Study of acoustic grinding method developed for Tokaido shinkansen

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ABSTRACT

The rail grinding has been performed as one of the noise reduction methods of high-speed railway line in Japan. The noise reduction effect of the rail grinding, however, is not quantitatively grasped in the recent work by using the special train-set of rail grinding machines. In this study, we conducted the field measurement of wayside noise of high-speed train and rail surface roughness, before and after the rail grinding work in order to examine the grinding effect. It was found out from the field measurement result that the "trace pattern" of rail surface generated by grinding work has a big impact on the wayside noise of certain frequencies and it continues for several months. From this notice, we developed the new grinding strategy called "Acoustic Grinding" with the combination of grinding pressure and train-set speed by which we can decrease the grinding trace of rail surface. As a result, the most effective method was established for the rail grinding work to decrease the trace pattern and consequently, wayside noise.

Keywords: Rail traffic noise, Noise reduction I-INCE Classification of Subjects Number(s): 52.4

1. INTRODUCTION

Various countermeasures aiming at environmental noise reduction have been taken on the Tokaido Shinkansen. High-speed and congested railway service has been made with the environmental consideration, for instance, smoothing car surfaces, noise reduction of pantographs, taller noise barriers, development of noise-absorbing barrier and periodical maintenance of tracks. Countermeasures against rolling noise have become more important in recent years because the contribution of aerodynamic noise has been decreased by the development of car aerodynamics. As one of the countermeasures against rolling noise, rail grinding has been widely adopted. The main purpose of this grinding work is track maintenance by grinding rail surface using grindstones and removal of rolling fatigue layers. Also, it's considered as one of the efficient methods for rolling noise reduction because rail surfaces are smoothed by rail grinding (1, 2, 3, 4). On the Tokaido Shinkansen, rail defects happen less frequently than before because of standardized cars, the standardized running speed and much frequent track maintenance, which mean rails are in relatively good condition for a long time.

On this technical context, it is desired to grasp the noise reduction effect quantitatively and to optimize the rail grinding operation. Therefore, this study evaluates the noise reduction effect of the present method of the rail grinding by the measurements of wayside noise and rail surface roughness. In this paper, in order to develop the better rail-grinding methods for noise reduction, experimental measurements and data analysis are conducted.

2. RAIL GRINDING ON TOKAIDO SHINKANSEN

On the Tokaido Shinkansen, 48 stone grinding trains run basically the whole line once a year. A grinding on a normal section is called "2 passes", which means going and returning. The special 4 passes are adopted for newly replaced rails or for the main purpose of environmental noise reduction.

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Since the ordinary grinding aims at removal of rolling fatigue-layers, the amount of removal of the layers is determined as more than 0.05mm.

An operator on a rail grinding machine decides the pressure and running speed for grinding as 18A (ampere) and 5-6km/h. These days, the pressure and speed has fixed as the same condition on each passes.

3. EVALUATION OF THE PRESENT METHOD OF RAIL GRINDING

3.1 Measurement

To evaluate the effect of countermeasures against wayside noise by the present method, noise and rail roughness were measured before and after the rail grinding work. Measurement sites were chosen on the Tokaido Shinkansen. These are Site A on a viaducts section and Site B on an embankment section. Measurement periods were decided at 6 times; before grinding and 14 days, 1 month, 2 months, 3 months and 4 months after grinding. The tracks were ballasted tracks on which more than a year had passed after the last grinding. For this measurement, 4 passes were conducted by the standard method that time.

Rail surface roughness was measured using a roughness measurement system with 500mm long, on the center of running bands. Roughness measurement is on 6 lines on each site, which are shown on Figure 1. Maximum entropy method, MEM, by which even short data provides stable solutions was used for data analysis. The roughness data were corrected by considering the contact area between wheels and rails (5, 6). The results of data analysis were processed into 1/3 octave bands. Noise made by trains running on the nearside track was measured at a point near rails, which height is +0.45m from

