VERIFICATION OF DOPPLER EFFECT REMOVAL METHOD FOR THE NEEDS OF PASS-BY RAILWAY CONDITION MONITORING SYSTEM

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Summary

The description of the experiment verifying the method of Doppler's Effect removal from the acoustic signal of moving object was discussed in the paper. Doppler's Effect was removed by dynamic resampling according to the theoretical frequency changes curve as well as with use of the curve obtained by passband filtration of the signal around the carrier frequency and differentiation of the phase of the analytic signal. Described solutions were tested in the GPS synchronised field measurements on the moving railway cars and simultaneously the stationary measurements taken next to the railway track.

Keywords: Doppler's Effect, nonstationarity, task oriented dynamic resampling instantaneous frequency, monitoring station.

WERYFIKACJA METODY USUWANIA EFEKTU DOPPLERA DLA POTRZEB PRZYTOROWEJ STACJI MONITORINGU STANU TECHNICZNEGO

Streszczenie

W pracy przedstawiono opis eksperymentu weryfikującego metodę usuwanie efektu Dopplera z sygnału akustycznego poruszającego się obiektu. Efekt Dopplera z sygnału usuwano poprzez dynamiczne przepróbowanie sygnału zarówno zgodnie z teoretyczną krzywą zmian częstotliwości chwilowej sygnału jak również z użyciem krzywej otrzymanej przez wąskopasmową filtrację sygnału wokół częstotliwości nośnej a następnie różniczkowanie fazy sygnału analitycznego. Zaproponowane rozwiązania zostały przetestowane w warunkach poligonowych podczas jednoczesnych, synchronizowanych sygnałem GPS, pomiarów na poruszających się pociągach oraz pomiarów przytorowych.

Słowa kluczowe: efekt Dopplera, niestacjonarność, zorientowane zadaniowo dynamiczne przepróbkowanie, chwilowa częstotliwość, stacja monitoringu.

1. INTRODUCTION

Doppler Effect, a change in frequency of a sound wave emitted by a moving source recorded by stationary observer, is a barrier that reduces the possibility of online diagnosing of moving vehicles, treated as the signal sources, with the use of stationary measuring equipment positioned outside the vehicle. This effect introduces the spectrum smear similar to the one caused by signal nonstationarity e.g. change of rotational velocity in rotating machines, forcing spectrum lines to shift from the proper place. A method of removal this phenomenon based on a task oriented resampling was proposed in [1]. In this paper the experimental results were shown confirming the theoretical simulation results shown in [1] and additional modifications of the method based on the field measurements were proposed. The removing of the Doppler Effect is crucial for any pass-by condition monitoring stations to correctly analyse Fourier spectrum components.

2. EXPERIMENT DESCRIPTION

Experimental measurements were taken in Żmigród on a CNTK railway test track. The testing object and a source of the signals was a four wheel drive rail vehicle WM-15A, with diesel engine of 147 kW (Fig. 1). The distance between the axles was 5.85 m and the wheels diameter 0.92 m. The measurements were taken on a cloudy day with temperature of 29 °C and moderate wind condition.

Fig. 1. WM-15A vehicle used for test measurements.

The measurements were taken on straight part of the rails on a test distance of about 30 m. The measurements were performed for different velocities of the vehicle.

For the measurement purpose the National Instruments measuring gear consisting of two independent signal recording computers (NI/PXI-8186 type) equipped with two PXI-4472B and one PXI-4462 data acquisition cards was used. Signal recordings were taken simultaneously on the pass-by ground recording station and on a moving recording station onboard of a WM-15A vehicle. Both sets of recordings were synchronised with each other using Pulse-Per-Second (PPS) signals from Garmin 18LVC GPS receivers. The GPS signal synchronisation principles used in the experiment were described separately in [2].

On the mobile station placed onboard a vehicle a total of 8 signals were recorded using PXI-4472B data acquisition card: GPS PPS signal for future synchronisation purposes, bearing vibrations (accelerations) in axial and perpendicular directions of both wheels on one side of the vehicle, acoustic pressure (noise) close to this bearings and acoustic pressure on the top of the platform as a reference signal (Fig. 2).

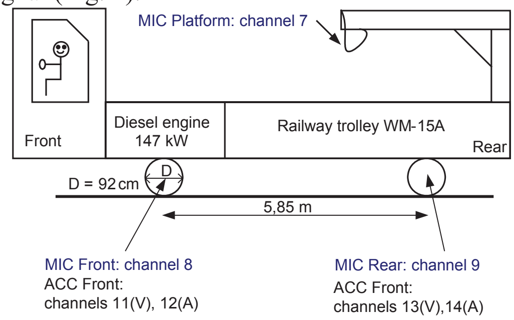

Fig. 2. Sensor placement on a mobile station used in the experiment.

