COMPARISON AMONG ACTIVE NOISE SYSTEMS FOR TYRE-PAVEMENT CONTACT NOISE REDUCTION

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ABSTRACT
Rolling noise, due to the tyre-pavement dynamical contact, is the main contribute to traffic noise when vehicle speed is higher than 100 Km/h. Actually rolling noise reduction methods are:
- particular tyre engraving shape;
- absorbing pavements.

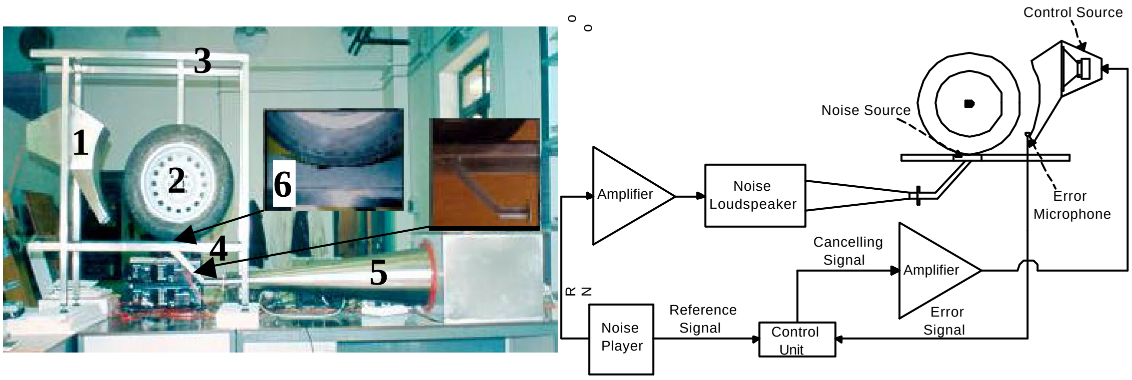
In this paper alternative active methods for rolling noise reduction are proposed and compared. Such a methods have been applied by realizing original prototypes which work on steady conditions with a previous recorded rolling noise. A future prototype is also proposed which is a dynamical system the working conditions of which are very close to the effective ones.

INTRODUCTION

Terrestrial vehicles noise is due to four different causes: 1) exhaust duct emission; 2) aerodynamic friction; 3) mechanical structures vibrations; 4) rolling of tyres on ground. The contribute of cause n. 4) may be predominant when vehicle speed is higher than 100 km/h [1]. Till now, rolling noise has been moderately fought by means of an appropriate design of tyre surface shape. In this paper, some active control prototypes for rolling noise reduction are proposed and compared. Two static prototypes have been realized. Canceling noise is generated by two acoustical emitters in order to reduce both compression and rarefaction noise [2]. A control unit receives tyre r.p.s. and an error signal as input data. The control unit output amplitude is the same of rolling noise with 180 degrees phase shift; thus a destructive interference occurs when control signal and rolling noise superpose. The prototypes acoustical performances have been measured by employing a custom test bench. The proposed systems produce strong noise reductions only for the main noise component which is due to a mismatch between noise and canceling signals. A dynamical prototype is also proposed, which mechanically generates “pure” rolling noise with absence of aerodynamical and engine noise.