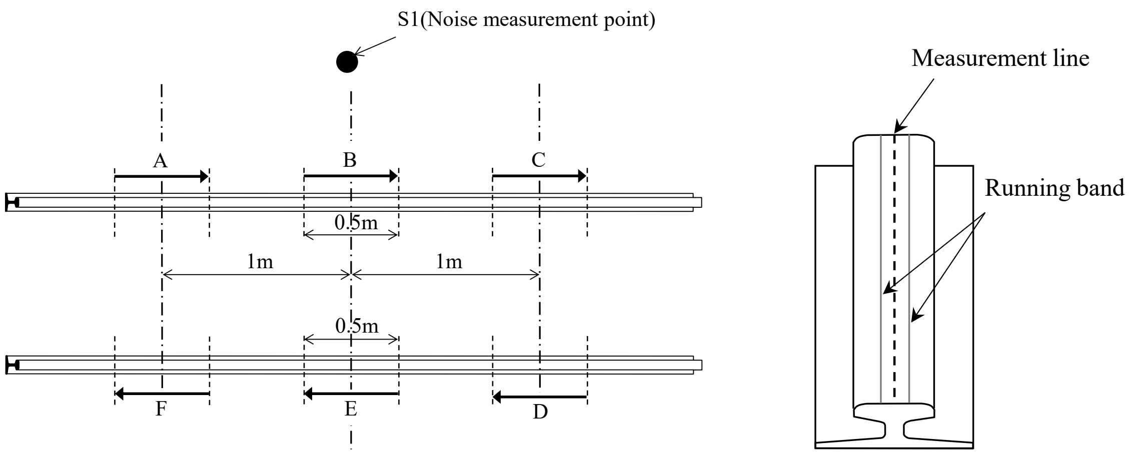


Figure 1 – Diagram of rail roughness measurements points

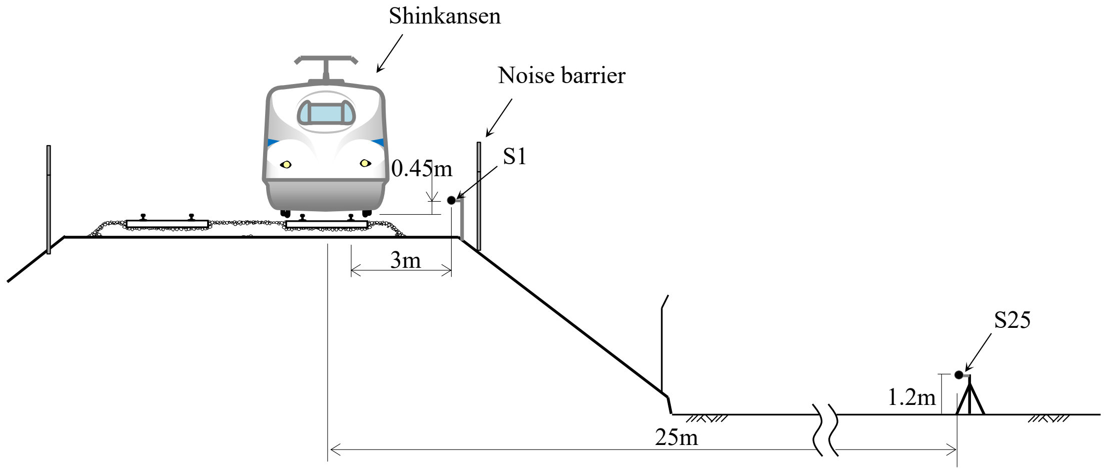
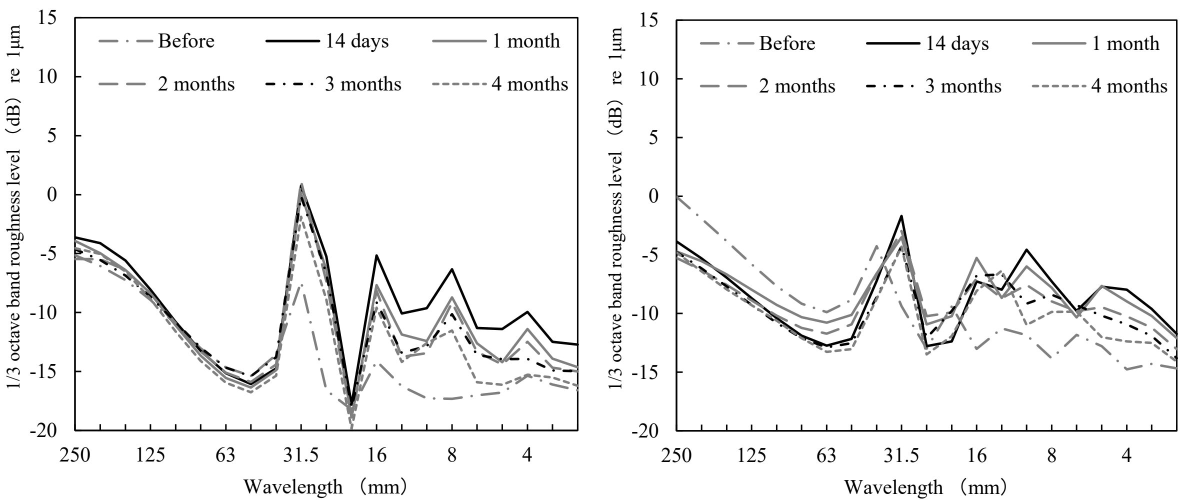


