First investigation on the applicability of an active noise control system on a tracked tractor without cab

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Abstract

In last years, several research teams pointed their attention on the application of active noise control systems (ANC) inside the cabs of agricultural tractor, with the purpose of reducing the driver exposition to noise, that is only partially controlled by the frame of the cab. This paper reports the results of a first experience that aimed at verifying the applicability of an ANC on a medium-high power, tracked tractor without cab. The tested tractor was a Fiat Allis 150 A, equipped with rear power take off, used in the execution of deep primary tillage in compact soils. It is a tracked tractor without cab, with maximum power of 108.8 kW at 1840 min^{-1} of the engine. The ANC consists of a control unit box based on a digital signal processor (DPS), two microphones, two speakers and a power amplifier. The instrumentation used in noise data collecting and processing consisted of a multichannel signal analyzer (Sinus - Soundbook), a ½" microphone capsule and an acoustic calibrator, both Bruel & Kjaer. The study aimed at evaluating the behaviour of the ANC by means of tests carried out under repeatable conditions, characterized by pre-defined engine speed values. Three replications have been made for each engine speed. The sampling time was 30 s. Two series of tests were performed in order to compare the results observed with the ANC on and off. The engine speed adopted in the study ranged from 600 min^{-1}, up to 2000 min^{-1} (maximum speed) with steps of 100 min^{-1}. The ANC proved to be effective in the interval of speed between 1400 and 1700 min^{-1}, where the samplings have been intensified, adopting steps of 50 min^{-1}. In such an interval, the attenuation observed with the ANC system on appeared evident both as weighed A sound pressure level (from 1.29 up to 2.46 dB(A)) and linear (from 4.54 up to 8.53 dB). The best performance has been observed at the engine speed of 1550 min^{-1}, with attenuations, respectively of 2.46 dB(A) and 7.67 dB. Outside of the engine speed interval 1400 - 1700 min^{-1}, the attenuations always resulted lower than 1 dB(A) for the weighed A sound pressure level and between 0.66 and 7.72 dB.

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Introduction

At about twenty-five years since the beginning of systematic work on the active noise control, we can draw some important conclusions and suggest programs and reasonable results for the foreseeable future (Hasegawa *et al*., 1992; Kuo and Vijayan, 1994). The enthusiasm of the researchers, emerging from the reading of the considerable amount of works reported in the Proceedings of the Conference 'ACTIVE-95', the first conference dedicated exclusively to this area of research, gradually decreased over time. The few applications that were successful in industry were primarily the result of large investments in applied research of the products and were aimed at very large market segments (Elliot, 2000). For instance, it was the case of the active headphone and of the active-cancelling microphone. The problem of noise reduction in the cab of tractors, as well as other vehicles, it is very sensitive today both for the preservation of health and for a greater operator comfort. For several years, research groups turned their attention to the active noise control into cabs of tractors and industrial vehicles trying to reduce operator exposure to the noise, that is only partly controlled by the cab structure (Del Duca and Nataletti, 2009; Nataletti and Del Duca, 2010).

This work describes a first experience aimed at verifying and evaluating the application of a system for active noise control on an agricultural tracked tractor of medium-high power, without cab. This type of vehicles is largely diffused and has significant noise impact on the operators. The originality of this study lies precisely in the application of an active control system in absence of cab. The system used, ATH311, already successfully used in tractors with cab, consists of a control unit based on the digital signal processor DSP. A widespread feedback algorithm configuration was used in the experiment. It will be briefly described in the following. In experimental tests it was implemented in a configuration with two feedback channels (Figure 1).

Materials and methods

The active noise control, henceforth indicated with the term ANC (Active Noise Control), is a technique characterized by the fact that the reduction of noise (primary noise) is obtained electronically generating a noise (secondary noise) that creates a destructive interference with the first, unlike the conventional techniques (passive) in which the reduction of noise is obtained with the use of sound absorbing and soundproofing materials and structures.

The tractor tested was a Fiat Allis 150 A, commonly employed in heavy works (plowing, subsoiling, etc.) in tenacious soil and fitted with a rear power take off. It is a tracked tractor, without cab, with maximum power of 108.8 kW at engine speed of 1840 min^{-1}. The diesel engine is turbocharged, with displacement of 8102 cm^3. Its total mass is approximately 12150 kg. It has steel tracks the tension of which is hydraulically adjustable. The gear box has three-speed gear ratios and a two gear range reducer (slow and fast). The maximum velocity is 2.41 m s^{-1} in III fast.

The system for the active control of the noise consisted of (Figure 2):
1. control unit based on the digital signal processor DSP;
2. stereo power amplifier Class D (600 W);
3. couple of electret microphones with cables and jacks,
4. woofer speaker pair of 13 ".

