evaluation of performance, taking into account all aspects of their use. An important parameter that should be taken into account in the study of mobile ventilators is its positioning stability. The mobile ventilator should be designed in such a manner that in the course of its operation (implementation of a technique such as positive pressure ventilation), it will not be displaced once the appropriate parameters for positioning the ventilator are established [7, 8]. Taking into account, the design and construction of the ventilator and the fact of using drive units of different types (electric and internal combustion engines with a wide range of power [5, 9, 10]) and the fact of the presence of thrust that accompanies the generated air stream – there is a risk of dislocation. The indicated effect can be catastrophic, as it will cause a change in the direction of the air stream, which will consequently contribute to a drastic reduction in the volumetric flow rate on the selected gas exchange path (e.g. the stairwell – which can be an escape route). The occurrence of such a phenomenon, for example, during the implementation of the process of evacuating people from a fire-affected building, may expose evacuees to toxic thermal decomposition products, which may contribute to the endangerment of life and health [11–14].

In literature, vibration studies of mobile ventilators used in rescue operations are basically unavailable. However, in the broader recognition of the topic of fan air vibration testing, one can distinguish works on the study of ventilation fans for residential [15], industrial [16, 17] buildings or mines [18]. Chan et al. conducted research on the durability and use of fan air vibration signals in application to monitoring their operation [15]. Showing that the signals from vibration sensors mounted on the ventilators distinguish very well whether the ventilator is running or not. Dhamande et al. in 2023 showed that vibration measurement has proven to be an effective tool for monitoring air fan wear status [16]. Similar conclusions will be made by Benchekroun et al. in 2023 showing that vibration diagnostics can accurately determine the need for preventive maintenance, especially for ventilators operating in conditions of high air pollution [17]. Jovanović et al. in 2013 monitored bearing wear in a ventilator drive unit by measuring vibration, showing that identifying bearing wear is feasible [19], and Lee et al. in 2021 analyzed the effect of vibration on bearing life in ventilators [20]. Lewandowski and Rozumek et al. in 2017 developed fan vibration test methods to assess the wear condition of the motor, ventilator rotor or mechanical gearbox [21], and Zachwieja in 2003 analyzed the influence of factors such as body stiffness, rotor disc unbalance or cracking, bearing damage, system clearances or misalignment of rotor and motor shafts on ventilator vibration [22].

In addition to descriptions of the measurement of ventilator vibration in monitoring fan operation or diagnostics, there are scientific articles describing design problems manifested through unwanted vibration. Such an example is described by Feese and Maxfield in 2008, where the problem is torsional vibration in the motor and ventilator system due to the pulse-width modulation (PWM) frequency converter [23]. Other cases are descriptions of studies of rotor cracks and hypotheses of their causes [24], descriptions of the identification of the form of vibrations induced by the unbalance of the ventilator rotor [25] or descriptions of the values of vibrations on the housing and ventilator noise [26, 27].

Apart from technical solutions using vibrations in diagnostics and descriptions of problems caused by vibrations, there are works describing the effects of negative impacts of vibrations on humans. The PN EN ISO 5349-2:2004 standard describing the permissible exposure of the human body to selected vibration levels is available. In case of mobile rescue ventilators, firefighters taking part in rescue operations responsible for changing the place of operation of the ventilator are exposed to vibrations. In addition, the vibration of the ventilator can cause a change in its position and, because of this, forces the operator of the device to make additional contact with the device responsible for improving the position of the device. The vibrations caused by these devices can also be adversely transmitted to the structure of the ventilated building, contributing to its weakening.

Preventing the harmful effects of vibration in the first place should be based on adherence to the principle of not exceeding the maximum permissible values (NDN) of mechanical vibration [28]. Many papers have adopted NDN values that are too high or too low compared to those indicated in the literature [29]. Therefore, the following work was undertaken to indicate the maximum permissible values (NDN) of general and local mechanical vibrations on the basis of an analysis of: the world literature, ISO standards, proposals for NDN values of the European Union Commission and projects developed abroad [30]. As the normative magnitude of mechanical vibration, the frequency-weighted effective value of the vector sum of accelerations with respect to 8 hours of vibration during a work shift was used. The PN EN ISO 5349-2:2004/A1 standard also indicates that vibrations transmitted by the upper limbs should be measured in the three directions of the rectangular coordinate system [31], which was also confirmed in a study performed by Von Gierke [32]. For general mechanical vibration, a vector sum acceleration limit of 0.8 m/s^2 for 8 hours and 3.2 m/s^2 for exposures of 30 minutes or less was assumed, respectively. For localized mechanical vibrations, the permissible values of vector sum of accelerations for 8 hours were assumed to be 2.8 m/s^2 and 11.2 m/s^2 for exposures of 30 minutes or less, respectively [30]. Prolonged exposure to excessive general mechanical vibration can cause nonspecific changes in the human body [33].

The purpose of the article is to determine the value and direction of vibrations expressed in the acceleration vector of mobile ventilators overpressure used in rescue operations. These devices are driven by electric motors, like the vast majority of ventilators studied in literature, but also by internal combustion engines, which have not been studied for vibration analysis. Furthermore, identifying the main sources of vibration and determining the direction of loss of stability of the ventilator frame and the consequent change in its position relative to the opening into which it pumps air. Imprecise mobile fan arrangement may reduce the flow rate from 41 to 76% in relation to the most favorable results [34]. Research was conducted for the four most popular ventilators used by the State Fire Service (representing the main group of used equipment).