Figure 2 – Diagram of noise measurements points (S1: near rails, S25:25m away from nearby track)

the rail top, see S1 on Figure 2, using precision sound level meters (NL-32, made by RION). The frequency-weighting function was an A-weighting filter and the time-weighting function was Fast (0.125s).

3.2 Measurement results

Figure 3 shows the distribution of rail roughness at six periods before to after 4 months of grinding by the present method. A prominent peak occurs at the wavelength of 31.5mm after grinding on both 2 sites. This is a periodic roughness which results from a rotation rate of grinding stones of a rail grinding machine and the machine's running speed, which means that the peak corresponds to grinding traces on Figure 4. The roughness level of the peak corresponding to grinding traces decreases slightly but remains as a prominent peak even after 4 months of the grinding. Much passing tonnage seems to smooth the rail surface roughness in several months because more than 300 trains of 16 cars per day run on the Tokaido Shinkansen, however, this results show that the effect of the rail grinding remains for a long time.



(a) Site A (b) Site B

Figure 3 – Distribution of rail roughness by the present method

Figure 4 – Rail surface roughness by the present method

Figure 5 shows the time series graph of the noise-level difference before and after grindings. The noise level at both 2 sites increases by 1.5-2.1dB at 14 days after the grinding then gradually decreases, but the level is still higher at 3 months after the grinding than that before the grinding and 0.3dB lower than before. If just after the grinding, a noise level is thought to be higher than before because of the rail surface roughness, but the result shows that the noise level remains still higher than before for

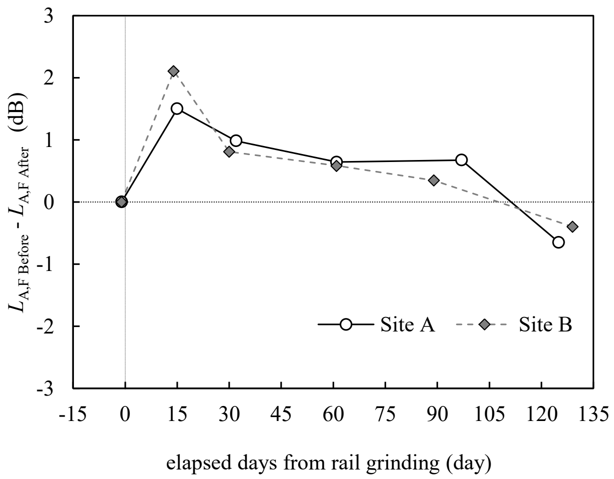
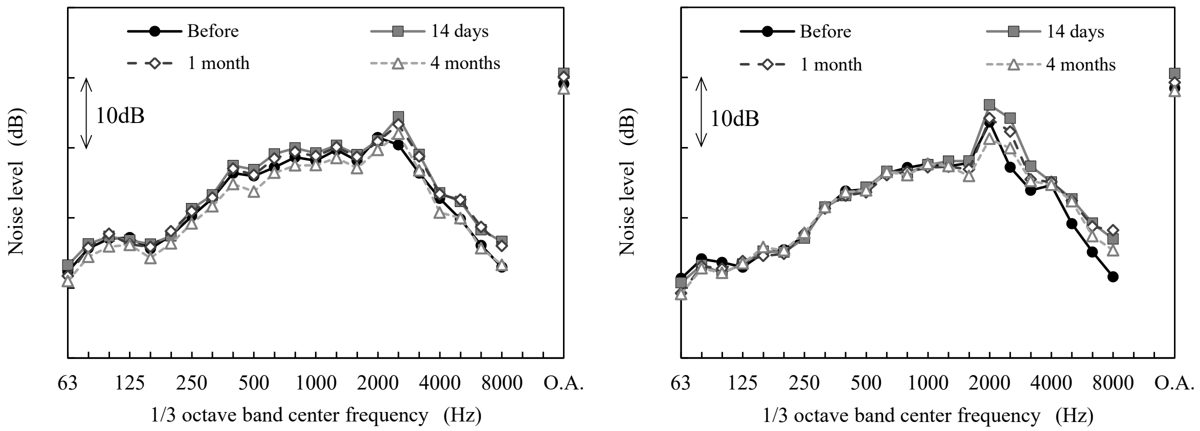


Figure 5 – Time series graph of the noise-level difference by the present method



(a) Site A (b) Site B

Figure 6 – Results of noise levels by the present method

several months. Thus, this countermeasure method against wayside noise might not be effective in this period.