In the configuration, the standard algorithm was implemented with an original routine software aimed at increasing the efficiency, stability and reliability of the system.

The sound measurements were recorded with the following instrumental chain:
- Sound Book - eight channels datalogger / signal processor with special software "Samurai";
- microphone capsule ½" Brüel & Kjær, mod. 4189, with windscreen;
- microphone calibrator Brüel & Kjær, mod. 4231;

The tractor was fitted with a magnetic tachometer for measuring engine speed. The tests aimed at evaluating the system of active noise control.

For this purpose, the measurements were carried out in repeatable conditions at various rotation speeds of the engine, first with the active control system turned on, then off. For each speed, 3 replications were performed with a sampling time of 30 s. The measurements were made with engine speed increments of 100 min^{-1} in the range 600-2000 min^{-1}. In a second time, in the interval between 1400 and 1700 min^{-1}, in which the system resulted more efficient, the sampling occurred with increments of 50 min^{-1}.

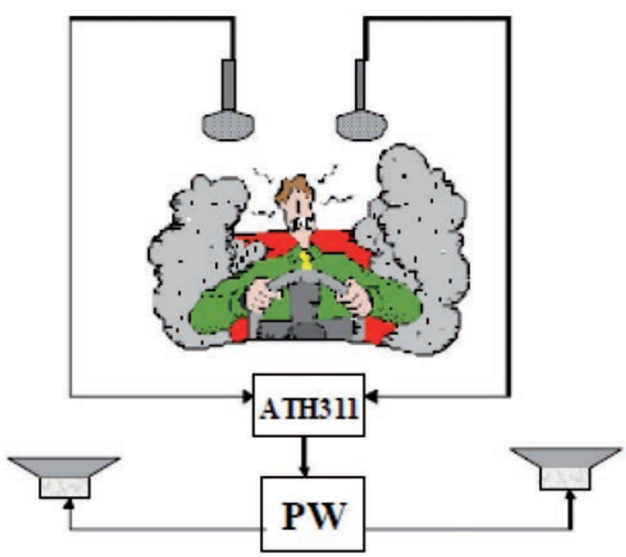

Figure 1. Configuration of the two channel feedback system.

Results

Figure 3 shows the frequency analysis in 1/3 of octave relating to the noise measured in the operator's station, with rotation speed of the engine of 600 min^{-1} (a), 1550 min^{-1} (b), and 2000 min^{-1} (c). The curves refer both to the ANC system "off " (brown and red lines) and "on" (blue and green).

In general, it can be noticed that the weighting filter A has the maximum effect on the frequencies ranging from 20 to 800-1000 Hz. Furthermore, it is evident that the frequency range in which the ANC system is more effective is between 40 and 200 Hz.

An attentive observation of the analysis in frequency shows that, in the cases in which the lower components of the spectrum (relative to the engine) prevail, the ANC system provides the best performance 40 Hz (Figure 3a and b).

Moreover, when the same low components of the spectrum are very pronounced in comparison to the other harmonic components, as in Figure 3 b, the best results are observed on the single frequencies which the system operates and on the total value in dB (A) as well.

Otherwise, from 1800 min^{-1} up to the max rotation speed (Figure 3 c), the lines of the spectrum are almost all at the same level, and the effect of attenuation results less effective.

The test results are reported in Table n. 1 and the above considerations indicate the opportunity to separate evaluation of the values obtained in linear and the A-weighted values. In the first case, the operation of the ANC system provides good attenuation, ranging from a

Figure 2. System for the active control of noise composed by a control unit based on the digital signal processor DSP and a power amplifier (A), two microphones (B), two speakers (C).

minimum of 3.0 dB to a maximum of 8.5 dB at engine speeds lower than 1700 min^{-1}.

As already mentioned above, for the rotation speeds higher than 1800 min^{-1}, the system is less effective, with attenuations ranging from 0.7 to 1.4 dB.

As to the A weighting filter, its action, inside the interval of the spectrum between 20 and 1000 Hz, almost completely cancels the ANC system action for engine speeds comprised between 600 and 1300 min^{-1}, where the maximum attenuation observed was 0.9 dB(A).

The attenuation level increased in the interval 1350-1800 min^{-1}, with values ranging from 0.9 up to 2.5 dB(A).

Even less significant differences were observed at higher engine speeds, with a light tendency to an increase of the global noise level at 1800 and at 1900 min^{-1}, while at 2000 min^{-1} the attenuation resulted of only 0.1 dB(A).

Considering the higher action value 85dB (A) and the limit value of 87 dB (A) defined in the Italian Legislative Decree no. 81/2008, for the first, the use of the system for the first ANC, at speeds of 1400 and 1450 min^{-1}, leads to a standardized level of exposure of the operator, for a working day of 8 h, which is within the range of lower risk.

