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Original Research

NOISE EMISSION AND VIBRATION STUDY OF A MISTA RD-165 FHAD GRADER TO REDUCE ENVIRONMENTAL HARMFUL IMPACT

BADANIA HAŁASU I DRGAŃ RÓWNIARKI MISTA RD-165 FHAD MAJĄCE NA CELU ZMNIEJSZENIE JEJ SZKODLIWEGO WPŁYWU NA ŚRODOWISKO

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Abstract

Construction machinery noise emission and vibration on the operator site are the most important harmful factors having impact on human health. They affect for people working on the operators and as well as other persons around the machine. The article concerns the issues of noise level and noise emission measurements applied to the earthmoving machinery which are covered by the EU directive 2005/88/EC. The methods of noise testing during design and in the certification, process has been described. The basic information about testing the noise emission to the environment has been presented.
Methods and results of vibration tests affecting the operator are also presented.
The reference documents and EU standards concerning this topics have been described.
The noise testing methods has been presented based on the prototyping and R&D cycle of the Mista RD-165 FHAD grader which is subjected to the European noise limits. The results of noise measurements and sound power level determination has been presented. The testing procedure implemented during two stages of R&D cycle. The article describes the effects of the improvements in the grader focused on noise emission limitation limits.

Keywords: earth moving machinery, grader**,** noise emission, noise level, vibrations.

Streszczenie

Hałas emitowany przez maszyny budowlane jest jednym z głównych czynników szkodliwych wpływających na środowisko, a szczególnie na zdrowie osób przebywających w obszarze oddziaływania tych maszyn. Narażonym na hałas poddane są osoby bezpośrednio zaangażowane w pracę, ale również inne osoby znajdujące się w otoczeniu maszyny. Artykuł porusza zagadnienia badania hałasu i drgań miejscowych w maszynach budowlanych podlegających pod dyrektywę Unii Europejskiej 2005/88/WE. Omówione zostały sposoby badania hałasu w trakcie produkcji i certyfikacji maszyn. Przedstawiono podstawowe informacje dotyczące przeprowadzania badań emisji hałasu do otoczenia. Przywołano dokumenty odniesienia i normy badawcze które regulują te badania.
Na przykładzie równiarki drogowej Mista RD-165 FHAD, która podlega limitom emisji hałasu, przedstawiono prowadzenie badań podczas prac badawczo-rozwojowych. Przedstawione zostały wyniki pomiarów hałasu i wyznaczona moc akustyczna maszyny. Badania były wykonywane na dwóch etapach prac konstrukcyjnych. W artykule zaprezentowano efekty prac doskonalących konstrukcję pod względem zmniejszenia emisji hałasu do otoczenia

Słowa kluczowe: maszyny do robót ziemnych, równiarka, emisja hałasu, poziom hałasu, wibracje.

1. Introduction

Every earthmoving machine introduced to the European Union market should got the CE marking. This confirms that the machine has undergone an assessment process of meeting the requirements of the New Approach Directives and/or standards harmonized with them for the human protection and environmental protection.

In the design procedure and subsequent certification of a new machinery, studies are conducted that target the impact of harmful factors on human health. Among such tests are: machine noise emitted into the environment, noise occurring at the operator's space and mechanical vibrations affecting the machine user.

Noise emitted into the environment by earthmoving machinery is a component of street and road noise. This type of noise in the opinion of people is considered the most harmful and annoying. The permissible levels of noise in the environment were published in the Regulation of the Minister of Environment of January 22, 2014 (Rozporządzenie Ministra Środowiska z dnia 22 stycznia 2014 r.). Studies conducted by the Chief Inspectorate of Environmental Protection (GIOŚ) have shown that road noise above 65dB threatens as much as 54% of the population in Poland. This is why it is so important to limit the noise emitted into the environment by any vehicle operating in and around the road, as well as construction sites.

It is also important to limit noise and vibration affecting the machine operator inside the vehicle, at the workspace. The permissible levels of these hazards are outlined in the Decree of the Minister of Family, Labor and Social Policy of June 12, 2018 (Rozporządzeniu Ministra Rodziny, Pracy i Polityki Społecznej z dnia 12 czerwca 2018 r.) on the highest permissible concentrations and intensities of factors harmful to health in the work environment, and in the Decree of the Minister of Economy and Labor of August 5, 2005 (Rozporządzeniu Ministra Gospodarki i Pracy z dnia 5 sierpnia 2005 r.) on health and safety at work involving exposure to noise or mechanical vibration. Health and safety regulations limit the exposure to harmful factors to which an operator of the machinery may be subjected. Exposure to noise and vibration in this case is determined on a 8-hour workday basis. In order for OSH supervision to be possible, it is required that the manufacturer informs in the manual what the noise and vibration exposure levels are at the operator's workplace, as well as what sound power the machine has.