The analysis of noise frequency at wayside points is shown on Figure 6. The noise is the average of that made by trains running around 270km/h. This figure explains that 2000-2500Hz band is prevailing after the grinding and raises the noise level. This feature agrees with the gradual decrease of a roughness level of grinding traces on rail surfaces. Results above confirm that the present method of rail grinding makes roughness at the wavelength of 31.5mm which is a prevailing peak. Then, the band level in the frequency accompanying with the wavelength increases and raises wayside noise. Besides, the roughness level continues to be the prevailing peak for up to 4 months after grinding and the higher noise level caused by roughness of traces generated by rail grinding remains about 3 months.

4. IMPROVED GRINDING METHOD

The present rail grinding method of the Tokaido Shinkansen is proved to take more than several months for noise reduction since effects of traces generated by rail grinding continue for a long time even on high-speed and dense railways. Thus, aiming at sooner noise reduction, methods suitable for the present high-speed railways are improved within a limited change of machine and working method. As revealed in the preceding chapter, the amplitude of roughness at the wavelength of 31.5mm generated by rail grinding causes increases the specific frequency band. Therefore, to reduce the amplitude of the roughness is examined in this chapter. The traces generated by rail grinding are

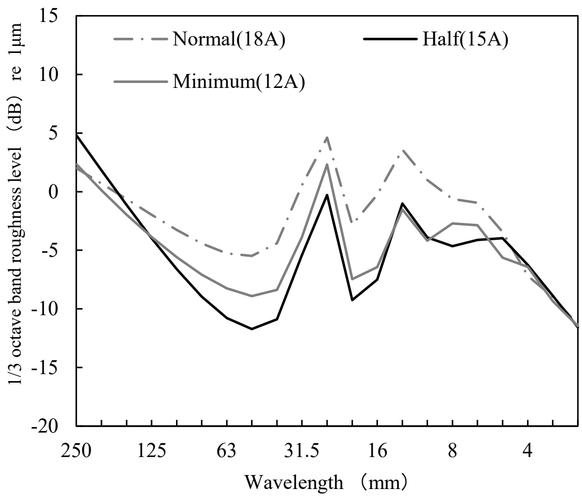


Figure 7 – Distribution of rail roughness on grinding pressure test

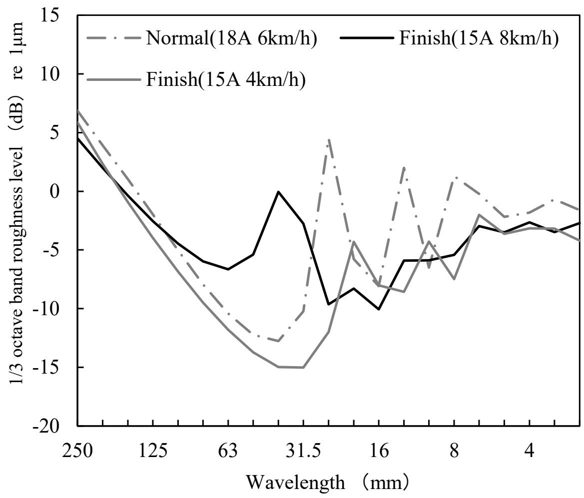


Figure 8 – Distribution of rail roughness on train-set speed test

periodic roughness caused by circular grinding stones which move and rotate at fixed speed (60 rotations per second) with fixed pressure on rails.

Countermeasures against the traces were to modify the materials, the shape of stones and a rotation direction, or modify the grinding pressure, the running speed and the rotation speed without changes in the specification of rail grinding machines. Since the former, to modify the specification of grinding stones, was difficult because of the maker's demands and a restricted time, to modify the pressure of grinding stones and running speed was mainly focused here. But when the pressure and speed are changed, it might be the problem if enough amount of removal from rolling fatigue layers cannot be obtained. Therefore, 4 passes is conducted by the following improved strategy; during first 2 passes, rails are grinded with the present pressure and speed to grind enough layers, and then next 2 passes are "finishing grindings" which reduce the grinding traces.

