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Dynamic comparison of a railway catenary section upgrade by field measurement assessments

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Abstract

The pantograph-catenary interaction is crucial for running trains on electrical railway lines. The coupled dynamic problem of an in space stationary system, the catenary system, and a system in motion, the pantograph, is dependent on the behaviour of both combined as well as individually. Different catenary systems exhibit different behaviour. This paper evaluates a catenary system upgrade by dynamic assessment. Existing railway catenary sections are upgraded or replaced due to wear, but also due to an aim for improved running quality or increased speed on the rail line. Field measurements were conducted on an old catenary section. This section was then upgraded, and some months later measurements were conducted on the new catenary section. Thus, field measurements were sampled at the same location twice. Since the measurements were sampled only months apart and that all measurements are recording behaviour under regular train operation, the loading is assumed to be identical. Dynamic assessment of both sections has been done using power spectral densities and histograms. Important differences and similarities in their response can be seen. This study further increases the knowledge regarding the dynamic behaviour of railway catenary sections when evaluating the impact of the upgrades.

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Keywords: railway catenary systems; dynamic assessment; pantograph-catenary interaction; field measurements

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1. Introduction

The dynamic behaviour of railway catenary systems under loading from trains is very important for the quality of the interaction between the pantograph and catenary, and thus the electrical transfer and mechanical contact. Uninterrupted contact is essential for the transfer of electricity[1]. However, too high contact forces lead to unnecessary high wear. The best for the pantograph-catenary interaction is a stable contact force that both ensures electrical transfer and a minimum of wear. Arcing, loss of contact between pantograph and contact wire, happens to a limited amount today. The reason for arcing is that the contact force is equal or less than zero which might be because the speed, and thus the loading, has been increased on existing infrastructure and have led to a change in the response compared to design. Another might be that the design of the particular section is not ideal for the dynamic behaviour, even though it has been planned according to codes. Today, positions with arcing are identified due to increased wear, and maintenance workers adjust the wires to try to reduce arcing and excessive wear at the position.

The contact force along the railway line is dependent on a great number of parameters, such as speed, the pantograph, the static uplift force and properties of the catenary. It is natural that contact force measurements are used to verify the quality of built catenary sections. However, from a design point of view, the only thing that is stationary in time and space is the catenary section. It is therefore important to identify the correlation between the design of catenary sections and the pantograph-catenary interaction so that one can consider dynamic response during design. To be able to do this, one need more knowledge about the dynamic behaviour of existing structures, and what parameters from the design of the catenary that influence the interaction.

Frequency analysis of time series is vital for understanding the dynamic response of a structure. They give knowledge about which frequencies that are important for the response. Different information can be extracted from different parts of a train passage time series; see [2,3]. That is, the pre-passage data include more information about the load frequencies relevant to the section, such as the pantograph frequency and the different span-pass frequencies and fundamental frequencies. The post-passage data on the other side typically reveal the fundamental system frequencies. The advantage of dividing the signal into parts with possible various information contents is also supported by the findings in [4].

This study compares the dynamic behaviour of a catenary section upgrade with the original to find similarities and differences in the response based on analyses of field measurements. The field measurements were sampled during normal train operations and over a duration of several days at the same position along the railway line, so that the loading can be assumed the same for both sections. This gives a good basis for comparison of the dynamic behaviour of two different catenary sections. Power spectral density estimations and peak frequency histograms of whole time series and post-passage time series are used in this investigation. They show that the new section has in general less energy in its response and it has a clearer dynamic response. However, at some frequencies an increased response is observed.

2. Railway catenary systems and pantographs

Railway catenary systems or overhead contact lines are systems of wires that supply electrical energy to the trains. They are located above the train and are mounted on poles along the rail line. There exists many different catenary systems around the world, but the most common components are a contact wire, a messenger wire, dropper wires, stitched wires and cantilevers, as shown in Fig. 1. Along the rail line, the catenary is divided into sections of up to around 1600 m. A section is then divided into spans which is the length between two poles, and this is between 35 and 65 m in Norway. Structurally, the contact wire is carried by droppers fastened in the messenger wire, which in turn are fastened to brackets at the cantilevers that are fasten to poles. The dropper spacing is mainly dependent on the span length, and can approximately be between 5 m and 10 m. The light steady arm ensures correct horizontal geometry of the contact wire. The contact wire is the part that is in contact with the pantograph on the train, and transfers the electricity to the train. For more details see [5,6].

