AN INTERACTIVE DATA PROCESSING SYSTEM, MICRO LABOCS, FOR THE MAINTENANCE MANAGEMENT OF A RAILWAY TRACK IN THE DAYS OF A SPEED UP OF TRAINS

Akiyoshi YOSHIMURA
Dr. Eng.
Computational Analysis Labo.,
Railway Technical Res. Inst.,
Kokubunjishi Tokyo, Japan

Takehiro HOSOKAWA
Track and Structures Div.,
Railway Headquarters,
West Japan Railway Company
Ohsakashi Ohsaka, Japan

INTRODUCTION

Today in the railway of the world a great deal of effort is put into realizing a speed up of trains. For example, TGV in France attained the high speed test running of more than 500 kilometers an hour. Also in Japan, after division and privatization of Japanese National Railway (JNR) as of April 1987, Japan Railway companies compete with each other for a speed up of trains.

In the advent of a new age of a speed up in the railway, innovations of technology are required in various fields of usual railway systems, especialy in the field of the maintenance management of a railway track. A railway track has a very important role in securing the running safety and maintaining a comfortable riding quality of high speed trains. But a practice of its maintenance management costs a great deal. So a study of some new methods and a development of appropriate supporting systems by which we can perform it more effectively and more economically are necessary.

On such circumstances, so far we have been studying the various methods concerning the railway track maintenance management and at the same time we have been developing the interactive data processing system called Micro LABOCS. In this paper we mainly describe the functions of data analysis in the Micro LABOCS system and some examples of their applications related to the railway track maintenance management in the days of a speed up of trains.

1.MICRO LABOCS SYSTEM FOR THE RAILWAY TRACK MAINTENANCE MANAGEMENT

A geometrical shape of a railway track is decided in considerations of various conditions such as topographical restrictions, running speeds of trains, etc. But under frequent traffic of trains such an original geometrical shape of the track varies gradually. Consequently a so-called track irregularity occurs.

To the railway track maintenance management in the days of a speed up it is the most important work to measure such track irregularities periodically and repair them appropriately.

The measurement of track irregularities has long been done on the principle of the 10 m chord versed sine method. And the track maintenance management has been planned and practiced according to the magnitude and its statistical distribution of the 10 m chord versed sine. But a waveform of such track irregularity measured by this versed sine method is different from its original one corresponding to a true track irregularity on the ground.

Actually, among various wavelength components composing a track irregularity, magnitude gains for long wavelength ones by this measurement method are considerably small comparing with those for other wavelength ones.

On the other hand, for a high speed train such as Shinkansen, from the point of view of a vehicle dynamic characteristic it is important to manage carefully such long wavelength components included in a track irregularity. So in order to grasp a true track irregularity including such long wavelength components, we have been studying a general method of restoring an original waveform of it from measured data. As a result we have developed a restoring method with no any distortions in the waveform by using a linear phase digital inverse filter. And through several verifications we have confirmed that a state of track irregularities can be grasped very well by this new method.

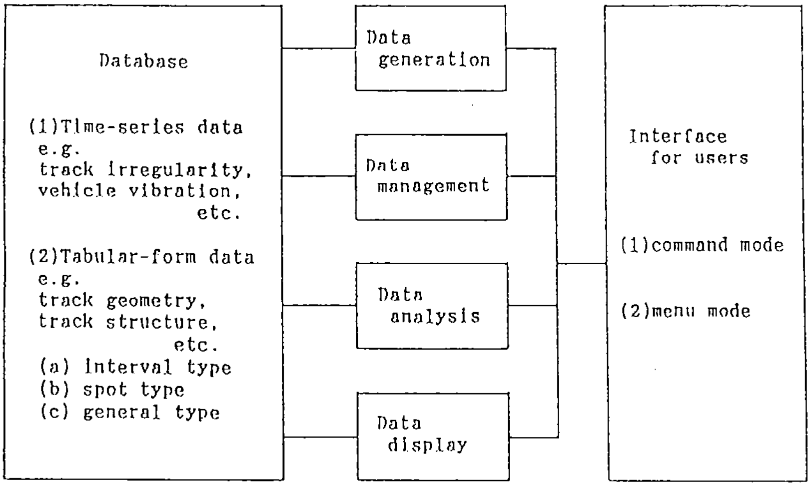
Next, with intention to apply this restoring method, we also have been investigating the influence of a track irregularity on the vibration of a vehicle through the analysis of many actual measured data, so that we can find how to practice the railway track maintenance management more effectively and more economically. From these investigations we have obtained many useful results.

In order to put these results of our research in practical use of the railway track maintenance management, we have developed an interactive data processing system called Micro LABOCS. The LABOCS(LABOratory's Conversational System for time-series analysis) has been developed by authors originally as a general purpose conversational data processing system, so as to improve the data analysis techniques and the efficiency of data processings in various tests and experiments in RTRI laboratories by applying the modern digital signal processing techniques.