Before working on main lines, the improved finishing grinding method was examined on test lines by measurements of rail roughness before and after grinding. The ordinary pressure of grinding stones of rail grinding machines for the Tokaido Shinkansen is set to 18A and can be modified between 12A-21A. Here, in order to reduce the roughness of grinding traces, the pressure for test grindings was 15A and 12A which are half of the standard pressure 18A and minimum, respectively. The result is shown on Figure 7. "Normal" method is with 2 passes by the grinding pressure of 18A. "Half" method is with standard 2 passes plus 2 passes of finishing grindings of 15A. "Minimum" method is with standard 2 passes plus 2 passes of finishing grindings of 12A.

The peaks corresponding to trace patterns lie at the wavelength of 25mm on Figure 7. The grinding speed on test lines is supposed to slightly slower than on main lines by which the peak occurs at 31.5mm. The roughness level of grinding traces generated by the half method is a minimum. However, the roughness level by the minimum method is not a minimum although the pressure is less than the half method. The reason is that because of too weak pressure, grinding stones rotated without grinding rails and the roughness of grinding traces generated by the first 2 passes remained.

Then, in addition to pressures, the grinding speed is considered. Usually the speed is set to 6km/h and can be modified between 4-8km/h, thus 4km/h and 8km/h are examined. Figure 8 shows the wavelength distribution of roughness with 3 grinding strategies. As mentioned above, "standard" method is 2 passes grinding, "Finish (4km/h)" method is 2 passes of finishing grinding at 4km/h after standard 2 passes and "Finish (8km/h)" method is 2 passes of finishing grinding at 8km/h after standard 2 passes. From the figure, the wavelength corresponding to trace patterns varies with the speed, which occurs at 20mm if running at 4km/h and 40mm if running at 8km/h. The minimum roughness level occurs by finishing grinding with 15A pressure and 4km/h speed. This is considered as followings; Slower grinding speed makes a longer contact time among rails and grinding stones and more grinding at a point, then much dense roughness is widely produced and the roughness corresponding to specific grinding traces is relatively reduced.

5. TEST GRINDING ON MAIN LINES

5.1 Measurement

Using the previous investigation of grinding strategies on test lines, test grinding on main lines were conducted and noise and roughness were measured before and after grindings. The method is with 2 passes of standard grinding enough to reduce rolling fatigue layers, and with 2 more passes of finishing grinding to reduce rail surface roughness. Table 1 shows strategies of finishing grindings. Rail grinding machines have 48 stones. The measurements were carried out along ballasted tracks on an embankment without noise barriers. The measurements were conducted in 5 times: before grinding, just after grinding, 14 days, 1 month and 2 months after grinding. “Just after grinding” means that rail roughness measurement is conducted before any passing of trains. As for noise measurements, around 30 trains pass in several hours, and then wayside noise was measured. The locations of rail roughness measurements and noise measurements are the same with Figure 1 and 2. Noise level at a distance of 25m away from the track center was also measured.

Table 1 – Strategies of finishing grindings on main lines

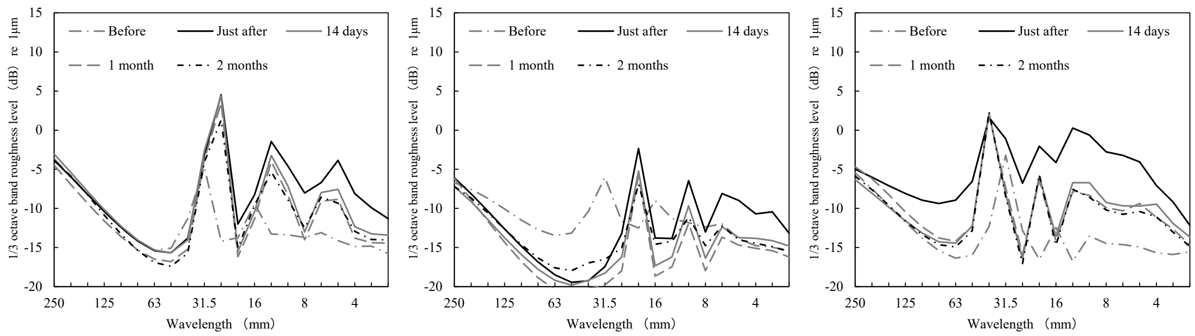
No.	Grinding method	Grinding pressure	Train-set speed
1	Normal	18A	6km/h
2	Test 1	15A	4km/h
3	Test 2	15A	8km/h