1.1. Study machine

Grader RD-165 FHAD manufactured by MISTA Sp. z o.o. Stalowa Wola is the example of a machine that falls under the above mentioned requirements and was subjected to vibroacoustic testing at the prototype and manufacturing stage. Machine intended for testing was indicated by the manufacturer, i.e. the MISTA company. The grader has got a 129kW engine with a maximum speed of 2200 rpm. It worked 10 hours until the measurements began (Fig. 1).

Fig. 1. Front view of the Mista RD-165 FHAD grader

1.2. Noise emitted into the environment

The grader was subjected to tests of noise emissions to the environment, which were conducted in accordance with PN-EN ISO 3744. The detailed conduct of measurements, preparation of the test object and processing of the results were conducted in accordance with the ISO 6395 standard for earthmoving machinery. The latter standard details the test method to determine sound power for all common earth-moving machinery. The requirements for graders are outlined in Annex G of ISO 6395. The machine is subjected to measurements of time-averaged sound pressure levels corrected for A-frequency characteristics.

Tests are carried out at points around the machine, distributed over a defined measuring surface matched to the test object. In the case of earthmoving machinery, this is usually a hemisphere or quarter of sphere with a reflective plane, which is a hardened surface. Due to the type of testing ground, a quarter sphere with a hardened concrete slab was used to test the grader. The machine, due to its pneumatic tires, moved on the paved surface. For the grader, the standard stipulates driving forward only during the work cycle. The radius of the quarter sphere was 16 m. A set of Bruel & Kjaer microphones connected to

a PULSE portable recorder was used for the measurements. The microphones were distributed at 3 points according to the indications of the standard, and the measurements were carried out while the machine was positioned in both directions along the X axis, thus reflecting the measurement on the hemisphere. Based on the averaged result of the sound pressure measurement, the acoustic power of the machine was calculated.

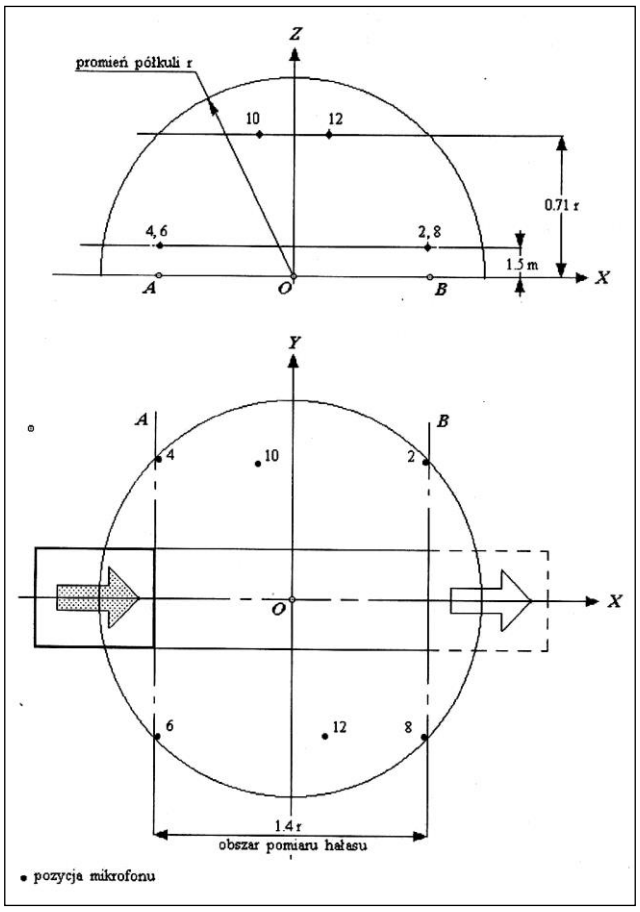

Fig. 2. Microphone array for determining sound power (Source: ISO 6395 standard page 4.).

