Comparison of Loaded and Unloaded Noise Test Methods Within the Scope of Annexe XIII of EU/1322/2014

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Abstract. In this study, test methods for measuring noise levels in the driver's ear in Annexe XIII of EU/1322/2014, one of the delegated regulations of the type-approval regulation EU/167/2013, which determines the production and market-supply conditions of agricultural tractors, were compared. Tractor noise levels, an area where manufacturers continuously strive to improve user health and comfort, are measured using two different methods under the regulation: Test Method 1 and Test Method 2.

The researchers measured noise levels in the driver's ear for five different tractors using two methods, then compared the resulting values and test procedures. The tractors have similar dimensional measurements and the same protective structure, but they have three different engines.

In this study, the researchers compared the two methods specified in the regulation and evaluated the results for tractors equipped with different engines. They examined how engine type influences noise levels in the driver's ear under various operating conditions and identified the most suitable engine. In addition, the researchers observed how the noise level of tractors changes when the machines operate under load.

The results of the study revealed that Method 1 requires more equipment than Method 2, has a longer, more complex testing process, and involves greater difficulty in applying load to the tractor. The testing team evaluated the results and ranked the tractors under load according to Method 1 as Tractor E > Tractor B = Tractor D > Tractor A > Tractor C. They also ranked the tractors without load according to Method 2 as Tractor A = Tractor C > Tractor E > Tractor B > Tractor D. Considering that farmers typically use tractors under load during fieldwork, these results indicate that selecting a tractor using Engine Type 1 would result in lower noise exposure.

Keywords: Noise test; driver's exposure to noise level; Tractor noise; Agricultural tractor; Noise test method.

INTRODUCTION

The mechanisation of agricultural machinery has exposed farmers working in this field to increased noise levels. In particular, the noise emitted by tractors with internal combustion engines can cause problems such as decreased concentration, fatigue, difficulty in communication between workers, and hearing loss for users and people around the tractor [1, 2].

Among agricultural machinery, the most prolonged exposure to noise-related discomfort occurs in tractors, followed by combine harvesters, soil cultivation machines, and balers. For this reason, tractor manufacturers have conducted numerous studies to identify and reduce noise and vibration sources [3–6].

The Organisation for Economic Co-operation and Development (OECD) created test codes for agricultural tractors in 1965. Member states of the organisation began testing tractors for performance and reliability using the same methods, based on a joint decision. In 1970, 'environmental noise' and 'requirements for measuring noise at the driver's ear level' were added to the OECD codes [7–10].

The noise level to which drivers are exposed, measured using code 5 in the OECD codes, was specified in 1977 by the European Economic Community (EEC) in Directive 77/311/EEC, which set out the conditions for the noise level to which drivers are exposed in tractors with type approval valid in member states. The directive, which requires measurement using one of two different methods with limits of 90 dBA and 86 dBA, was updated in 2009 as 2009/76/EC and again in 2014 as Annexe XIII of 1322/2014/EU [11].

Many studies have been conducted to meet regulatory requirements and improve comfort inside tractor cabins. Koizumi and colleagues developed an active noise control (ANC) system that reduces low-frequency engine noise, thereby lowering noise levels around the driver's ears to acceptable levels [12].

Authors [13] measured noise levels inside the cab under changing road and tractor operating conditions. They found that rubber material placed under the tractor floor helped reduce noise levels around the driver's ears.

Authors [14] compared noise and vibration levels reaching the driver in two tractors with the same characteristics but different protective structures and found that the noise level at the driver's ears was lower in the tractor with a safety-framed protective structure than in the tractor with a single-post roll bar.

Authors [15] demonstrated through their tests that acoustic holography detects noise sources in tractors more effectively and that installing noise absorbers under the tractor cab floor reduces noise levels to acceptable limits.

Authors [3] identified the tractor's noise sources and measured noise levels around the operator and in the tractor's external environment under different operating conditions and at variable speeds in different gear positions. They identified the lowest and highest noise levels.

Authors [16] investigated the health effects of noise exposure on individuals directly operating tractors and those in the vicinity. Tests conducted with two tractors of varying engine power found that insulation materials reduced noise and that individuals working within 7 metres of the tractors must use ear protection.

Authors [17] identified the noise sources and reflection points that amplify noise in the tractor model they selected, which had a noise level of 87 dBA, and reduced the noise level to below 80 dBA. In their studies, they noted that flat sheet materials transmit noise through vibration, so they replaced the sheet material with composite material. It has been determined that changing the aerodynamic shape of the engine cooling fan, changing the number of blades from 6 to 11, and using insulation material in locations close to the primary noise sources and the front firewall are methods that reduce noise levels [17].