MATERIALS AND METHODS

Tested equipment and test procedure

Tests were performed for four mobile ventilators of positive pressure (Fig. 1), the technical parameters of which are included in Table 1. According to research by Warguła and Kaczmarzyk from 2022, the tested fans belong to the most popular group used in the State Fire Service in Poland [9, 34]. The adopted test procedure involved performing the test with two speeds of the ventilator impeller. The first speed, denoted as low, indicated operation of the device at the minimum speed controllable by the device's operating interface, and the second speed, denoted as high, indicated the maximum rotor speed controllable by the device's available interface. The accelerometer used for the test was mounted in accordance with PN-EN ISO 5349-1:2004 "Mechanical vibration – Measurement and evaluation of human exposure

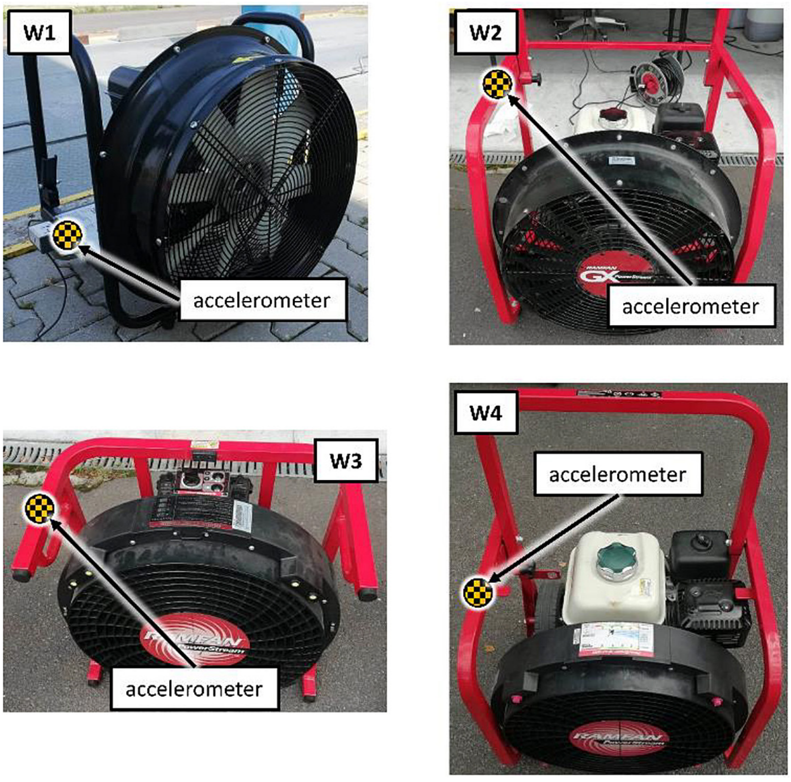

Fig. 1. Tested ventilators with indication of the location of the accelerometer mounting

Table 1. Summary of characteristics of tested ventilators

Parameter	W1	W2	W3	W4
Number of fan model	FOGO MW 22	GX500	EX50Li	GX350
Manufacturer (city, country)	FOGO Sp. z o.o. (Wilkowice, Poland)	Ramfan (Spring Valley, USA)	Ramfan (Spring Valley, USA)	Ramfan (Spring Valley, USA)
Power of the drive unit	4.4 kW	6.3 kW	0.6 kW	4.1 kW
Quantity of the rotor blades	8	7	5	9
Flow straightener on the fan impeller	no	yes	yes	yes
Rotary speed minimum	1355 rpm	1325 rpm	499 rpm	1405 rpm
Rotary speed maximum	3289 rpm	3230 rpm	2795 rpm	3585 rpm
Fielding of the accelerometer with respect to the rotor axis (reference system according to Figure 2)	Δx = -300 mm Δy = -290 mm Δz = 100 mm	Δx = -380 mm Δy = -350 mm Δz = -350 mm	Δx = -145 mm Δy = -265 mm Δz = 240 mm	Δx = -175 mm Δy = -240 mm Δz = -290 mm

to hand-transmitted vibration – Part 1: General requirements” is a support frame to which the drive unit was also attached, as well as supports that keep the entire device on the ground. The accelerometer was attached mechanically using rubber pads, and the location of its attachment to each of the test ventilators is marked in Figure 1. The location of the accelerator was determined by the design features of the supporting frame of the tested object. a place was selected that provided a solid and flat base for the accelerometer.

Due to the differences in the design features of the fans, their classification was supplemented by the position of the accelerometer relative to the rotor rotation axis (Δx, Δy i Δz) (Table 1). This data allows you to use the acceleration results and transfer them to force inputs transferred from the fan supports to the ground. Referring to the assumed fan rotational speed, it resulted from the maximum speeds offered by the tested fans.

Method of signal analysis

The tests were performed using an in-house accelerometer consisting of a KIONIX kx023 inertial sensor (with a resolution of 0.009576801 m/s^2 and a measurement range of 78.4532 m/s^2), a data archiving system and a power supply system. Acceleration was measured at a frequency of 100 Hz. The mass of the measurement system did not exceed 100 g and was negligibly small in relation to the mass of the test objects. The accelerometer was permanently attached to the frame with fastening screws, while the contact between the accelerometer and the cart frame was achieved through the use of rubber washers with a Shore A hardness of 40–50. The position of the *X*, *Y* and *Z* measurement axes of the accelerometer relative to the frame shown in Figure 2.

The measurement methodology involved measuring linear accelerations with a built accelerometer for the three main axes *X*, *Y* and *Z* during the operation of the ventilator at low and high speeds. In addition, background acceleration was measured for each ventilator, that is, the measurement without the drive unit on. In further analysis, the background signal was removed from the measurement signal by subtracting the average background acceleration a_{TX}, a_{TY} and a_{TZ} from the accelerations during the operation of the ventilator a_{PX}, a_{PY} and a_{PZ}, thus obtaining the accelerations resulting from the operation of the drive unit of the tested ventilators a_X, a_Y and a_Z (1-3).

$$a_X(t) = a_{PX}(t) - a_{TX} \quad (1)$$

$$a_Y(t) = a_{PY}(t) - a_{TY} \quad (2)$$

$$a_Z(t) = a_{PZ}(t) - a_{TZ} \quad (3)$$

where: *t* - time.