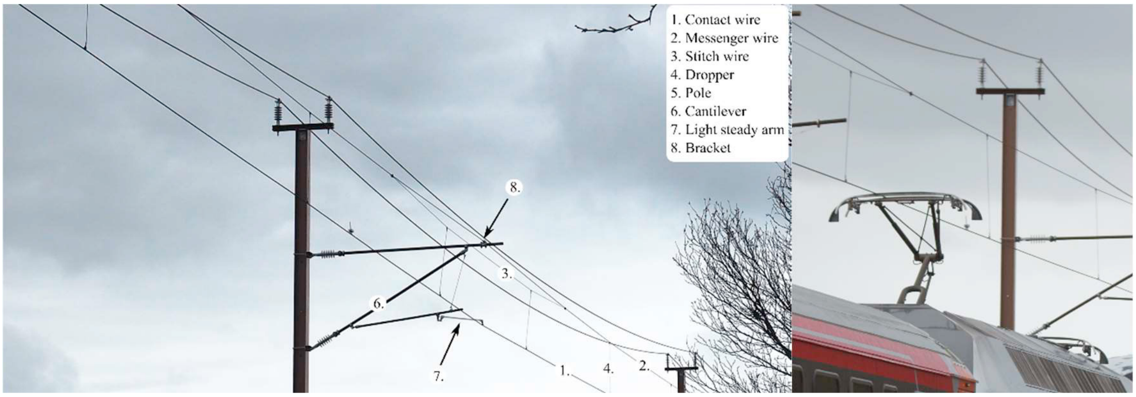

Fig. 1. Important structural components of railway catenary systems, left [7]. Pantograph catenary interaction, right. Photo: NTNU/Petter Nåvik.

3. Field measurements and assessment methods

Field measurements have been sampled at two existing, railway catenary sections. An upgrade of the catenary section was done at Fokstua along the Dovre rail line in Norway in 2015. Two catenary sections of the Norwegian System 35 was changed to one of System 20 C1. Measurements were sampled at both old, and new section.

3.1. Field measurements

The main properties of the two different catenary types, from now on called Fokstua old and Fokstua new, are presented in Table 1. Please note, the span lengths at the position of measuring are almost equal, approx. 45m. Sampling position on the two catenary sections were also approx. the same, i.e. for span, and geographically.

A wireless monitoring system[8] with ten wireless sensors and a master unit was used to sample accelerations from the catenary. A sensor consists of a battery pack, a radio antenna and a motion-processing unit (MPU). The particular MPU include of a microelectromechanical system (MEMS) tri-axial accelerometer, and a Digital Motion Processor™. The sensors are mounted directly on the wires in the catenary. All the measurements were sampled during normal train operation, including both passenger and freight, triggered by passing trains. The loading is therefor assumed the same for the two sections. One observed difference from the measurement was that there were more wind during the measurement at the new section. All measurements were performed with a sampling rate of 200 Hz and 8 minutes time series. The time partitioning was for old section 4 minutes before and after passage, while for new it was 2 and 6 minutes. For a more detailed description see [5,8].

The theoretical first symmetrical and non-symmetrical natural frequencies of one span calculated in accordance with equation 9.66 in Kiessling et al.[6] give 1.053 Hz and 1.146 Hz for the old section, and 1.329 Hz and 1.388 Hz for the new section at a 45 m span length.