The study aims to compare both test methods in terms of results, applicability, ease of use, and preference. Additionally, to investigate why method one specified in the regulation, which has not been studied much in the articles, is not preferred by manufacturers, and to determine the most appropriate method for manufacturers by examining the rationale for defining two different approaches and limit values.

MATERIALS AND METHODS

The noise level to which the driver is exposed was measured using test methods 1 and 2 specified in the regulation on five different tractors. The prototype tractors belonging to Erkunt Traktör Sanayii A.Ş. are subject to type approval tests under the EU/167/2013 Regulation on the Approval and Market Surveillance of Agricultural and Forestry Machinery. One of the conditions tractors must meet is the driver's exposure to noise levels, as specified in Annexe XIII of EU/1322/2014. The researchers compared the two different test methods specified in the regulation.

The researchers fitted the selected tractors with front roll-bar-type protective structures. Three of the tractors have 16 forward and eight reverse gears, while two have 16 forward and 16 reverse gears. Three different types of engines from two different manufacturers are used. All engines comply with Stage V emission standards, and both tractors include a Diesel Oxidation Catalyst (DOC), a Diesel Particulate Filter (DPF), and Exhaust Gas Recirculation (EGR). In this study, the researchers used two engines: one from Erkunt

Traktör Sanayii A.Ş. and another from an external company. Tractors A and Tractor C have engines manufactured by the same engine manufacturer. The engine used in Tractor A has over 56 kW, so it has an SCR system. Tractors B, D, and E have engines manufactured by the same manufacturer. The Tractor E has a 3-cylinder engine. The engine used in Tractor B has over 56 kW, so it has an SCR system. The tractors have the exact physical dimensions. Tractor specifications are listed in Table 1.

Table 1 – Tested Tractors

Tractor Name	Transmission	Engine	Rated Engine Power
Tractor A	16+16	Engine Type 1	63 kW
Tractor B	16+16	Engine Type 2	68,5 kW
Tractor C	16+8	Engine Type 1	55,4 kW
Tractor D	16+8	Engine Type 2	52,2 kW
Tractor E	16+8	Engine Type 3	49,9 kW

A sound level meter (microphone) is used to measure noise, and the device is periodically checked for calibration by accredited calibration laboratories. The device provides measurement results in dB(A).

Methods. EU/1322/2014 Annexe XIII specifies two different test methods for the conditions applied to the driver's exposure to noise. Tractor manufacturers can test their tractors using either of these two methods. The conditions specified in the regulation are found in the sections describing test methods 1 and 2, as well as the measurement conditions. If the noise level is below the value specified below, the tractor is considered to meet the regulation's requirements.

In Test Method 1, the maximum noise level should be 90 dB(A). In Test Method 2, the maximum noise level should be 86 dB(A).

Test Conditions. There should be no extra weight on the tractor, and optional equipment and parts should not be attached. However, engine coolant, engine and transmission oils, a full fuel tank and the driver should be present on the tractor during the test. The driver's clothing should be of normal thickness, and they should not wear a scarf or hat. There should be no objects on the tractor that could affect the noise level.

Tyres should be inflated to the pressure recommended by the tractor manufacturer. The engine and power transmission components should be at normal operating temperature, and the radiator air intake ducts should be open during measurements.

On the tractor being tested, the power take-off shaft, heater fan, windscreen wipers, and other equipment that operate with the engine or its own power system may not be operated during measurements if it is thought that they will affect the noise level. However, parts that are active by design while the engine is running, such as the engine cooling fan, must be active during the test.

The test location should be open and as quiet as possible; for example, it could be an open area with a radius of 50 metres, a centre section with a radius of at least 20 metres, and a sufficiently smooth (pothole-free) and flat surface. The ground should be dry and clean if possible.

The road surface should not cause excessive tyre noise. The weather should be clear, with little or no wind. The noise level at the driver's ear caused by noise sources other than the tractor or by wind should be at least 10 dB(A) below the noise level emitted by the tractor. The test team should take all tractor measurements during testing on the same road.

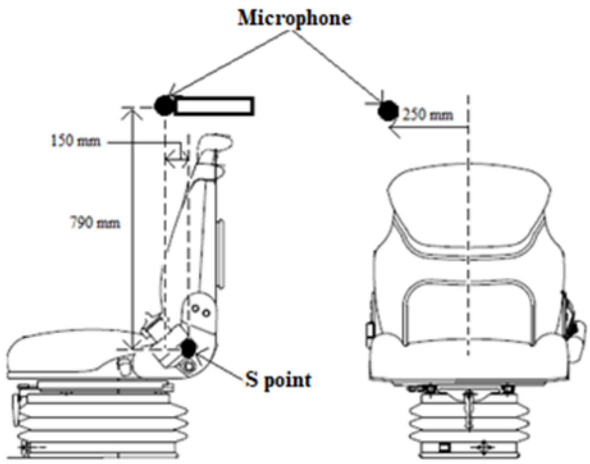

Figure 1 – Microphone position [11]

When taking measurements, the noise measurement device (microphone) should be held 250 mm to the right or left of the seat centre, as shown in Figure 1. The results from the side with higher noise will determine the test result. The (S) point defined in the regulation is the seat reference point. The microphone should be positioned 790 mm above and 150 mm in front of this point. This positioning approximately represents the driver's ear level.