From the accelerations measured in the three axes of the system, the resultant vector *R(t)* (4) and the rms value of the vibration expressed in the *RMS R* (5) were calculated.

$$R(t) = \sqrt{a_x(t)^2 + a_y(t)^2 + a_z(t)^2} \quad (4)$$

$$RMS\ R = \sqrt{\frac{\sum_{i=1}^{n} {R_i}^2}{n}} \quad (5)$$

where: t – time;
n – the number of measured values of the *R* vector over the entire time interval *t*;
i – a single value of the *R* vector from the measured whole time interval.

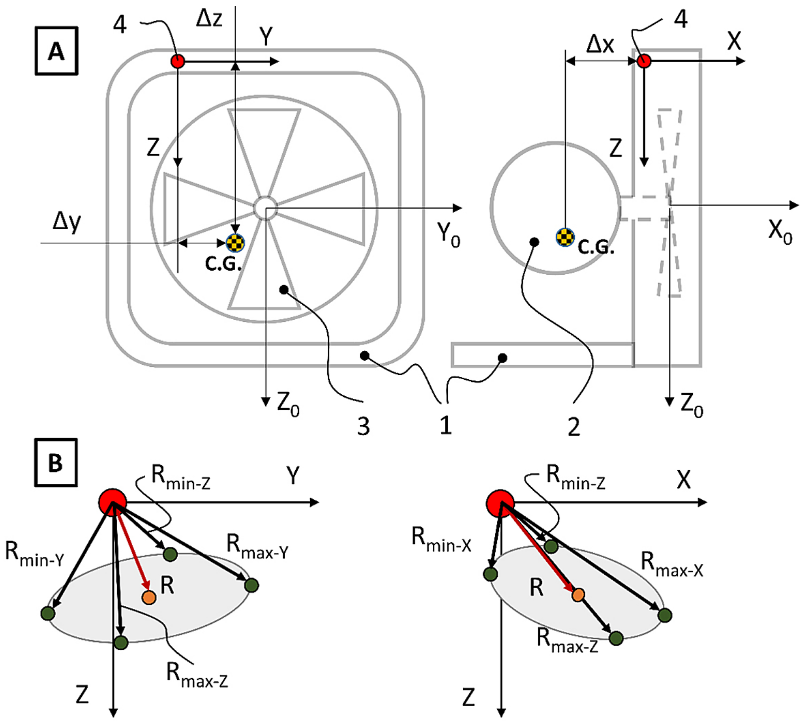

Fig. 2. Schematic representation of the tested ventilator (A) with the variation pattern of the resultant vibration vector *R* (B) marked, where: 1– ventilator frame; 2 – motor, 3 – ventilator; 4 – accelerometer centre; *C.G.* – position of the centre of gravity of the tested ventilator; X_0, Y_0, Z_0 – main axes of the reference system; *X*, *Y*, *Z* – axes of the accelerometer reference system

The performed analysis also included an evaluation of the amplitude of vibration of the resultant vector A_R and the amplitude of vibration on the individual axes of the adopted coordinate system A_X, A_Y and A_Z. In addition, for each ventilator, an analysis of vibration distribution relative to the ventilator support structure was performed (Fig. 1). This distribution took into account the direction of the mean vibration vector R, the area of variation of the vibration vector and its extreme values on the *X*, *Y* and *Z* axes. The calculated average values of the amplitude of vibration A_R and vibration vector *R* were determined on the basis of the analysis of the measurement signal lasting 60±5 from which 200 samples were extracted representing successive maximum values from the analyzed signal.

RESULTS AND DISCUSSION

The vibration waveforms in the form of the resultant vector *R* expressed in units of ground acceleration G are shown in Figures 3–6. These waveforms show the average *AR* amplitudes and *RMS R* rms value for maximum engine speed and engine speed during idling. The analyses presented here showed that, regardless of the type of ventilator, the amplitude of vibrations as well as the vibrations themselves decrease significantly when operating at minimum speed. The smallest *RMS R* values were measured for the W3 ventilator and were 0.637 G for maximum speed operation and 0.056 G for minimum speed operation. They refer to the *AR* amplitude for this ventilator (W3) which was 1.389 G for maximum speed operation and 0.103 G for minimum speed operation. The largest *RMS R* values measured for the W1 ventilator were 0.970 G for maximum speed operation and 0.174 G for minimum speed operation. They refer to the *AR* amplitude for this ventilator (W1) was 1.815 G for maximum speed operation and 0.276 G for minimum speed operation. In the category of combustion ventilators (W1, W2 and W4), the W4 ventilator had the lowest vibration values. In the case of this ventilator, the value of vibration at the minimum RMS R speed was 0.056 G, which is similar to a ventilator with an electric motor (W3) operating at maximum rotational speed. Vibration values expressed in unit G, are in the ranges of other researchers as, Dahlgren et al. in 1985 indicates that the vibration of their Tested ventilators could reach 2G [35].