But as above mentioned, through its application to our studies on the railway track maintenance management, many useful data processing functions have been newly developed and built into the LABOCS system. Thus the Micro LABOCS, which operates under the well-known MS-DOS operating system on a personal computer, has become a railway track maintenance management oriented system and been utilized to analyze actual problems in the field of the railway track.

An organization of the Micro LABOCS system is as shown in Graph 1. The Micro LABOCS has many useful data processing functions such as data aquisition, calibration, spectral analysis, frequency response analysis, digital filtering, decimation, etc.

Further it has also a database function. The database can deal with two kinds of data of time-series data and tabular-form data. Thus using the micro LABOCS we can store many kinds of measured data such as ones obtained by a track inspection car and miscellaneous



Graph 1 Organization of the Micro LABOCS system

track environmental data such as track structures, initial designed track geometries, welding positions of long-rails and circumstances of track maintenance operations, etc., into the database system.

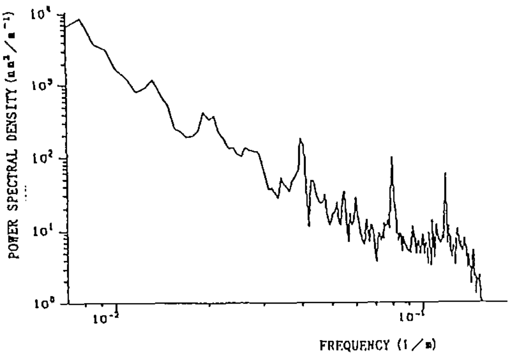
Also in the Micro LABOCS system we can access to the database by a kilometer-index defined along the railway line, instead of a data number in the data file. That is, in every command of a data processing we can specify a range of data processed using a kilometer-index following after the input data file name. This facility is very convenient to railway field engineers because they are more familiar to the use of a kilometer-index rather than a data number.

In addition the Micro LABOCS has flexible graph drawing facilities available in interactive mode, to the various measured data and their analysis data. Further we can display the above mentioned tabular-form data illustrately in the predefined graphical symbolic mode together with time-series data.

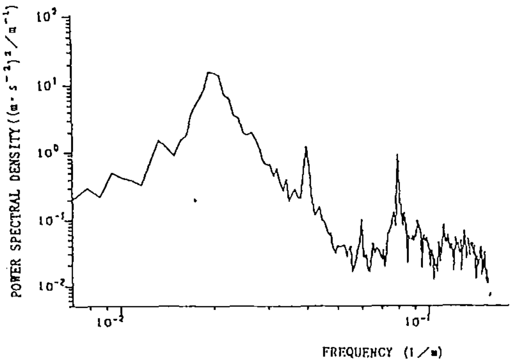
2.NECESSITY OF THE MAINTENANCE MANAGEMENT FOR LONG WAVELENGTH COMPONENTS OF A TRACK IRREGULARITY

In this and following sections we mainly describe the functions of data analysis and some examples of their applications related to the track maintenance management in the speed up of trains.

At the beginning, taking the JR Shinkansen as an example, we describe our study concerning the influence of track irregularities in longitudinal level on the vertical vibration of vehicles through a frequency response analysis of actual data measured on the track

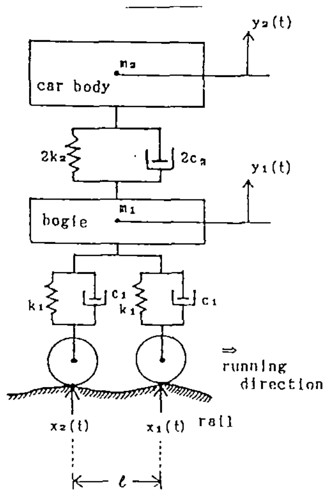


(a) track irregularity in longitudinal



(b) acceleration of vehicle vibration

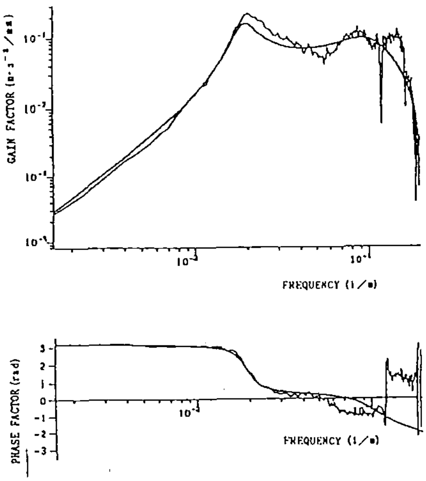
Graph 2 Typical power spectra



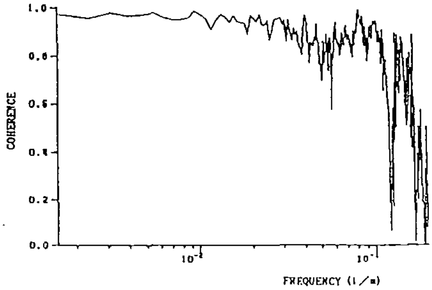
Graph 3 Simple vertical vibration model

inspection car.