Test Method 1. If the tractor being tested has a protective cab structure, the researchers conduct the initial series of measurements with all doors and windows closed. Test personnel open the doors and windows during the second series of tests if doing so does not compromise road safety; if they cannot open the doors and windows, they keep the front windows closed.

The testing team conducts the test in three stages. In the first stage, they shift the tractor into the gear that provides the speed closest to the design speed of 7.5 km/h. They start the test with the throttle fully open and gradually apply a load to the tractor, which initially runs unloaded. They measure the noise level at each load increase and repeat the measurement until the value stabilises. The researchers continue increasing the load until they measure the maximum noise level. In the second stage, they select a different gear position than in the first stage. As in the first stage, they gradually increase the load, ensuring that the noise level measured in this stage is at least 1 dB(A) higher than the value recorded in the first stage. They repeat the test as many times as necessary to determine the appropriate gear position. The researchers take three recordings in both the first and second stages.

In the third and final stage, the noise measurement is performed without applying any load to the tractor. The noise level of the tractor moving forward in the gear position where it reaches maximum speed is measured. The test team took two recordings in this stage.

The loading method specified in the first and second stages was performed by pulling another tractor with a 10-metre-long rope attached to the tow bar of the tested tractor, as shown in Figure 2. Initially, the researchers drove the tractors at the same speed to start the unloaded test, then gradually reduced the rear tractor's speed to place the tested tractor under load. They determined the maximum load as the point at which the tested tractor struggled to pull the rear tractor and slowed to nearly a stop. In the third stage, the researchers removed the tow rope between the tractors and drove the tested tractor alone at its maximum speed.

The highest value of all measurements taken at each stage indicates the measurement result for that stage. If the maximum noise level measured in all three stages is below 90 dB(A), the tractor is deemed to meet the regulation requirements and the test is completed.

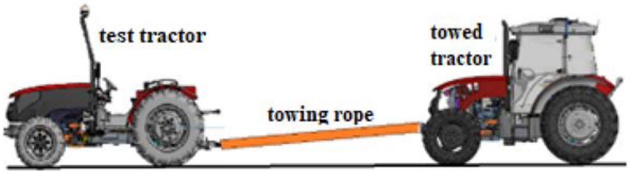

Figure 2 – Test method one measurement setup

Test Method 2. The researchers repeat each noise measurement three times and record each measurement for 10 seconds. If the tractor being tested has a protective cab structure, they perform the first series of measurements with all openable doors and windows closed. For the second series, the researchers open the doors and windows during testing if doing so does not compromise road safety; if they cannot open the doors and windows, the researchers keep the front windows closed.
The noise level reaching the driver's ear is measured at the gear position that comes when the tractor is travelling at a speed closest to 7.5 km/h, which is the design speed, at nominal rpm. The noise levels on the driver's right and left sides are measured separately and recorded.

The testing team considers the tractor to meet regulatory requirements if the noise levels measured in both series are below 86 dB(A) and concludes the test.

RESULTS AND DISCUSSION

All five tractors tested reached the speed closest to 7.5 km/h in the field-fast-3 gear combination. The researchers selected this gear position based on the speed table calculated using the motor wheel ratio and nominal motor speed. They used this gear position in both test methods. In Method 1, during the first stage, the researchers loaded the tractor in three stages while it was in the field-fast-3 gear and took recordings. In the second stage, they loaded the tractor in stages while it was in the field-slow-3 gear, took three recordings, and then proceeded to the next step. In the third stage, they used the road-fast-4 gear to measure the noise level the driver experienced at maximum speed and took two recordings. The researchers present the test results in Table 2.

Table 2 – Test Method 1 Measurement Results dB(A)

Tractor Name	Step 1	Step 2	Step 3	Result
Tractor A	85,2	86,7	86,1	87,7
	85,6	87,6	86,4	
	86,1	87,7		
Tractor B	88,0	89,1	89,4	89,5
	88,1	89,2	89,5	
	88,2	89,4		
Tractor C	83,9	84,7	84,3	86,4
	84,6	85,7	84,4	
	85,4	86,4		
Tractor D	86,6	87,5	86,5	89,5
	87,9	88,8	86,7	
	88,3	89,5		
Tractor E	85,5	86,5	85,3	89,8
	86,5	87,8	86,2	
	87,3	89,8		

The researchers calculated the results of the tractors tested under Method 1 conditions as percentages of their proximity to the 90 dB(A) limit value. The results were as follows: Tractor A: 2.56%; Tractor B: 0.56%; Tractor C: 4.00%; Tractor D: 0.56%; and Tractor E: 0.22%. During testing under load, the researchers recorded the highest noise level in Tractor E, which uses Engine Type 3. Tractor B and Tractor D, which use Engine Type 2, are very close to the limit value. Tractor A and Tractor C, which use Engine Type 1, performed better than the other tractors under load.