STATIC PROTOTYPE N°1

A first prototype has been designed and realized at Perugia University Acoustical Laboratory (Figure 1.a) [3]; it is a static facility the geometrical characteristics of which may be modified in order to calibrate and optimize the active noise system parameters on steady conditions. The prototype acoustical characteristics reproduce the tyre-pavement contacting system ones. The main prototype element is a particular shape acoustical source which is suitable to be installed inside a mudguard (item 1 of Figure 1.a). The source and a static tyre (item 2 of Figure 1.a) are sustained by a steel frame (item 3 of Figure 1.a) [2]. The tyre lies on a plate (item 4 of Figure 1.a) the acoustical characteristics of which are equivalent to the road pavement ones. The prototype may be employed to reduce both compression noise due to the front end of the tyre which superposes the ground and rarefaction noise generated by the tyre that gives up the pavement [4]. Thanks to a custom test bench, measurements allowed to find the prototype optimal working conditions: geometry and control unit algorithm. Test bench is constituted by a truncated cone shape steel structure (indicated as 5 in Figure 1.a), which permits to reproduce a previously recorded rolling noise signal (compression and rarefaction noise) at the tyre-pavement contact point (item 6 of Figure 1.a) [5].The control unit is based on a FxLMS adaptive algorithm which is implemented on a DSP. The control unit input signals are: one reference signal, two microphone error signals. Experimental measures have been carried out by using the recorded rolling noise as reference signal. Error signal are derived by two microphones which are placed near the tyre-pavement contact point. One microphone picks up the compression noise, the other picks up the rarefaction noise; during experimental measurements, microphones work alternatively. The control unit generates, alternatively, two control signals, one for compression noise, the other for rarefaction noise. The block diagram and the prototype mechanical scheme are shown respectively in Figure 1.b and in Figure 2. Control unit processing speed is suitable to instantaneously modify control signal characteristics in order to keep a 180° phase shift between canceling and rolling noise at tyre-pavement contact point.



(a) Picture of prototype and test bench (b) Block diagram

Figure 1: Prototype n° 1

PROTOTYPE N° 1 MEASUREMENT CAMPAIGN

The prototype acoustical performances have been tested by measurement campaign. The prototype has been connected to the test bench. Measurement point (see Figure 2) lies along the noisiest direction starting from tyre-pavement point of contact [5]. Each single measure has been carried out for a 1 minute time interval. Prototype performances have been evaluated for three different conditions:

A) noise signal is a sinusoidal single tone;
B) noise signal is a square wave signal;
C) noise signal is the recorded rolling noise.

Noise reduction introduced by prototype for A) condition is 15 dBA in 200-750 Hz frequency range; furthermore when the disturbing noise frequency is higher than 2000 Hz, the DSP performances are no more suitable to achieve noise abatement. A) condition measurement results are shown in Table 1. B) condition measurements results (see Table 2) show a 7 dBA reduction when disturbing noise (square wave) main frequency is in the 200-750 Hz range. C) condition measurements campaign have shown that the active control system reduces only the noise main component (7 dB reduction). Results show that active control system performances get worse and worse as disturbing signal complexity grows; in fact acoustical matching between disturbing and canceling noise is achieved only for one frequency component.

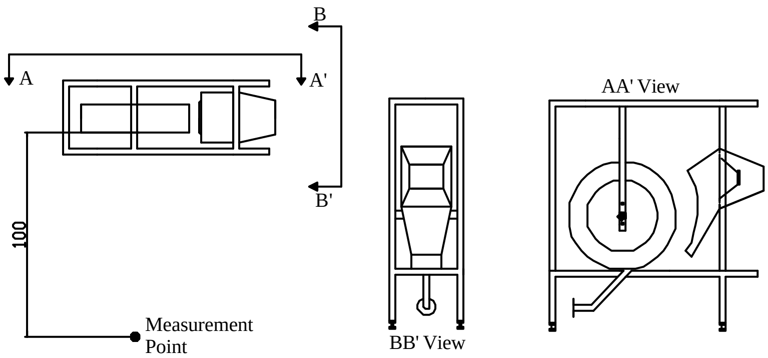


Figure 2: Prototype n° 1 mechanical scheme and measurement point

Table 1: Measurement results. Prototype n° 1, Condition A

	Control System OFF		Control System ON		Noise Level Reduction	
Sine wave frequency (Hz)	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]
63	65.5	90.0	63.0	84.0	2.5	6.0
125	70.5	85.5	66.5	81.0	4.0	4.5
250	84.5	92.5	70.0	77.5	14.5	15.0
500	90.5	94.0	76.5	79.5	14.0	14.5
1000	100.0	100.5	98.0	99.0	2.0	1.5
2000	90.0	88.5	90.0	88.5	0.0	0.0
4000	69.0	70.0	69.0	70.0	0.0	0.0