Graph 2 shows typical examples of a power spectrum of a track irregularity and also one of a vehicle vibration in the case of the running speed of a train, 210 km/h. Generally a power spectrum of a track irregularity decreases in proportion to a power of two or three of a spatial frequency (1/meter). This is mainly due to the stiffness of rails laid on a railway track. On the other hand, a power spectrum of a vehicle vibration concentrates at the vicinities of some specific frequencies which correspond to the ones of the natural vibration of a vehicle. In fact it is well known that Shinkansen's electric car has two natural frequencies at the vicinities of about 1 Hz and 5 Hz, as estimated from a simple vertical vibration model of a vehicle shown in Graph 3. In the case of Graph 2 they correspond to



Graph 4 Frequency response



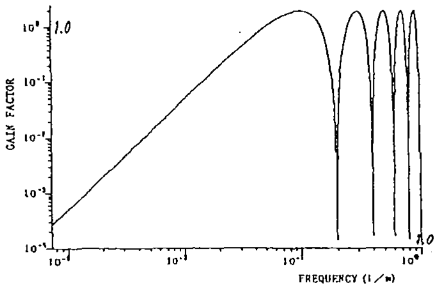
Graph 5 Coherence

the wavelengths of a track irregularity about 50 - 60 m and 10 - 20 m respectively, as known from considering the running speed of a train.

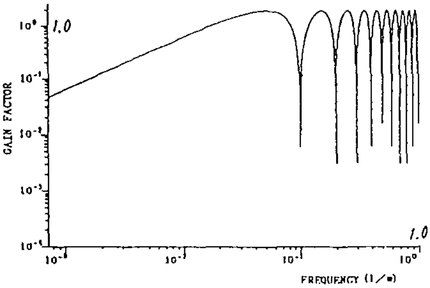
Graph 4 and 5 show the typical result of the frquency response analysis. From these analysis it has become clear that in the running at the high speed of about 200 km/h, a hypothetical mean track irregularity in longitudinal level obtained by averaging two ones for both right- and left-rail, instead of one for either rail, has a strong coherence of 0.8 - 0.9 on the vertical vibration of vehicles over the range of wavelengths of more than 6 m. Thus it follows that a vertical vibration of vehicles is mainly due to the track irregularities in longitudinal level and there holds a relationship of strong linear dependence between the two. Further comparing the above result with a theoretical frequency characteristic computed from the linear model given in Graph 3 there is generally a good correspondence between the two, and especially concerning the phase characteristic a remarkable correspondence is observed in a range of wavelengths of more than 30 m.

As above mentioned, in the maintenance management for track irregularities it is necessary to take both a dynamic characteristic of a vehicle and its running speed into consideration. Especially as a speed of a train goes up, a maintenance management of longer wavelength components in track irregularities becomes more important relatively.

By the way, as described in the section 1, a measurement of track irregularities has long been done on the principle of the 10 m chord versed sine method. This method has a frquency characteristic given in Graph 6. As a wavelength of a track irregularity becomes longer,



Graph 6 Gain factor in the 2nd order difference method



Graph 7 Gain factor in the 1st order difference method

the gain in the measurement for it decreases. For example, the gain for the wavelength of 70 m is only 5 percent of that for the wavelength, 10 m. But if the above Shinkansen electric car runs at, for example, the faster speed, 250 km/h, components in the vicinity of the wavelength of about 70 m of a track irregularity will have a large influence on the vibration of the vehicle as seen from the above analysis. Therefore in the speed up of trains it is clearly insufficient to rely on only the usual track maintenance management methods based on a magnitude of a 10 m chord versed sine. That is, some new methods to grasp accurately the long wavelength components of a track irregularity are required.

3. RESTORING AN ORIGINAL WAVEFORM OF A TRUE TRACK IRREGULARITY

We have developed a general method of restoring an original waveform of a true track irregularity from the data measured by the 10 m chord versed sine method. The basic idea of this restoring method is to design a digital inverse filter whose frequency characteristic corresponds to an inverse of that of a measuring system of a track irregularity. In such a restoration concerning a waveform it goes without saying that amplitude gains of each frequency component must be restored as exactly as possible. But it is considered to be more important to restore their phases exactly. In other words, this requirement to phases says that the frequency characteristic of the total process from the measurement to the restoration should have a so-called complete linear phase. A complete linear phase assures that a restored track irregularity has no any distortions in its waveform. This feature is very desirable for the purpose of indicating which places along the railway line to be repaired in the practice of the railway track maintenance work.