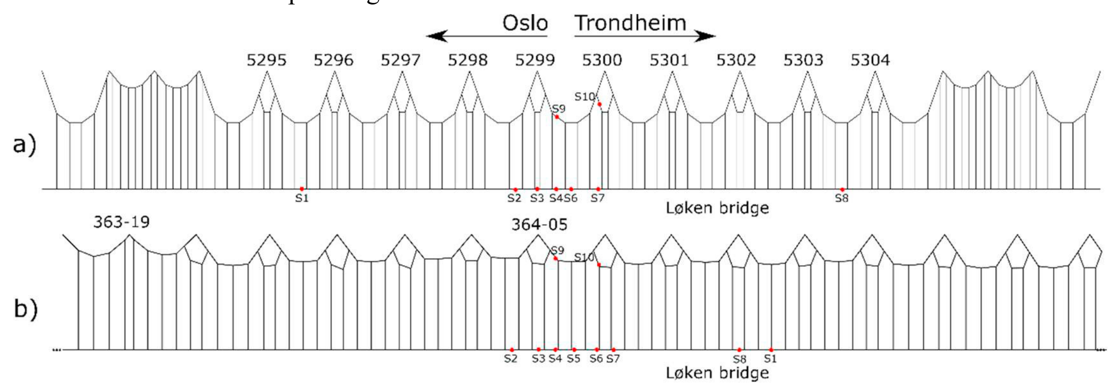

Fig. 2. Sensor positions for a) the old section and b) the new section at Fokstua.

Table 1. Selected properties of the two studied catenary sections.

Catenary section	Length	No of spans	Tension CW	Tension MW	Area CW	Area MW	Number of time series
Fokstua old	705 m	17	7.06 kN	7.06 kN	100 mm^2	50 mm^2	248
Fokstua new	1295 m	28	13 kN	13 kN	120 mm^2	70 mm^2	593

3.2. Assessment methods

The acceleration time series can be divided into different parts according to what information one want to extract[2]. In this study, we compare results analysing whole time series and post-passage time series. Two methods have been used in this study. The first is a previously developed and used assessment method for identification of system frequencies of one system that uses a combination of power spectral density (PSD) estimations by the Burg method[9] and histograms of peaks in the PSDs[8]. In more detail, the method is to add the PSD of acceleration time series from all sensors and from all train passages together to form a total PSD, and to pick the peaks from each of the included PSDs to produce an overall histogram, and study them together. The result represents both the energy and peak distribution of the system. The PSD is typically dominated by the post-passage result, due to much higher energy content after passage, so including the histogram distribution highlights natural frequencies that are often excited but with low energy content under the current loading situation. The second method, divide the total PSDs with the number of PSDs going into it to create a mean PSD for each section. This was included for clearly in identifying differences.

4. Results and discussion

This study focuses on the vertical motion of the railway catenary systems. The whole result part is a comparison between the dynamic behaviour and properties of two catenary sections based on field measurements. The two sections are expected to be different in behaviour due to their differences in properties such as catenary system and design. However, they are also expected to have similarities due to the same loading. First, total PSDs and histograms for the post passage and whole part of the time series are compared. Second, total PSDs normalized by the number of time series that were sampled are compared, illustrating the average level of energy for a time series for the two sections.

The measurements were analysed to estimate total PSDs and histograms from the two studied sections, for whole time series and the post passage part separately, see Fig. 3. This was done to get an overview about the general behaviour of the sections. It is clear that the combination of the total PSDs and the histograms give valuable information about system frequencies as well as response frequencies for both sections. The histograms show the number of occurrences, highlighting differences between the energy input during a passage and the number of times that frequency is excited during regular traffic. The PSDs are in general showing the response frequencies. For both sections it is clear that the major response is around 6 Hz and multiples of this. It is yet to be investigated in detail, but it is quite certain that the cause is a combination of the first natural frequency of the pantograph, which is in this range, and the first natural frequency of the contact wire between droppers, also in this range. The “whole part” results from the old section shows a significant response close to 0 Hz which the new one lack. This is most likely due to the old section being softer and typically having a longer period of quasi-static behaviour, and that the measurements at the new section are more influenced by wind loading. Due to this, it is easier to compare the post passage results than from the whole time series. The first three peaks in the PSD are at 0.79 Hz, 1.14 Hz and 1.57 Hz for the old, and 0.94 Hz, 1.31 Hz and 1.74 Hz for the new section clearly showing that the newer, as expected, is stiffer than the old one. It should be noted that these frequencies are more prominent when regarding the histogram of peak frequencies. Another observation is that the theoretical values for the first natural frequencies matches the second system frequencies from the field study. The reason lower frequencies than the theoretical frequencies are observed in the PSDs comes from a combination of two things. One is that each section have spans with longer span lengths than the monitored spans which result in lower natural frequencies, the other is that the mode shape corresponding to the lowest frequency is longer than a span length, as is assumed by the equation used for estimation of the theoretical first frequencies. It is difficult to know if the frequencies matching the theoretical frequencies are symmetrical or non-symmetrical because the span lengths might differ slightly from design and thus changing the theoretical values. All three frequencies are clearly system dependent since the newer and stiffer section give higher frequencies for all of them. The total PSDs and the histogram gives information about system frequencies, but in the current form, they are difficult to use to compare the energy of the response, another procedure is therefore needed.