A summary of the rms value of R and the average amplitude of A_R vibrations is shown in Fig. 7. Based on the summary, it was determined that, regardless of the type of ventilator, the difference between the vibration during low-speed and high-speed operation ΔRMS R (6) rotational speed is

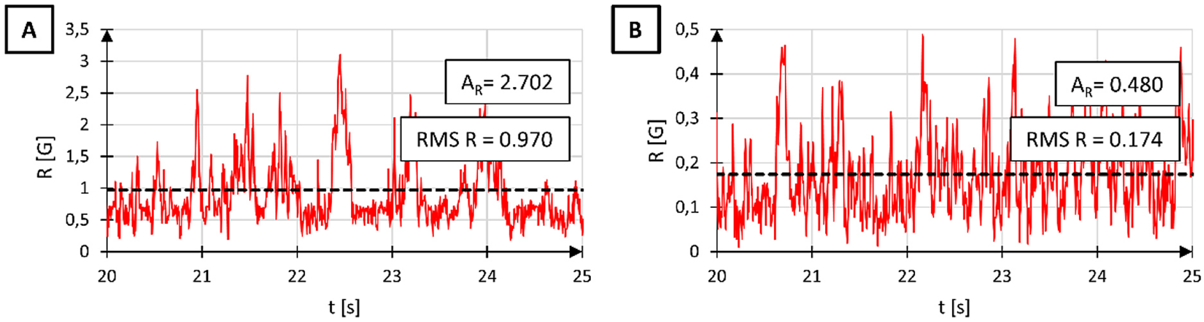

Fig. 3. Vibration waveform expressed in terms of resultant vector R as a function of time for ventilator W1 during operation at maximum speed (A), and during operation at minimum motor speed (B)

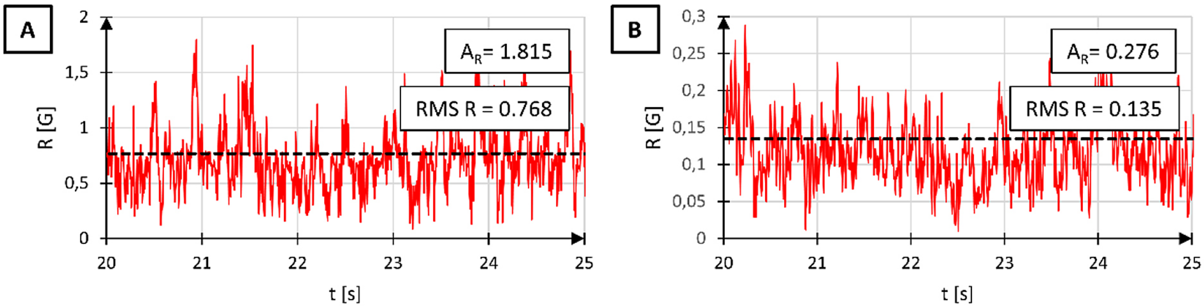

Fig. 4. Vibration waveform expressed in terms of resultant vector R as a function of time for ventilator W2 during operation at maximum speed (A), and during operation at minimum motor speed (B)

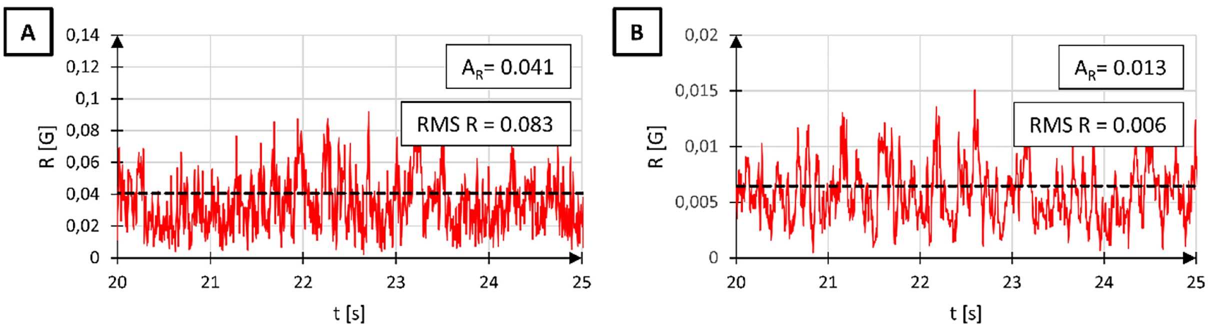

Fig. 5. Vibration waveform expressed in terms of the resultant vector R as a function of time for the W3 ventilator during operation at maximum speed (A), and during operation at minimum motor speed (B)

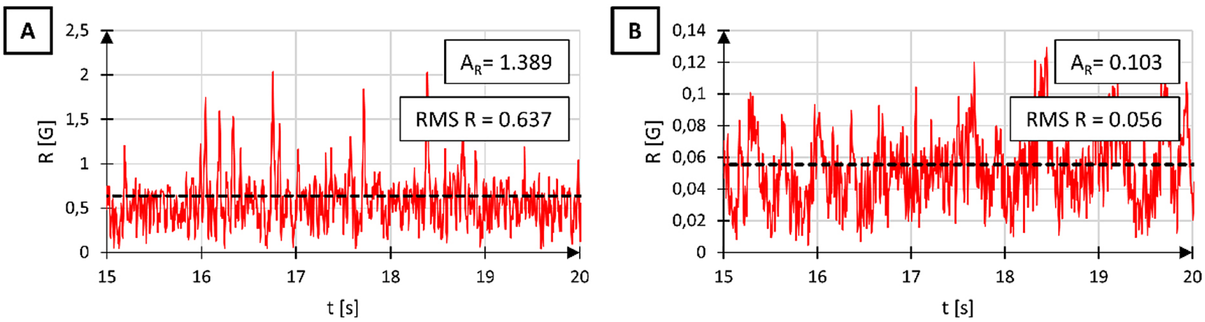

Fig. 6. Vibration waveform expressed in terms of the resultant vector R as a function of time for the W4 ventilator during operation at maximum speed (A), and during operation at minimum motor speed (B)

several times. In the case of ventilator W4, the ΔRMS R value was 11. For the other ventilators, the difference ranged from 6.8 to 5.6. Similar differences were also measured for the difference between the average amplitude for maximum and minimum speed ΔA_R (7). In this case:

$$\Delta RMS\ R = \frac{RMS\ R^{high}}{RMS\ R^{low}} \tag{6}$$

$$\Delta A_R = \frac{A_R^{high}}{A_R^{low}} \tag{7}$$

where: $RMS\ R^{high}$ – $RMS\ R$-value for maximum speed operation;
$RMS\ R^{low}$ – $RMS\ R$-value for minimum speed operation;
A_R^{high} – A_R value for operation at maximum speed;
A_R^{low} – A_R value for minimum speed operation.