5.2 Measurement results

Figure 9 shows the results of rail roughness measurements. Wavelengths corresponding to grinding traces differ among the grinding speed, which lie at 25mm for standard grinding running at 6km/h, 20mm for slower finishing grinding, Test 1 running at 4km/h and 40mm for higher finishing grinding, Test 2 running at 8km/h. Among three tests just after grinding without passing any trains, the roughness level of the peak corresponding to grinding traces by Test 1 is the minimum. The level of Test 1 decreases by 4dB 14days after the grinding and continues to be at similar level. On the other hand, the results of Normal and Test 2 which are faster grinding speed method exhibit more than 5dB higher than Test 1 and continues as high level for 2 months, so the effect of grinding traces does not decrease.

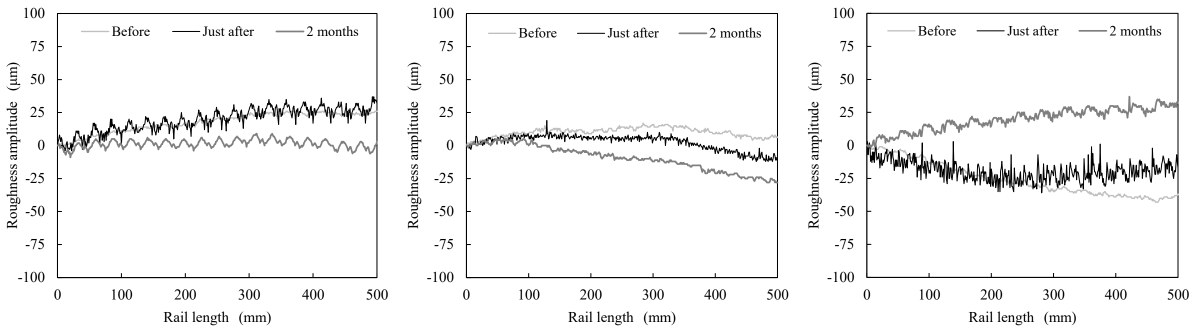
Wave amplitudes of rail roughness are shown on Figure 10. The amplitude of Test 1 is already low immediately after grinding, but Normal grinding displays periodical roughness amplitude which is considered as grinding traces and the periodical roughness is still remarkable after 2 months, but slightly smoother than immediately after. Also, Test 2 shows periodical roughness amplitude after 2 months. From results above, the level of roughness on rail surfaces generated by rail grinding could be reduced by pressure reduction of finishing grindings into 15A and lower speed at 4km/h. The effect could be further reduced in relatively short time, approximately 2 weeks.

Figure 11 shows the results of noise measurements near tracks. Noise levels are calculated with mean values of trains running around 270km/h. From this, before grinding Test 1 which successfully reduced the rail surface roughness displays a peak at 2000-2500Hz band corresponding to grinding traces. After grinding, the noise level did not differ compared to the level measured before grinding although a small peak lies at 4000Hz band after grinding. This 4000Hz band is considered to be caused by the peak corresponding to grinding traces because the grinding speed is slower, 4km/h. Thus, the prevailing peak by grinding traces is reduced by rail grinding while the frequency band is changed. On the other hand, since the prevailing peak at 2500-3150Hz band for Normal and at 2000Hz band for Test2 occur, these peaks increase the noise level immediately after grinding then the level remains high for 2 months. That is, the peak at a certain wavelength corresponding to grinding traces generated by rail grinding make the noise level higher. Noise level of Test 2 increases more than that of Standard strategy, so the grinding traces effect tend to be obvious if the grinding speed is higher.