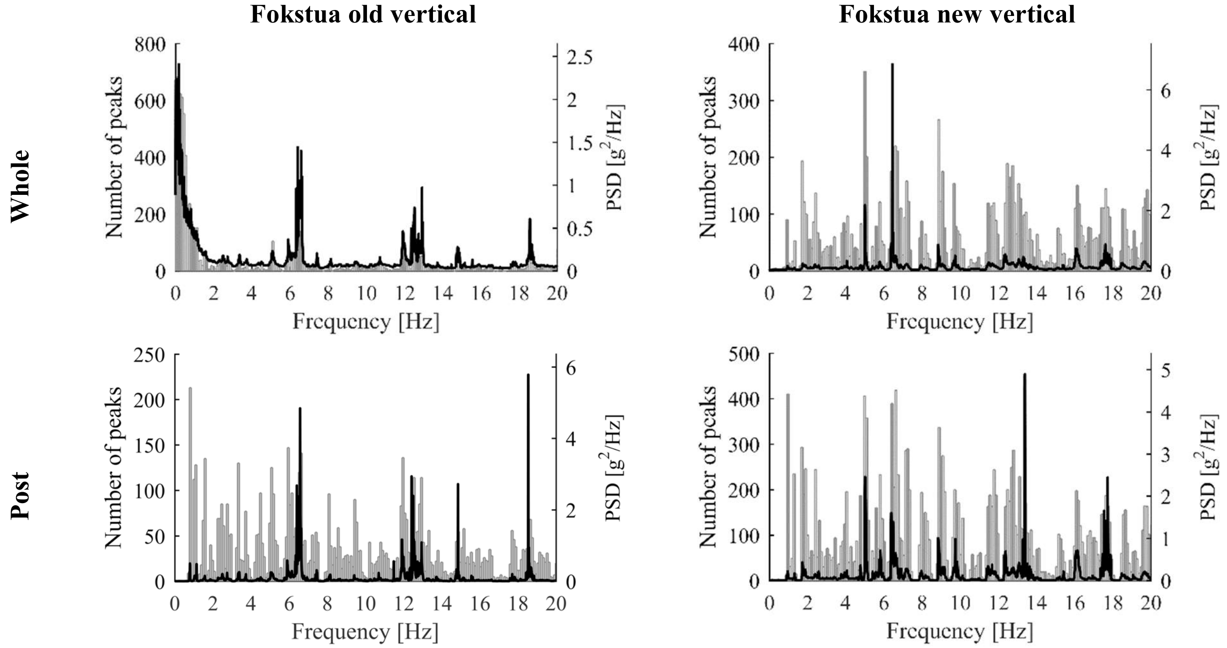

Fig. 3. Total PSDs and histograms for the old and new Fokstua catenary sections, whole time series and post part.

The total PSD represents the energy for all train passages, and for all sensors, together. By dividing by the number of time series included in the total PSD one get a mean total PSD representative for one section. This has been done for the whole and post passage, see Fig. 4 and Fig. 5. Similarities and differences are both clear from these figures. In general, it looks as if the response in the new catenary is less than the old even though the measurements at the new section was performed with more wind. Difference in measurement length between the old and new section might influence the PSDs but less than the difference in amplitude due to section differences. The most interesting is the clarity of the response in the new section, seen by the low values between peaks in the PSDs, which is much less clear for the old section, especially at higher frequencies. This makes it easier to find the system frequencies for the new section than for the old section. The response around 6 Hz and 12 Hz close to pantograph frequencies are also slightly lower, but there is higher response at some frequencies between 8 and 10 Hz. Seemingly, some frequencies shifted to higher values, due to the stiffer section, exhibits same response as lower frequencies in the old section, such as; the first three frequencies, 15 Hz in the old and 16.5 Hz in the new.