Table 2: Measurement results. Prototype n° 1, Condition B

	Control System OFF		Control System ON		Noise Level Reduction	
Square wave main component frequency (Hz)	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]
63	78.5	85.0	77.0	81.5	1.5	3.5
125	90.5	94.5	83.5	86.5	7.0	8.0
250	83.5	83.5	77.0	75.5	6.5	8.0
500	86.0	88.5	80.0	80.5	6.0	8.0
1000	95.0	94.5	93.5	93.5	1.5	1.0
2000	84.5	83.5	84.5	83.5	0.0	0.0
4000	77.0	83.0	77.0	83.0	0.0	0.0

Table 3: Measurement results. Prototype n° 1, Condition C

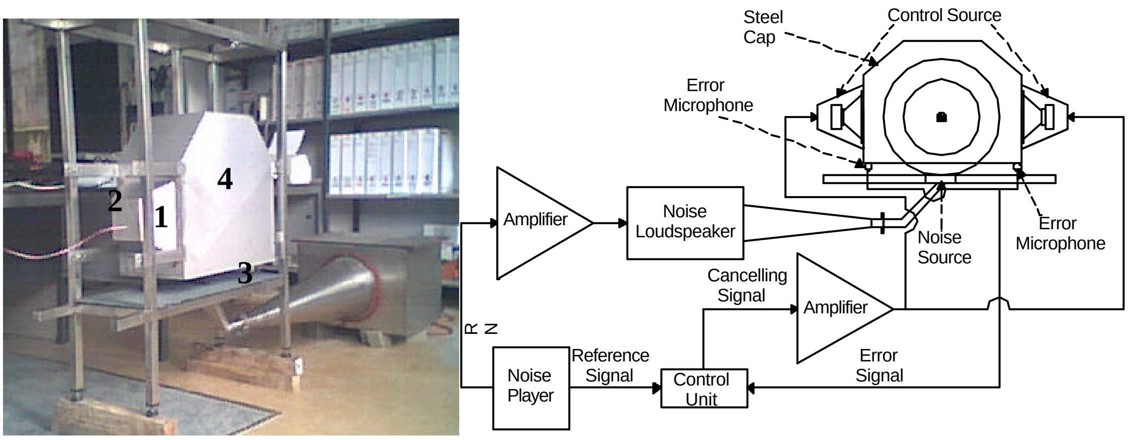
	Control System OFF	Control System ON	Level Reduction
Vehicle Velocity (Km/h)	Main 1/3 octave band Noise Equivalent Level L_{eq} dB	Main 1/3 octave band Noise Equivalent Level L_{eq} dB	Main 1/3 octave band Noise Equivalent Level L_{eq} dB
50	90.5	87.5	3.0
70	98.0	93.5	4.5
90	101.5	95.5	6.0
110	105.5	99.0	6.5
130	107.5	102.0	5.5

STATIC PROTOTYPE N°2

An evolution of prototype n°1 has been designed and realized in order to obtain better acoustical performances. The prototype n° 2 is shown in Figure 3.a. It is designed to reduce the mismatch between rolling noise and canceling noise. The tyre is wrapped by a steel cap (see fig. 3.b). The system is equipped with two loudspeakers (item 1 of Figure 3.a) which are installed inside the cap and insulated by a steel cover (item 2 of Figure 3.a). The loudspeakers reproduce canceling noise which is generated by the control unit. The canceling noise propagates inside the steel cap and destructively interferes with rolling disturbing noise in the space which separates the pavement to the steel cap (item 3 of Figure 3.a). The cap (item 4 of Figure 3.a) may be vertically translated in order to get a compromise between the following opposite trends:

- tyre strongly covered, higher rolling noise-canceling noise matching but lower suitability for traveling conditions;
- tyre low covered, lower rolling noise-canceling noise matching but more suitability for traveling conditions.