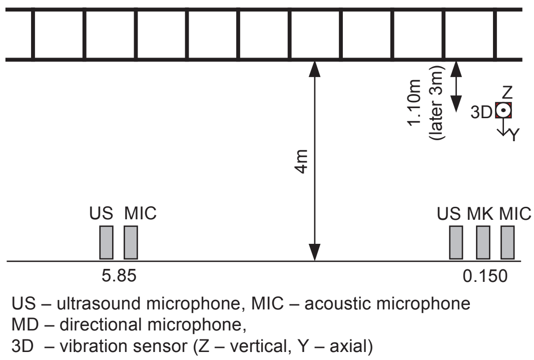

Fig. 3. Sensor placement on a ground station used in the experiment.

On the pass-by ground station besides GPS PPS signal, acoustic pressure (noise) signals using five microphones (2 conventional measuring microphones, 2 ultrasonic and one directional microphone) were recorded. The distance between microphones group's positions was selected according to the vehicle axle distance of 5,85m. Additionally the ground vibrations in two directions next to the railway track were recorded. The transducers setup of the ground pass-by station is shown schematically on Fig. 3.

3. SIGNAL POSTPROCESSING FOR DOPPLER EFFECT REMOVAL TESTS

Recorded signals were later processed to test the Doppler Effect removing method described in [1]. The described tested algorithm relies on the task oriented dynamic resampling of the recorded signal. The signal resampling was done according to the changes in the frequency of the recorded signal from a moving source (a vehicle). As was proved in [1] a frequency change of the pure tone acoustic signal moving relatively to the microphone could be described with (Fig .4)

$$f_R(t) = f_0 \cdot \frac{1}{1 - \frac{V_z}{V_d} \cdot \frac{s - V_z \cdot t}{\sqrt{h^2 + (s - V_z \cdot t)^2}}} \qquad (1)$$

where:

- f_0 - real frequency of the signal source,
- f_R - instantaneous frequency of the recorded signal,
- V_d - sound velocity in the air (V_d = 343 m/s was assumed),
- V_z -velocity of the moving vehicle (signal source),
- h - distance from the microphone to the railway track,
- s - distance describing the position of the vehicle in the moment of signal recording beginning defined as a distance from the point closest to the microphone.

Having fixed f_0 frequency and $f_R(t)$ waveform one can resample the recorded signal using the new $dt(t)$ according to the formula:

$$dt_{new}(t) = \frac{f_o \cdot dt}{f_R(t)} \qquad (2)$$

where dt is the sampling interval (inverse of the sampling frequency).

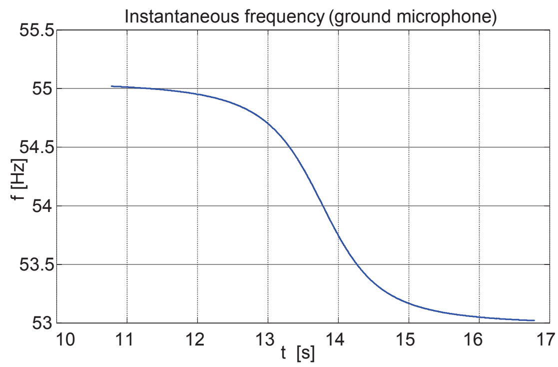

Fig. 4. Change of instantaneous frequency of 54 Hz according to equation 1.