Other machine tests concerned the operator's workspace. Inside the cab, the noise affecting operator was measured, as well as the level of general and local vibrations to which the operator is subjected during the work cycle.

Noise tests affecting the operator were carried out in accordance with the method specified in ISO 6396. The measurement microphone of the SONOPAN SON-50 device was placed on the operator's helmet near the operator's ear and pointed in the direction of his gaze. Three measurements lasting 5 minutes each were carried out while the machine was in operation, driving around the testing ground on both unpaved and paved surfaces. During the runs they were measured:

- equivalent A-frequency corrected sound level,
- maximum frequency-corrected sound level A,
- peak sound level corrected by frequency characteristics C.

1.3. Vibration test

The EN 1032+A1 standard governs the mobile machinery vibration emissions tests. In addition, other standards define the rules for measuring and determining exposure to two types of vibrations affecting humans working on machinery.

The basic type of vibration is general vibration, which affects the entire human body. These vibrations are dealt with in PN-EN 14253 +A1 standard. Such vibrations are introduced into the body either through the ground on which the machine operator works in a standing position, or through the seat. The latter situation is most common in earthmoving machines. The test is carried out by measuring with a special seat vibration sensor measuring in the three axes of the coordinate system, which is placed in the center of the seat and pressed down by the weight of the operator's body.

The second type of vibration is that which acts locally, such as the machine handles parts, which operator holds with his hands. This could be, for example, the steering wheel, other handles or manipulators. A tri-axial sensor is mounted to such items, the orientation of which is specified in EN ISO 5349 standard, which specifies a method for measuring local vibrations. Either type of vibrations are measured by recording their value during the work cycle, which is representative of the machine operating characteristics, i.e. including the full variability of the emitted vibrations.

The vibration waveforms are then subjected to tertial analysis, which results in vibration acceleration results in 1/3 octave frequency bands. The effective vibration accelerations in the frequency bands are corrected by filters that perform frequency weighting according to the curves specified in the mentioned standards. General and local vibrations have separate weighting curves, resulting from the characteristics of the effects of these vibrations on the human body. In the grader, vibration measurements were made with a set of two tri-axial sensors connected to a portable recorder made by Bruel & Kjaer. The waveforms were analyzed on dedicated software. The measurements were made during runs lasting 5 minutes each. Five runs were recorded, and the results obtained from these runs were then averaged.

Fig. 3. Rear view of the Mista RD-165 FHAD grader

2. Acoustic power and vibration tests to improve vehicle mechanical design

MISTA RD-165 FHAD grader acoustic power tests were carried out at 2 stages of research and development works. The first measurements were carried out at the first version of the prototype. The machine tested at this stage had a developed superstructure and drive train, while body finishing elements such as engine covers, radiator covers, or exhaust system mounting and insulation elements were not yet worked out.

Fig. 4. MISTA RD-165 FHAD – first tested prototype

The measurements carried out at this stage gave an indication of the estimated sound power level for the first machine prototype. The test results of this stage slightly exceeded the acceptable guaranteed sound power level, i.e., the measurement uncertainty margin - 107.5 ± 1.9 dB (A) exceeded the limit imposed by the Noise Directive for a grader with a power of 129 kW., It was LwA ≤ 108 dB(A). This meant that the guaranteed sound power level was not within the limit.

The grader underwent further work, The new engine covers were design. Soundproofing liners were applied to their inner side. A louver was installed to direct the propagation of noise from the radiator fan toward the ground. The installation of the exhaust system was improved, isolating it from the body. This reduced the number of potential secondary noise sources. The second series of test included a production version of the machine. It score the changes due the tests from the first prototype.

Fig. 5. MISTA typ RD-165 FHAD – second prototype

The designers took into account in their design work issues related to the elimination of noise sources in the machine. Tests of the machine after the development work yielded satisfactory results. The determined sound power level has decreased so much that, taking into account the measurement uncertainty, it is possible to guarantee compliance with the requirements of the EU Noise Directive 2005/88/EC.

Standards take so-called dominant value as the final result of the tests for local vibrations. The dominant value is the highest value of vibration from each direction of measurement, taking into account the coefficients. The Z-axis is the direction along the spine of the seated operator, while X is the forward direction and Y is the side direction For local vibration, the test result is the resultant vector from the 3 measurement directions.