In the next stages of the research, the vibrations of the ventilators were analysed against the adopted reference system. The values of the average vibration amplitudes on each axis are shown in Figure 7 and in Table 2. Based on the performed analyses, it was concluded that the highest values of vibration amplitude occur in the vertical direction, *Z*-axis. The second largest amplitude of vibration lay in the horizontal direction, the *Y* axis. The exception is an electrically driven ventilator for which the second-to-last amplitude value was recorded in the horizontal direction, the *X* axis.

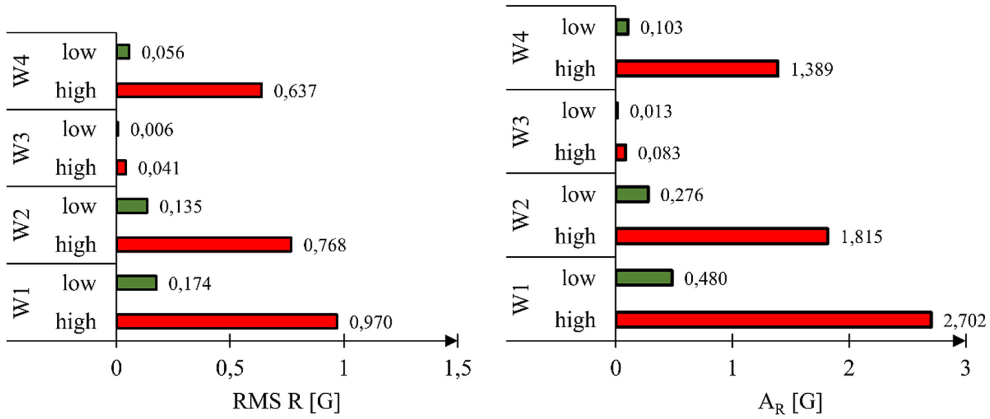

Fig. 7. Summary of *RMS R* and vibration amplitude A_R for tested ventilators where high – is operation at maximum speed and low – is operation at minimum speed of the ventilator

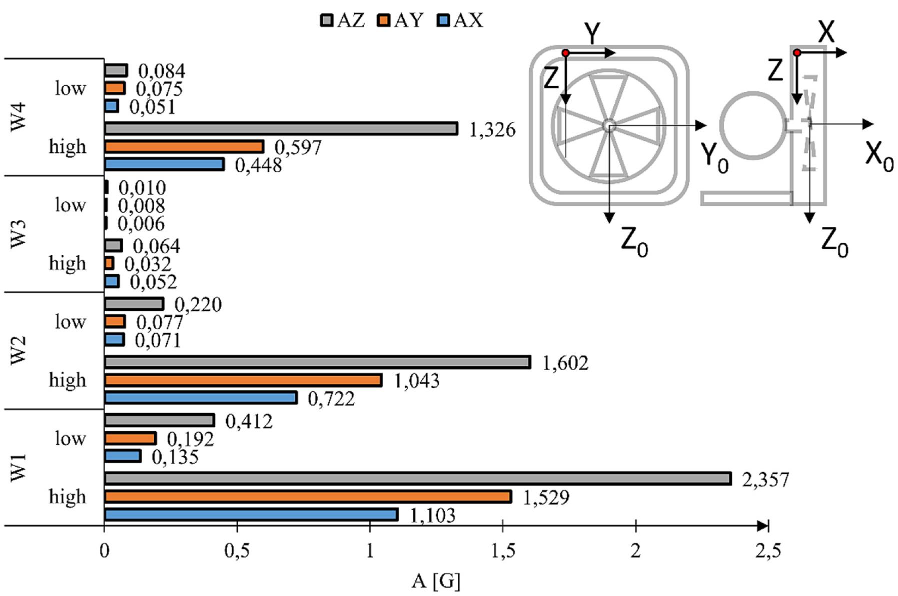

Fig. 8. Summary of the values of the average vibration amplitudes on the adopted axes of the *XYZ* reference system for the tested ventilators where high – is the operation at maximum speed and low – is the operation at minimum speed of the ventilator

Table 2. Summary of the values of vibration amplitudes on each axis of the reference system (A_X, A_Y, A_Z), and the amplitude of the resultant vibration vector (A_R) for four ventilators and two operating speeds of the drive unit

Amplitude	W1		W2		W3		W4	
	high	low	high	low	high	low	high	low
	G	*G*	*G*	*G*	*G*	*G*	*G*	*G*
A_R	2.702 ±0.044	0.480 ±0.012	1.815 ±0.030	0.276 ±0.004	0.083 ±0.001	0.013 ±0.001	1.389 ±0.030	0.103 ±0.001
A_X	1.103 ±0.016	0.135 ±0.002	0.722 ±0.015	0.071 ±0.001	0.052 ±0.001	0.006 ±0.001	0.448 ±0.015	0.051 ±0.001
A_Y	1.529 ±0.034	0.192 ±0.005	1.043 ±0.021	0.077 ±0.003	0.032 ±0.001	0.008 ±0.001	0.597 ±0.012	0.075 ±0.001
A_Z	2.357 ±0.032	0.412 ±0.010	1.602 ±0.028	0.220 ±0.004	0.064 ±0.001	0.010 ±0.001	1.326 ±0.029	0.084 ±0.001

The analysis of the excitations in the three axes of the reference system made it possible to present the main directions of the vibrations illustrated in the form of closed areas (Figures. 8, 9). These areas were determined from the set of points determined by the vibration vectors *R* measured during the measurement tests. In order to simplify the presented areas, they were plotted on the basis of 4 points corresponding to the largest and smallest value on the *X*, *Y* and *Z* axes (Table 2).