As to the limit value, at the engine speeds of 1500 and 1550 min^{-1}, the ANC system seems capable to reduce the level below it (Table 1).

Conclusions

The study described in the present paper aimed at contributing to the improvement of the health safe and comfort levels through the reduction of the noise level to which the drivers of tractors without cab are exposed. The tests, carried out on a tracked tractor, using an active noise control system based with an original feedback configuration, provided good results. The most significant attenuations (up to 8.5 dB) occurred in the interval of engine speed between 1000 and 1400 min^{-1}, where the action of the ANC system appeared particularly effective towards the prevailing low frequencies. However, even at higher speeds, where the attenuation of the low frequencies is less significant in the prevention of the hearing damage, the ANC system could contribute to an increase of the level of comfort, through reduction of loss of attention and hearing fatigue. However, the link between the exposure to low frequency noise and the loss of attention and working efficiency should be suitably studied.

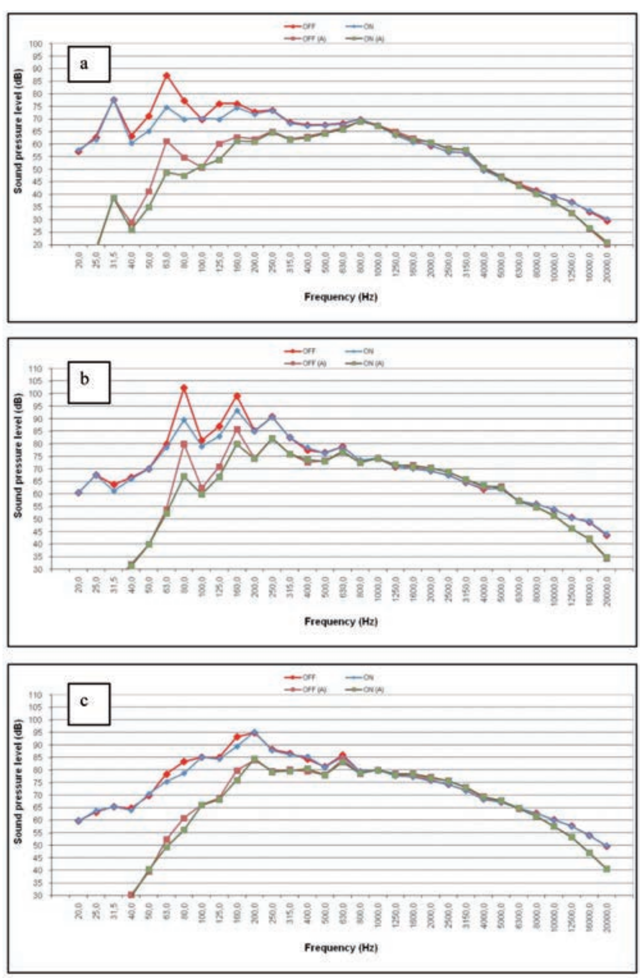

Figure 3. Spectrum in 1/3 of octave relating to the tests with the ANC system, "off" and "on" at the engine speeds of 600 min^{-1} (a), 1550 min^{-1} (b), 2000 min^{-1} (c).

Table 1. Results obtained in the noise measurements with the ANC system connected (on) and disconnected (off) at different engine speeds.