The block diagram is shown in Figure 3.b.



(a) Picture of prototype and test bench (b) Block diagram

Figure 3: Prototype n° 2

PROTOTYPE N° 2 MEASUREMENT CAMPAIGN

A measurement campaign has been led to evaluate prototype n° 2 performances. Measurement conditions are the same as the prototype n° 1 ones (A, B, C). Prototype n° 2 mechanical scheme and measurement point are shown in Fig. 4. Each single measure has been carried out for a 1 minute time interval.

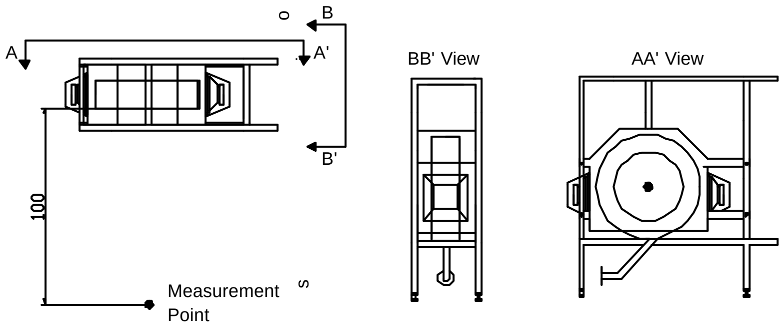


Figure 4: Prototype n° 2 mechanical scheme and measurement point

A) condition measurements have shown a 15 dBA level reduction which is close to the first prototype into 200-750 Hz frequency range. A 10-15 dBA level reduction has been obtained when disturbing signal frequency is below 200 Hz or higher than 750 Hz (see Table 4). The control system performances strongly decrease for frequencies higher than 2000 Hz, however no rolling noise component belongs to such frequency range. A) 15 dBA reduction is attained for the only noise main component on A) and B) conditions. Results demonstrate that prototype 2 performances are improved with respect to prototype 1 because of the increased matching between disturbing and canceling noise. However, important noise abatements are attained again just for the noise main component. Table 5 and 6 shows respectively the B) and C) condition measurements results.

Table 4: Measurement results. Prototype n° 2, Condition A

	Control System OFF		Control System ON		Noise level Reduction	
Sine wave frequency (Hz)	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]
63	66.0	90.5	61.0	79.5	5.0	11.0
125	70.5	86.0	57.0	68.0	13.5	18.0
250	85.0	93.0	70.0	78.0	15.0	15.0
500	90.0	93.5	75.5	79.5	14.5	14.0
1000	100.5	100.5	81.0	81.0	19.5	19.5
2000	89.5	88.5	89.5	88.5	0.0	0.0
4000	68.0	69.5	68.0	69.5	0.0	0.0

Table 5: Measurement results. Prototype n° 2, Condition B

	Control System OFF		Control System ON		Noise level Reduction	
Square wave main component frequency (Hz)	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]	A-weighted noise level L_{Aeq} [dBA]	Equivalent noise level L_{eq} [dB]
63	78.5	84.5	72.5	75.0	6.0	9.5
125	90.0	94.5	76.0	79.5	14.0	15.0
250	83.0	85.5	68.5	70.5	14.5	15.0
500	86.0	89.0	70.5	72.0	15.5	17.0
1000	95.0	95.0	75.0	75.5	20.0	19.5
2000	84.5	83.5	84.5	83.5	0.0	0.0
4000	77.5	83.5	77.5	83.5	0.0	0.0

Table 6: Measurement results. Prototype n° 2, Condition C

	Control System OFF	Control System ON	Level Reduction
Vehicle Velocity (Km/h)	Main 1/3 octave band Noise Equivalent Level L_{eq} dB	Main 1/3 octave band Noise Equivalent Level L_{eq} dB	Main 1/3 octave band Noise Equivalent Level L_{eq} dB
50	91.0	80.0	11.0
70	98.0	85.0	13.0
90	102.5	88.5	14.0
110	106.0	92.5	13.5
130	108.0	94.0	14.0