Table 1. Comparison of test results with the Polish and EU requirements for machinery

No	Tested product feature or quantity and requirements	Tests or observation results
1	Noise acting on the operator - Equivalent sound level A According to the Dziennik Ustaw Nr 2014 June 6, 2014, No. 817 LAeq,dop ≤ 85 dB(A) According to the Dziennik Ustaw Nr 157, August 5, 2005 r. No. 1318 "action threshold" ≤ 80 dB(A)	L_{Aeq} = 79 ± 3 dB(A)
2	Noise acting on the operator - Maximum sound level A According to the Dziennik Ustaw Nr 2014, August 6, 2014 r. No. 817 LAmax,dop ≤ 115 dB(A)	L_{Amax} = 80 ± 3 dB(A)
3	Noise acting on the operator - Peak sound level C According to the Dziennik Ustaw Nr 2014, August 6, 2014 r. No. 817 LCpeak,dop ≤ 135 dB(C)	L_{Cpeak} = 107 ± 5 dB(C)
4	Vibrations acting on the whole body According to the Dziennik Ustaw Nr 2014 z dnia June 6, 2014 r. No. 817 Effective frequency-weighted vibration acceleration dominant among vibration accelerations determined for the three directional components X, Y, Z, taking into account a factor of 1.4 for X,Y directions, with an 8-hour vibration effect on humans avmax dop = 0.8 m/s^2 according to the Dziennik Ustaw Nr 157 z dnia 5 sierpnia 2005 r. poz.1318 "action threshold" = 0.5 m/s^2	a_{wmax} = 0,41±0,13 m/s^2,
5	Regulation of the Ministry of Economy of October 21, 2008 on essential requirements for machines Dz.U. nr 199, No. 1228 The manuals of the moving machine should include the highest weighted effective value of the acceleration of vibrations acting on the whole body of the operator, when this value exceeds 0.5 m/s^2 - if this value does not exceed 0.5 m/s^2, this information should be included in the instructions	
6	Vibrations acting through the upper limbs According to the Dziennik Ustaw Nr 2014 of June 6, 2014 r. No. 817 The values of the vector sum of the effective weighted vibration accelerations determined for the three directional components X, Y, Z should not exceed 2.8 m/s^2, with an 8-hour vibration effect on a person. ahv /(w,śr)wek (8h)dop = 2.8 m/s^2 according to the Dziennik Ustaw Nr 157 August 5, 2005 r. No. 1318 "action threshold" = 2.5 m/s^2	a_{hv} = 1,253 ± 0,49 m/s^2,
7	Regulation of the Ministry of Economy of October 21, 2008 on essential requirements for machines Dz.U. nr 199, poz. 1228 The manual of the moving machine should include the total value of vibrations acting on the upper limbs of the operator, if the value exceeds 2.5 m/s^2, if the value does not exceed 2.5 m/s^2, this information should be included in the manual	
8	Corrected sound power level L_{wA} ≤ 108 dB(A)	Prototype L_{wA} = 107,5 ± 1,9 dB(A) Manufacture machine L_{wA} = 103,9 ± 1,9 dB(A)

3. Summary and conclusions

The RD 165 FHAD grader is a machine developed by MISTA Sp. z o.o. of Stalowa Wola under the project POIR.01.01.01-00-0236/15 "Development of innovative technology for the control system and engine cooling system of a hydrostatic drive road grader - RD-165 FHAD (Full Hydrostatic Advance Drive)". The machine is equipped with a 129 kW diesel engine, and its driving system is fully hydrostatic. As a result of cooperation between the manu-

facturer and the Łukasiewicz Research Network - Institute of Mechanization of Construction and Rock Mining, Machinery and Construction Laboratory, vibro-acoustic tests of the machine were carried out during development work, as well as after its completion and manufacturing of the final unit. As a result, it was verified whether the levels of sound power and noise at the operator's workstation and vibrations affecting him are at an acceptable level in relation to the legal regulations in force in this matter. A comparison of the results with the requirements is shown in Table 1. The first tests of sound power were carried out at the prototype stage, and their results, taking into account measurement uncertainty, did not provide a guarantee of compliance with the requirements of the Machinery Directive. The manufacturer improved the components responsible for reducing noise emissions to the environment. Re-testing was carried out on the production copy, with successful results that ensured compliance with the requirements. The tests carried out indicate that vibro-acoustic testing is an important component of research and development work on earth-moving machinery and any other machinery where optimization of the design in terms of vibration and noise emissions is taken into account.

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