Engine speed (min^{-1})	Active control	L_{Aeq} dB(A) Repetitions			Average	Stand. Dev.	Δ	L_{eq} dB Repetitions			Average	Stand. Dev.	Δ
		1	2	3				1	2	3			
600	OFF	76.3	75.4	75.6	**75.8**	0.45		89.5	89.3	89.8	**89.6**	0.26	
	ON	75.7	74.8	75.2	**75.2**	0.46	**0.6**	83.9	83.1	85.4	**84.2**	1.17	**5.4**
700	OFF	78.5	78.0	77.9	**78.1**	0.35		94.4	95.5	95.4	**95.1**	0.61	
	ON	77.8	77.0	77.0	**77.3**	0.45	**0.9**	87.5	87.7	86.9	**87.4**	0.42	**7.7**
800	OFF	78.7	78.4	78.2	**78.4**	0.25		93.3	93.8	93.4	**93.5**	0.22	
	ON	78.0	77.4	77.5	**77.6**	0.35	**0.8**	86.7	85.8	86.7	**86.4**	0.48	**7.1**
900	OFF	79.8	79.8	80.2	**79.9**	0.19		91.6	92.4	90.9	**91.6**	0.74	
	ON	79.4	79.5	80.0	**79.6**	0.33	**0.3**	87.9	88.4	88.7	**88.3**	0.39	**3.3**
1000	OFF	81.2	81.0	80.8	**81.0**	0.19		91.4	91.9	91.4	**91.6**	0.33	
	ON	80.8	80.6	80.7	**80.7**	0.11	**0.3**	88.2	88.2	89.2	**88.5**	0.57	**3.0**
1100	OFF	81.5	81.2	80.9	**81.2**	0.27		94.7	93.3	93.5	**93.8**	0.74	
	ON	81.1	80.9	80.8	**81.0**	0.14	**0.3**	88.9	88.7	90.0	**89.2**	0.71	**4.6**
1200	OFF	83.9	83.5	83.1	**83.5**	0.40		96.1	96.6	95.7	**96.1**	0.45	
	ON	83.1	82.4	82.7	**82.7**	0.35	**0.7**	90.9	90.7	91.7	**91.1**	0.49	**5.0**
1250	OFF	83.8	83.6	83.5	**83.6**	0.15		96.7	96.0	96.2	**96.3**	0.34	
	ON	83.5	83.4	83.4	**83.4**	0.06	**0.2**	91.9	92.2	91.6	**91.9**	0.27	**4.4**
1300	OFF	84.5	84.5	83.7	**84.2**	0.47		96.9	99.3	97.4	**97.9**	1.27	
	ON	84.0	84.0	83.4	**83.8**	0.33	**0.4**	92.2	92.3	92.3	**92.3**	0.06	**5.6**
1350	OFF	84.9	84.5	83.9	**84.5**	0.51		99.8	99.3	98.5	**99.2**	0.66	
	ON	83.7	83.7	83.4	**83.6**	0.18	**0.9**	92.8	92.8	91.9	**92.5**	0.56	**6.7**
1400	OFF	85.5	85.3	85.1	**85.3**	0.25		101.6	102.3	102.0	**102.0**	0.37	
	ON	83.7	83.5	83.5	**83.6**	0.10	**1.7**	93.5	93.9	93.1	**93.5**	0.36	**8.5**
1450	OFF	87.1	86.8	86.6	**86.8**	0.25		103.2	102.4	102.3	**102.7**	0.49	
	ON	84.7	84.9	84.8	**84.8**	0.10	**2.0**	94.5	95.3	94.7	**94.8**	0.40	**7.8**
1500	OFF	88.1	87.9	88.0	**88.0**	0.13		103.6	102.8	103.2	**103.2**	0.38	
	ON	85.5	85.4	85.8	**85.6**	0.19	**2.4**	95.0	94.4	95.5	**95.0**	0.56	**8.2**
1550	OFF	89.7	89.5	89.2	**89.5**	0.24		104.6	104.3	104.2	**104.4**	0.19	
	ON	87.2	87.3	86.4	**87.0**	0.51	**2.5**	97.3	97.5	95.2	**96.7**	1.27	**7.7**
1600	OFF	90.2	90.1	90.1	**90.1**	0.08		104.2	104.4	104.5	**104.4**	0.15	
	ON	88.2	88.1	87.3	**87.9**	0.48	**2.2**	98.3	98.8	96.3	**97.8**	1.32	**6.6**
1650	OFF	90.2	90.0	89.8	**90.0**	0.21		103.9	103.7	103.6	**103.7**	0.12	
	ON	88.5	88.1	88.3	**88.3**	0.19	**1.7**	98.5	98.4	98.2	**98.4**	0.18	**5.4**
1700	OFF	89.9	89.7	89.8	**89.8**	0.13		103.1	103.0	103.3	**103.1**	0.13	
	ON	88.2	88.4	88.9	**88.5**	0.34	**1.3**	97.8	98.5	99.4	**98.6**	0.78	**4.5**
1800	OFF	89.8	89.8	89.8	**89.8**	0.04		100.9	101.6	101.0	**101.2**	0.39	
	ON	89.1	91.2	90.3	**90.2**	1.09	**-0.4**	97.5	101.9	100.2	**99.8**	2.23	**1.4**
1900	OFF	90.3	90.3	91.8	**90.8**	0.87		99.1	99.8	102.2	**100.4**	1.65	
	ON	90.2	90.8	92.3	**91.1**	1.08	**-0.3**	98.0	99.0	102.0	**99.7**	2.04	**0.7**
2000	OFF	91.5	91.6	91.6	**91.6**	0.05		99.3	99.5	99.4	**99.4**	0.11	
	ON	91.3	91.5	91.6	**91.4**	0.16	**0.1**	98.6	98.9	98.7	**98.7**	0.11	**0.7**

The results of these first experiences indicate that further tests are needed with the purpose of observing the behaviour of the ANC system during the execution of the classic operations the tractor is devoted to, such as ploughing or harrowing, and evaluating its capability of reaction to the variation of the conditions of working and, consequently, of noise.

Possible improvements of the system could be achieved through the use of audio components with more suitable characteristics, with reference to the working target represented by limited intervals of frequency (for instance between 40 and 200 Hz, as evidenced in the tests).

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