DYNAMICAL PROTOTYPE

A dynamical prototype is going to be built at the Acoustics Laboratory of University of Perugia. The new prototype is constituted by two rotating wheels (see the scheme shown in Figure 5): the upper wheel is a commercial vehicle tyre which may rotate inside a steel cap (see prototype n° 2). The lower wheel diameter is double than the tyre one. The lower wheel is moved by an electrical motor and is coated by an asphalt like film. The prototype will simulate as close as possible the tyre-pavement contacting phenomena; a proper pressure between the upper tyre and the lower wheel is applied. Thus rolling noise may be mechanically generated and studied without affection of aerodynamical and engine noises. Control unit which are thought to be used belong to the last DSP generation the processing speed of which is three times higher than the previously employed DSP one [6].

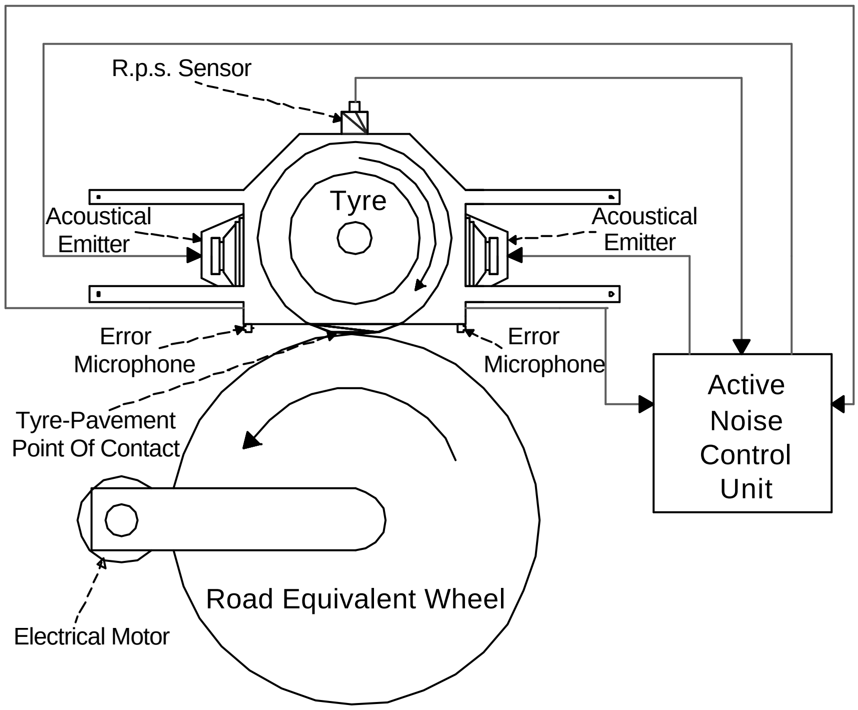


Figure 5: Dynamical prototype scheme

CONCLUSIONS

Two different methods have been proposed to contrast rolling noise by means of active noise control technique. The methods have been proved by realizing two prototypes the working condition of which are stationary (not traveling condition); thus a test bench was made up to reproduce a previously recorded rolling noise. The first prototype is constituted by a particular acoustical emitter to be installed inside a car mudguard. The second prototype is a cap which covers the car tyre; inside the cap are logged the canceling noise loudspeakers. Both the first and the second prototype are equipped with a DSP based control unit. A measurement campaign has shown that the second prototype performs higher noise abatement thank to an improved matching between noise and canceling noise. However results have also demonstrated that rolling noise secondary frequency components can not be jet contrasted because of a not perfect acoustical matching between rolling and canceling noise and a not adequate DSP processing speed. Further experience will be earned thank to another prototype which is going to be realized. Such a prototype is a dynamical rolling noise generator which can reproduce a pure mechanical rolling noise without the affection of the aerodynamic and the engine noises.

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