Analysing the directions of the resultant vibration vector, it was observed that, for internal combustion engine ventilators operating at high speed, the excitations resulting from vibrations in the *XZ* (lateral) plane point downward and are evenly distributed between the positive and negative directions of the *X* axis. On the other hand, the *YZ* (frontal) plane showed a predominant distribution of vibrations in the positive direction of the *Y* axis, which corresponded to the direction of rotation of

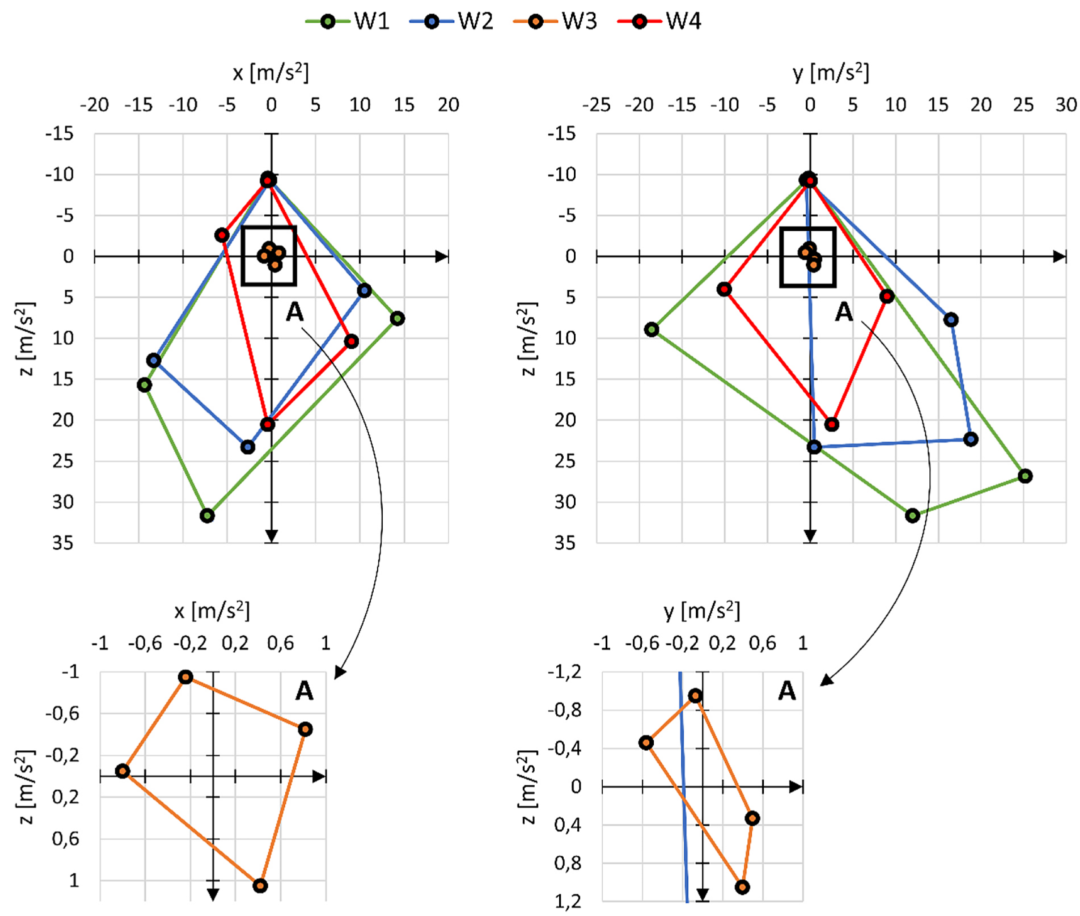

Fig. 9. Areas of influence of the resultant vibration vector *R* during operation of ventilators at high speed, where A – enlargement of the fragment of the main diagram