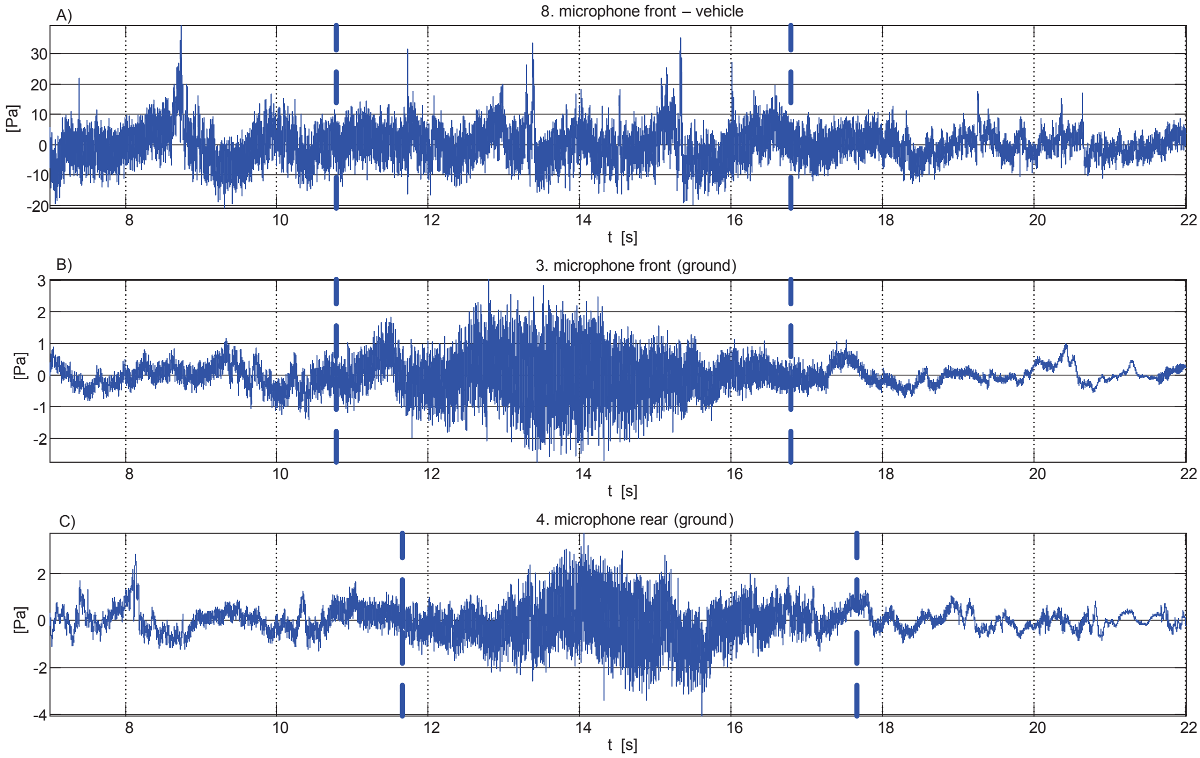

Fig. 5. Time waveforms with selected parts for removing Doppler Effect

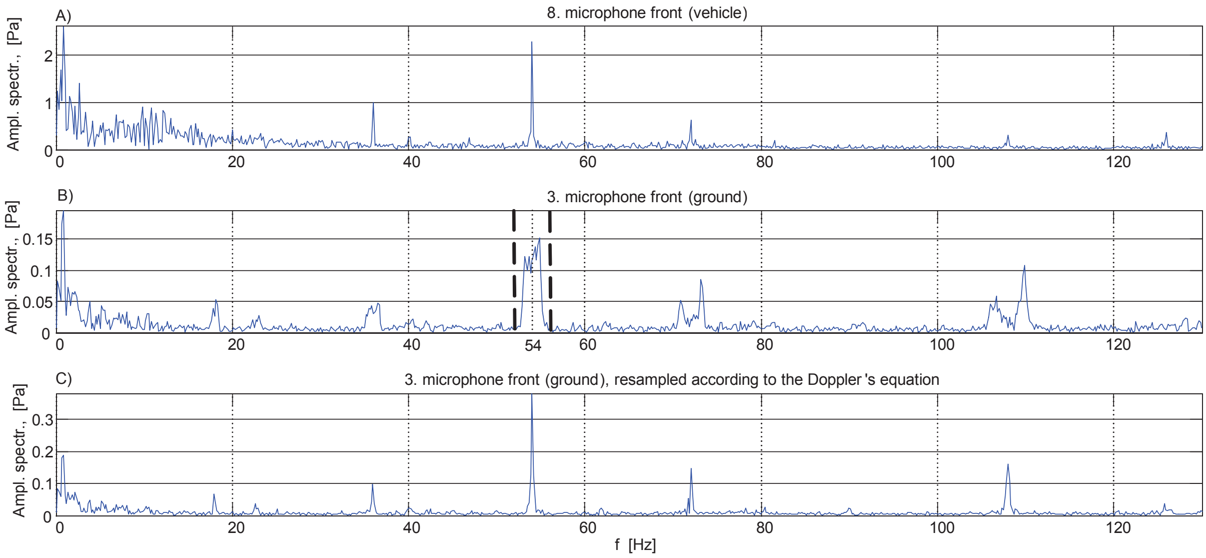

Fig. 6. Acoustic pressure amplitude spectrum for reference signal recorded
A) near the front bearing of the vehicle; B) on the front microphone of a ground pass-by station;
C) Signal from B) with Doppler's Effect removed using equations (1) and (2)