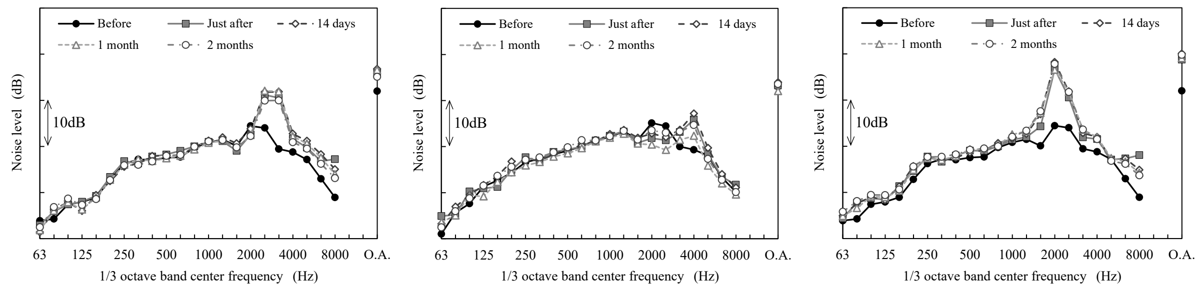
(a) Normal Grinding (b) Test 1 (c) Test 2

Figure 9 – Distribution of rail roughness by test grinding



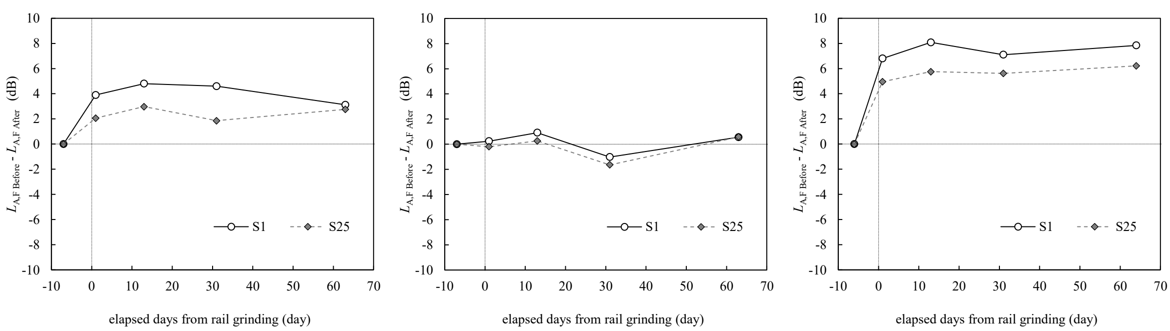
(a) Normal Grinding (b) Test 1 (c) Test 2

Figure 10 – Wave amplitudes of rail roughness



(a) Normal Grinding (b) Test 1 (c) Test 2

Figure 11 – Results of noise measurements near tracks by test grinding



(a) Normal Grinding (b) Test 1 (c) Test 2

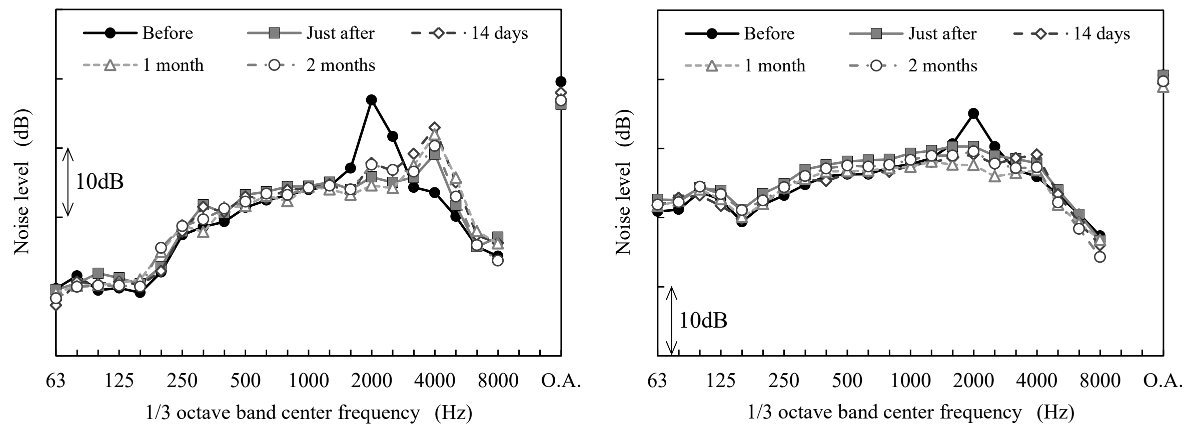
Figure 12 – Time series graph of the noise-level difference by test grinding

Time series of the noise near tracks and at a distance of 25m away from tracks are shown on Figure 12. Also at 25m away, while the noise level of Standard and Test 2 after grinding increase by maximum 6dB, that of Test 1 immediately after grinding does not increased temporarily and decreases by 1.6dB after a month. Here, it should be noted that the noise reduction effect at 25m away has high contribution of rolling noise because noise barriers do not exists along the line.