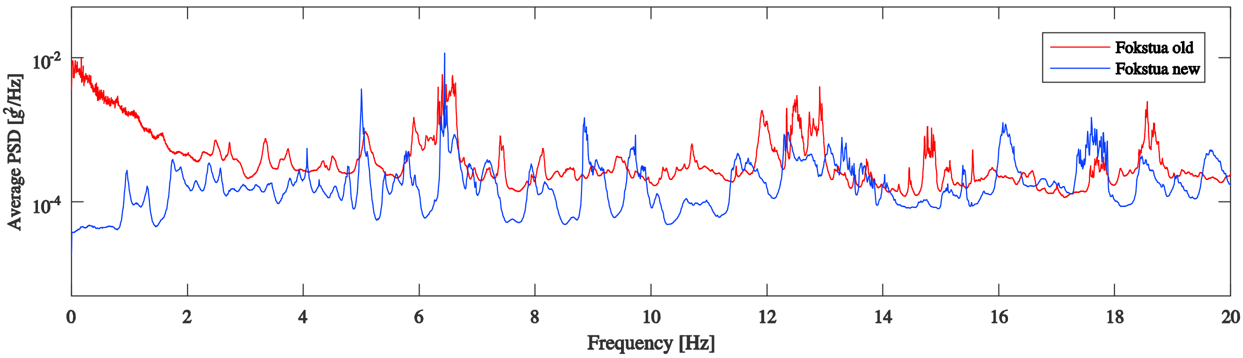

Fig. 4. Total PSD of whole time series, Fokstua old and new, divided by the number of time series included.

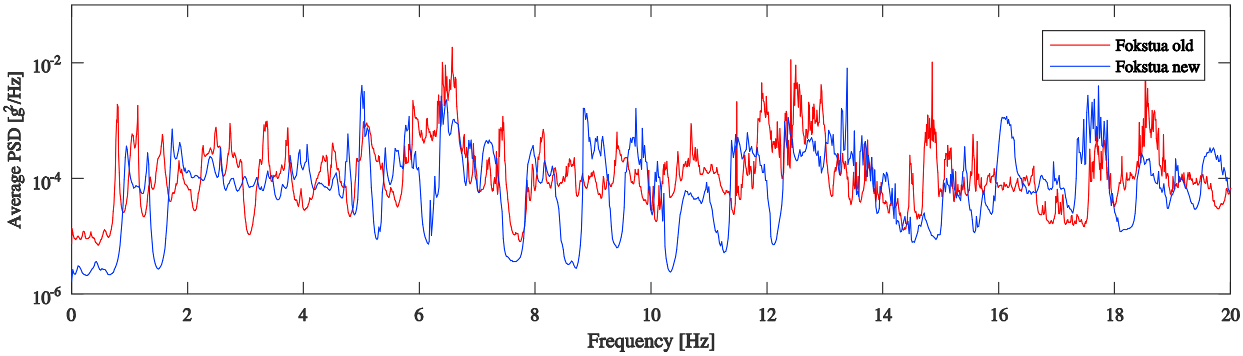

Fig. 5. Total PSD of post time series, Fokstua old and new, divided by the number of time series included.

5. Conclusion

This paper compares the dynamic response of an upgraded catenary section with the original based on field measurements sampled under regular traffic. The strength of this is that one is able to identify differences due to design and system parameters because the loading is assumed the same. Similarities and differences are both identified. The response of the new section is a bit lower in general, and the response looks more clear than the response of the old section. However, this is not the case for the whole range. The response in the new section is higher at several frequencies. The fact that some of the response is less at some frequencies and larger at others makes it important to identify the origin of the movement. Another important finding is that the response around the pantograph loading frequencies are only slightly different, a little less in the new section. The aim for further research is to be able to decide whether a designed railway catenary section will have a good dynamic performance in interaction with a pantograph or several pantographs, and why.

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