To apply this method a part of a recorded signal should be selected symmetrically to the microphone position. Any errors would result in additional frequency smear of the resampled signal. On the Fig. 5 the recorded time signals with selected parts corresponding to the front and rear microphones of the ground pass-by station as well as a bearing noise reference signal were shown. On the Fig. 6 the results of this procedure applied to the noise recordings of the vehicle moving with a velocity of 24 km/h were shown. The similarity of signal's spectra recorded with a microphone near the vehicle bearing and spectra of the front microphone on a ground pass-by station is clearly visible. Similar results were obtained for the rear ground pass-by station microphone signal. The differences in the amplitudes of the signals are due to the distance between the microphones of the ground station and the railway track (4 m).

The described method has one serious drawback. It requires the precise knowledge of the vehicle position relative to the stationary, ground microphone as well as its velocity relative to the recording microphone. This method could be modified to get rid of this flaw.

To do this an instantaneous frequency f_R should be calculated from the analytical signal of the passband filtered signal [3]

$$x_a(t) = x(t) + j \cdot H\left[x(t)\right] = \left|x_a(t)\right| \cdot e^{j \cdot \varphi(t)} \qquad (3)$$

using well known equation [3]

$$f_r(t) = \frac{1}{2 \cdot \pi} \cdot \frac{d\varphi(t)}{dt} \qquad (4)$$

The passband of the filter should be selected in such manner as to remove from the signal all the frequencies except the single smeared frequency. For the signal from Fig. 5B a passband of 52-56 Hz was selected (Fig. 6B).

It is always a problem to design a digital filter with steep enough characteristic and a very narrow passband. In this application a filtering was performed using Fourier transform, removing all the frequencies except the desired passband and then applying inverse Fourier Transform to thus modified spectrum.

Results of calculating the instantaneous frequency for both front and rear ground pass-by station microphones are shown on Fig. 7. The signals are shifted in time for the equivalence of the axle distance (see Fig. 2, 3) The great similarity of the theoretical curves calculated from equation (1) and the curves calculated from the filtered spectrum (4) are the confirmation of the correctness of the method.

The spectra of this signals look extremely similar to the one presented on the Fig. 6C.

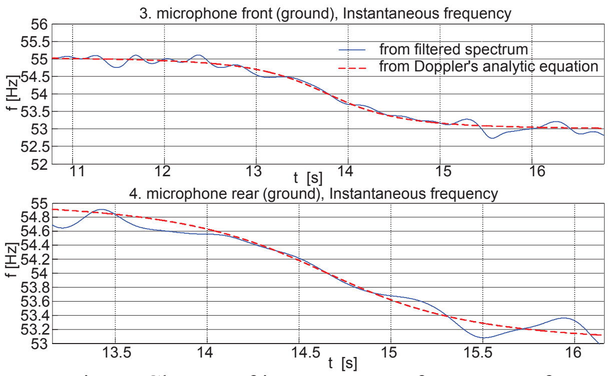

Fig. 7. Change of instantaneous frequency of 54 Hz according to equations (1) and (4)

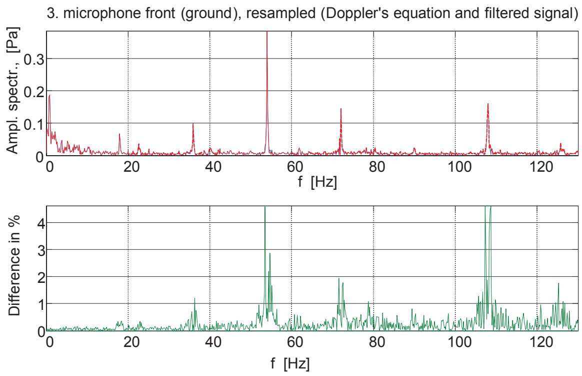

Fig. 8. Comparison of described Doppler's Effect removal methods

4. SUMMARY

Results of the experiment confirmed the possibility of Doppler Effect's removal from the real signal in the field measurements. The difference between results obtained with theoretical frequency curve and curve obtained using signal filtration differs only in maximum 5% (Fig. 8).

It was not the aim of this project to diagnose the technical state of the vehicle used in the experiment. The diesel engine used by the vehicle was noisy to such extent that it masked the bearings signals.

Described methods could be used in the development of the ground pass-by vehicle diagnostic station capable of monitoring the technical state of passing vehicles.

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