5.3 Practical evaluation on wayside noise

Wayside noise of high-speed railways in Japan is measured generally at a distance of 25m away from the center of the nearby track. Noise barriers are common alongside the Tokaido Shinkansen and they are mostly higher up to 2.0m, so the effect of grinding by Test 1 method for wayside noise with noise barriers is investigated on this chapter. The height of noise barriers is 1.1m from the rail top. Figure 13 shows results of the 1/3 octave analysis for noise levels near rails, (a)S1 and 25m away from tracks, (b)S25. While a peak lies at 4000Hz band near tracks after grinding, a spectrograph at the distance of 25m away is gentle and there are no any prevailing peaks. Meanwhile, comprehensive noise level is reduced since the noise level at 2000Hz band is reduced by rail grinding. The peak at 2000Hz before grinding is considered to be caused by residual grinding traces generated by the former grinding.

Figure 14 shows the time series of noise level and the noise level at 25m away is decreased by 2dB a month after grinding compared to before grinding. This is explained as below; Wayside noise is reduced because the residual effect of the former grinding was removed by the grinding this time and it did not make grinding traces newly.



(a) S1 (b) S25

Figure 13 – Results of noise levels for section of noise barriers

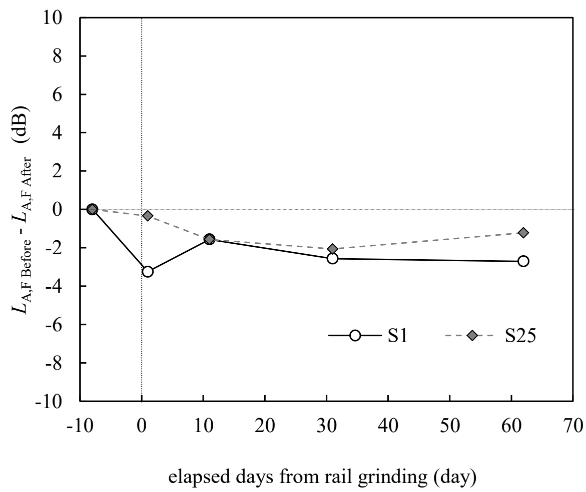


Figure 14 –Time series graph of the noise-level

6. CONCLUSION

This paper has investigated the effect of noise reduction by rail grinding as one of the countermeasures against wayside noise on the Tokaido Shinkansen, then field measurements have been conducted in order to develop the grinding method specialized for environmental measures. The results are summarized below:

(1) Rail grinding results in grinding traces and the peak lies at the wavelength of 31.5mm on rail heads. The roughness of grinding traces remains 4 months after grinding while passing tonage are considerably heavy.

(2) Noise level at the specific frequency band corresponding to the wavelength of grinding traces increases, and also tend to increase wayside noise after grinding. Moreover, the effect of grinding traces of grinding continues for a long time, so more than several months are required for noise reduction.

(3) The improved method to reduce roughness on rail heads generated by rail grinding is invented. Rail grinding machines conduct 4 passes. The first 2 passes are conducted by the standard method then the latter 2 passes are finishing grindings which changes the grinding speed and the pressure of grinding stones. As a result, by the method with slower grinding speed of 4km/h and half pressure of grinding stones of 15A, roughness on rail heads were reduced and further reduced after around 2 weeks.

(4) The reduction of roughness reduces the wayside noise. At the distance of 25m away from tracks, which is a representative evaluation point of noise for Japanese Shinkansen, wayside noise is reduced by 2dB a month after grinding.

From results above, to grind slowly and less pressure could reduce wayside noise because by this strategy rails are grinded more uniformly and roughness of prevailing wavelength is hard to occur. The factor for reducing roughness is that the wavelength corresponding to grinding traces is shorter and contact time among rails and wheels is longer. This method is called “Acoustic Grinding” and has been introduced to rail grinding on the Tokaido Shinkansen as a method specialized to noise reduction.

Further initiatives are to conduct this method under various conditions and evaluate the effect and to establish the optimal period of rail grinding for environmental measures. Moreover, more optimum grinding strategy will be investigated by which efficient “Acoustic Grinding” could be conducted with enough amount of removal for rail maintenance.

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