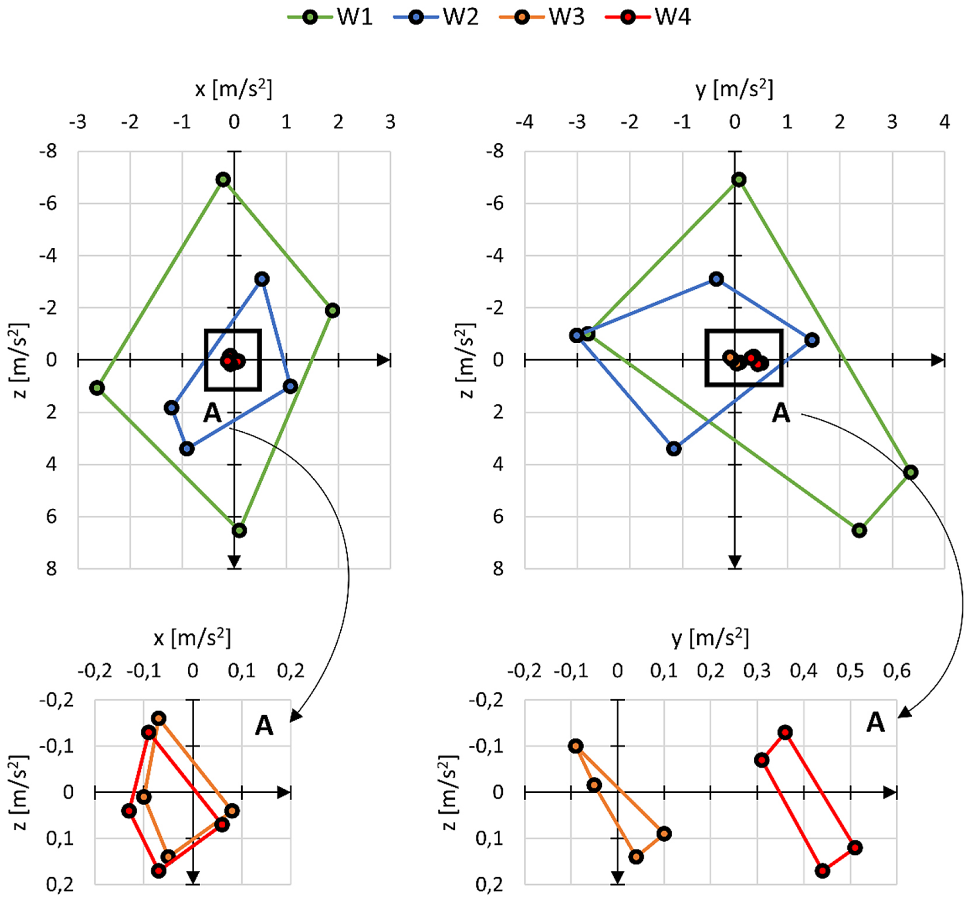

Fig. 10. Areas of influence of the resultant vibration vector *R* during the operation of ventilators at low speed, where A – enlargement of the fragment of the main diagram

Table 3. Summary of the coordinates of the extreme values of the resultant vibration vector R, for four ventilators operating at two speeds low and high

Ventilator	Vector name (according to Figure 1)	high			low		
		X	*Y*	*Z*	*X*	*Y*	*Z*
		m/s²	m/s²	m/s²	m/s²	m/s²	m/s²
W1	R_{max-X}	14.24	-1.46	7.57	1.89	-0.78	-1.89
	R_{min-X}	-14.34	3.79	15.69	-2.63	-2.02	1.07
	R_{max-Y}	4.23	25.19	26.82	1.63	3.35	4.31
	R_{min-Y}	2.00	-18.56	8.93	-0.41	-2.8	-1
	R_{max-Z}	-7.24	12.01	31.66	0,1	2.37	6.53
	R_{min-Z}	-0.39	-0.16	-9.55	-0.21	0.08	-6.91
W2	R_{max-X}	10.52	4.11	4.15	1.08	-0.35	1.01
	R_{min-X}	-13.29	7.53	12.68	-1.2	-1.1	1.83
	R_{max-Y}	-1.35	16.5	7.74	0.04	1.47	-0.76
	R_{min-Y}	2.49	-18.84	22.32	0.06	-3.01	-0.94
	R_{max-Z}	-2.66	0.49	23.29	-0.91	-1.16	3.4
	R_{min-Z}	-0.18	-0.46	-9.31	0.53	-0.35	-3.1
W3	R_{max-X}	0.82	-0.19	-0.45	0.08	0.03	0.04
	R_{min-X}	-0.8	0.13	-0.05	-0.1	-0.03	0.01
	R_{max-Y}	-0.1	0.5	0.33	0.04	0.1	0.09
	R_{min-Y}	0.19	-0.56	-0.46	-0.08	-0.09	-0.1
	R_{max-Z}	0.42	0.4	1.05	-0.05	0.04	0.14
	R_{min-Z}	-0.24	-0.07	-0.95	-0.07	-0.05	-0.16
W4	R_{max-X}	9.06	0.6	10.38	0.06	0.44	0.07
	R_{min-X}	-5.57	-3.85	-2.59	-0.13	0.38	0.04
	R_{max-Y}	1.64	9	4.87	0.02	0.51	0.12
	R_{min-Y}	1.44	-10.07	3.99	-0.1	0.31	-0.07
	R_{max-Z}	-0.41	2.55	20.53	-0.07	0.44	0.17
	R_{min-Z}	-0.45	0	-9.23	-0.09	0.36	-0.13

the drive unit. A high-speed test of an electrically driven ventilator showed that its area of variation in vibration-induced excitation is negligibly small compared to combustion engine-driven ventilators. In case of the W3 electric drive, vibrations in the dominant direction, i.e. the *Z* axis, took values from -0.95 to 1.05 m/s^2, while for the W1 combustion engine ventilator, for the same direction, vibrations took values from –9.55 to 31.66 m/s^2.

Referring to the areas of vibration variation during low-speed operation (Fig. 10), noteworthy is the internal combustion engine ventilator W4, whose area of vibration variation is similar in dimension and range to the electrically driven ventilator W3. For the other ventilators, a significant decrease in the variation of forcing in the positive *Z* direction was observed when operating at low speed.