Under Method 2, the researchers measured the noise level reaching the driver's ear at the Field-Fast-3 gear, which provides a speed closest to 7.5 km/h, for five tractors. The test results are presented in Table 3. All tractors are below the limit value of 86 dB(A) specified in Annexe XIII of EU Regulation 1322/2014.

Table 3 – Test Method 2 Measurement Result dB(A)

Tractor Name	Left Side dB(A)	Right Side dB(A)	Result dB(A)
Tractor A	86,0	85,5	86,0
	85,9	85,4	
	85,9	85,1	
Tractor B	84,7	85,1	85,1
	84,6	84,6	
	84,8	84,7	
Tractor C	86,0	85,5	86,0
	85,9	85,4	
	85,9	85,1	
Tractor D	84,7	84,8	84,9
	84,9	84,8	
	84,8	84,6	
Tractor E	85,5	85,9	85,9
	85,7	85,9	
	85,6	85,8	

When evaluating the test results for tractors, their proximity to the limit value of 86 dB(A) for method two was checked and calculated as a percentage. The results are as follows: Tractor A: 0%; Tractor B: 1.05%; Tractor C: 0%; Tractor D: 1.28%; and Tractor E: 0.12%. In this test method applied without load, it is observed that Tractor A and Tractor C, which use Engine Type 1, have noise levels exactly at the limit value. Tractor E, which uses Engine Type 3, is very close to the limit value. Tractor B and Tractor D, which use Engine Type 2, were found to produce lower noise levels than the others when unloaded.

CONCLUSIONS

There are many sources of noise in tractors, such as the engine, cooling fan, transmission, exhaust system, and metal parts that transmit noise through vibration. The five tested tractors have similar transmissions and body structures; this indicates that the differences in noise levels are due to variations in the engine, cooling fan and exhaust systems, as well as differences in engine operating characteristics.

When tractors equipped with engine two were tested using test method 2, the proximity of the noise level generated to the limit value was 1.05% for tractor B, and 1.28% in Tractor D, while in test method one, conducted under load, the proximity of the noise levels generated by both tractors to the limit value was 0.56%.

Tractor E, which uses Engine Type 3, obtained results very close to the limit values in both the loaded and unloaded test methods, at 0.22% and 0.12%, respectively.

Tractor A and Tractor C, which use Engine Type 1, obtained results at the full limit value in unloaded test method 2, while in method 1, which was performed under load, the measured noise level was close to the limit value, at 2.56% for Tractor A and 4.00% for Tractor C. These two tractors performed better than the other tractors. Additionally, the researchers found that using Engine Type 1 in the tested transmission and body reduced noise under load compared to the no-load condition. They also found that, because engine speed decreases with increasing load, the cooling fan accounts for a significant portion of the noise. Reducing the fan speed or using a fan with a lower noise level and a different blade design and configuration will reduce the noise level reaching the driver's ears and make the tractor more ergonomic [3].

According to Method 1, the noise level ranking of tractors is Tractor E > Tractor B = Tractor D > Tractor A > Tractor C. According to Method 2, the noise ranking of tractors is Tractor A = Tractor C > Tractor E > Tractor B > Tractor D.

When evaluating results, given that farmers generally use tractors under load in field work, selecting a tractor with Engine Type 1 indicates they will be exposed to lower noise levels because this motor generates less noise when loaded.

In addition, while measurement methods allow us to observe tractor characteristics under different conditions, testing has shown that manufacturers generally prefer method 2 in type-approval tests due to its labour-intensive nature, longer test times, and greater equipment requirements.

For example, in method 2, the test is completed in a single stage, whereas in method 1, it is performed in three phases. In Method 2, the researchers note that measuring at a gear ratio other than 7.5 km/h may produce higher noise levels, but they do not account for this. Additionally, in Method 1, the researchers find that identifying the gear producing at least 1 dB more noise in the second stage complicates the test process. They conduct the test in Method 1 only at 7.5 km/h and reduce the limit value from 90 dB to 89 dB. Furthermore, in Method 1, measuring the noise level at maximum speed in the third stage may pose a safety risk during driving. For this reason, the third stage, which typically yields a lower dB value, can be omitted from Method 1.

This study clearly shows that test method one needs improvement. To provide better suggestions for improving test method 1, more studies should be conducted.

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