The value of vibration of combustion-driven ventilators is greatest downward (z-axis) in the maximum range of 20 to 35 m/s^2, while sideways (y-axis) from 10 to 25 m/s^2, and along the axis of the rotor shaft (x-axis) from 9 m/s2 to 15 m/s^2. On the other hand, the vibration value of an electrically driven ventilator is much lower, equal to a maximum of 1.1 m/s^2 for the z-axis, 0.6 m/s^2 for the y-axis, and 0.8 m/s^2 for the x-axis, respectively. The value of vibration also strongly depends on the power of the drive unit, but in the literature we can find similar values of vibration for electric ventilators, for example, in the articles of Zachwieja in 2003 in the bearing nodes of fans (corresponds to measurement in the x or z axis) and is equal to 0.4 m/s^2 [22], while the value of vibration in the air-cooled turbogenerator tested by Kapler et al. in 2014 is at 0.45 m/s^2 [36]. A vibration value of about 11–12 m/s^2 according to Mansoor et al. in 2020 indicates a crack in the shaft on which the rotor is mounted [37]. The range of vibration of electric motors alone can be in the range of 0.4 to 0.8 m/s^2 according to a study by Kurkiewicz and Serwicki [38], from 0.05 to 0.35 m/s^2 according to Vasilevskyi et al. [39], and in high-powered engines (about 100 kW) vibrations can be at the level of 9 to 22 m/s^2 according to a study by Ismagilov et al. in 2020 [40]. In some applications, as in the electric ventilator tested by the authors, the working mechanism, which is the rotor of the ventilator, can cause an increase in vibration, a situation that is also seen, for example, in wood pelletizers [41], flat belt conveyor gears [42]. There is no research in literature for internal combustion powered ventilators, but there are perceived vibration studies of internal combustion engines. It should be noted that the study involved rescue ventilators equipped with low-power internal combustion engines [9] (according to the European Union's homologation regulations of up to 19 kW [43, 44], which are subject to more liberal emission regulations for pollutants in exhaust gasses, which translates into lower technical sophistication of drive units than, for example, in motor vehicles [44]. Vibration values of low-power internal combustion engines used in nonroad machines were presented in articles by Kończak et al. showing vibration values of up to 17 to 77 m/s^2 for high-speed operation, depending on the measurement location on the frame of the machine tested [45]. Meanwhile, Gravalos et al. in 2011 also for a non-road internal combustion engine obtained vibration values ranging from 22.1 to 100.5 m/s^2 during testing [46]. The results obtained by the article are within the vibration ranges of other researchers of this group of internal combustion engines. Manufacturers of mobile ventilators should strive to use systems to reduce vibrations transmitted to the ventilator frame, e.g. through appropriate tools such as vibroisaltors that enable effective compensation of vibrations – preventing mobile ventilators from moving during operation.The problem of vibrations in rescue fans during rescue operations is a significant concern that can impact both the effectiveness of the rescue mission and the safety of the rescue team and victims. Vibrations in rescue fans can result from various factors and can have several detrimental effects. Prolonged exposure to vibrations can lead to fatigue and discomfort among rescue team members operating the fans. This fatigue can reduce their efficiency and effectiveness in carrying out rescue operations, potentially endangering lives. Vibrations can make it challenging to maintain precise control over the rescue fan. In situations where precision is crucial, such as when trying to ventilate a confined space or control the direction of airflow to clear smoke or fumes, excessive vibrations can hinder the rescue team's ability to achieve their goals. Vibrations can lead to wear and tear on the rescue fan equipment, potentially causing malfunctions or breakdowns at critical moments. This could further delay rescue operations and put lives at risk. Vibrations can also make it difficult for rescue team members to communicate effectively with each other. Clear communication is essential in coordinating rescue efforts and ensuring everyone's safety.

To address the problem of vibrations in rescue fans during rescue operations, several steps can be taken. Regular maintenance and inspection of rescue fans can help identify and address issues related to vibrations early on. Ensuring that equipment is in good working condition is essential for safe and effective rescue operations. Incorporating vibration dampening technology into the design of rescue fans can help mitigate the impact of vibrations on both the equipment and the operators. This might involve using shock-absorbing materials or adding vibration isolators. Rescue team members should receive training on how to operate rescue fans effectively, including how to manage vibrations. They should also be aware of the potential risks associated with excessive vibrations. Implementing monitoring systems that can detect and measure vibrations during rescue operations can provide valuable data for identifying and addressing the problem. This information can be used to make real-time adjustments and improve safety. Consideration can be given to alternative technologies or equipment that may generate fewer vibrations while achieving the same or better results in rescue operations. It's essential to stay updated on advancements in technology and equipment design. Proper placement of the rescue fan can help minimize vibrations. Experimenting with different fan positions and angles may help find the most effective configuration while minimizing vibrations. If vibrations are unavoidable, it may be necessary to rotate rescue team members to prevent fatigue and discomfort caused by prolonged exposure. Addressing the problem of vibrations in rescue fans during rescue operations is crucial for ensuring the safety and effectiveness of rescue missions. This requires a combination of proper maintenance, technology, training, and monitoring to minimize the impact of vibrations on both equipment and rescue team members.

CONCLUSIONS

The problem of vibration of positive pressure ventilators used in rescue operations requires research to determine their range of values and causes in order to develop methods to reduce vibration. The resulting vibration of these devices can negatively affect operators and contribute to changes in the position of the device reducing the effectiveness of the rescue operation. The article established that the value of vibration of ventilators driven by a combustion engine is greatest downward (z-axis) in the maximum range of 20 to 35 m/s^2, while sideways (y-axis) from 10 to 25 m/s^2, and along the axis of the rotor shaft (x-axis) from 9 m/s^2 to 15 m/s^2. However, the vibration value of an electrically driven ventilator is much lower, equal to a maximum of 1.1 m/s^2 for the z-axis, 0.6 m/s^2 for the y-axis, and 0.8 m/s^2 for the x-axis, respectively. It has been established that in case of combustion-powered ventilators, the engine is the largest source of vibration (in the vertical axis), while during the exploitation of electric ventilators it is the momentum force that causes the largest vibration (along the rotor axis). Further work should be carried out on reducing vibrations transmitted to the ground or operators' limbs to improve exploration conditions.

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