According to the theory of a digital filter, a realization of a complete linear phase is restricted to only two types of FIR(Finite

Impulse Response) filter which correspond the cases of the impulse response of the filter, h(n), being either symmetric or antisymmetric.

Fortunately these two possible cases just meet to our design requirements of restoring inverse filters for two kinds of measurement methods of a track irregularity which are put into practical use in the track inspection car of Japanese Shinkansen. Here, one of these measurement methods is a well-known 10 m chord versed sine method and the other is 'a measurement method of long wavelength components of a track irregularity in longitudinal level'. This latter somewhat long name stems from the frequency characteristic intrinsic to its measurement principle, as shown in Graph 7. Mathematically these two kinds of measurement methods are able to be expressed simply as a 2nd order- and a 1st order- difference equations respectively, as follows.

$$y(t) = -\frac{1}{2}[\{x(t+5) - x(t)\} - \{x(t) - x(t-5)\}] \tag{1}$$

$$y(t) = x(t) - x(t-10) \tag{2}$$

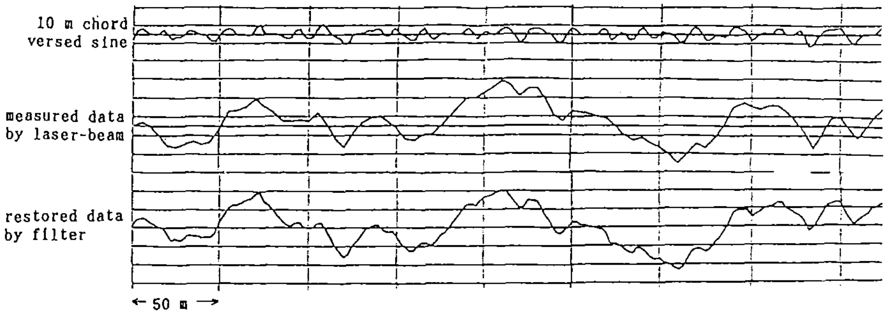
where t is a distance variable measured along the railway line, x(t) is a value of a true track irregularity at the place t and y(t) is a corresponding value measured by a 10 m chord versed sine method.

As seen from comparing Graph 6 with Graph 7, a 1st order difference method has higher gains to long wavelength components than that in the case of the 2nd order difference method. But in either cases measured waveforms are different from a true track irregularity.

Strictly speaking, we can not obtain a perfect original waveform of a true track irregularity by the above restoring method because of the existence of several frequency components whose gains on the measurement are zero. However if a restoration can be done in as wide a frequency band as possible, for example, of from the wavelength 6 m to 150 m, so as to contain a large part of frequency components which have a major influence on the vibration of vehicles, it will be sufficiently meaningful and useful in various applications. Especially if we can grasp the existence of track irregularities in the form of the waveform along the railway line by this restoring method, it is very effective and useful for a repairing work in the railway track maintenance management.

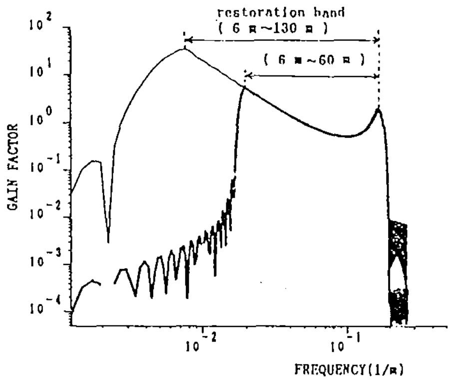
As an example, in Graph 8 we show the result of comparison of the waveform of a true track irregularity in alignment measured using the laser beam instrument with one obtained by the above restoring method from the 10 m chord versed sine measuring data. Both waveforms show a very good coincidence with each other. So far through many other verification tests the effectiveness of the restoring method has been confirmed.

Based on the above mentioned theoretical foundation we have developed programs for a interactive design of a restoring digital inverse filter and the fast filtering by the application of FFT algorithms. The design method adopts a frequency sampling method and



Graph 8 comparison of the waveform of a true track irregularity in alignment measured using the laser beam instrument with the restored waveform from a 10 m chord versed sine data

the filtering operation uses the overlap-adding method. In this program a frequency band and the accuracy of amplitude gain in a restoration are flexibly specified by the design parameters in the interactive mode. A phase characteristic holds still a complete linear phase. Example of the design of a restoring inverse filter are given in Graph 9.



Graph 9 Example of the design of inverse digital filter

By selecting the restoring frequency band appropriately we can extract precisely any desired wavelength components included in the track irregularity.

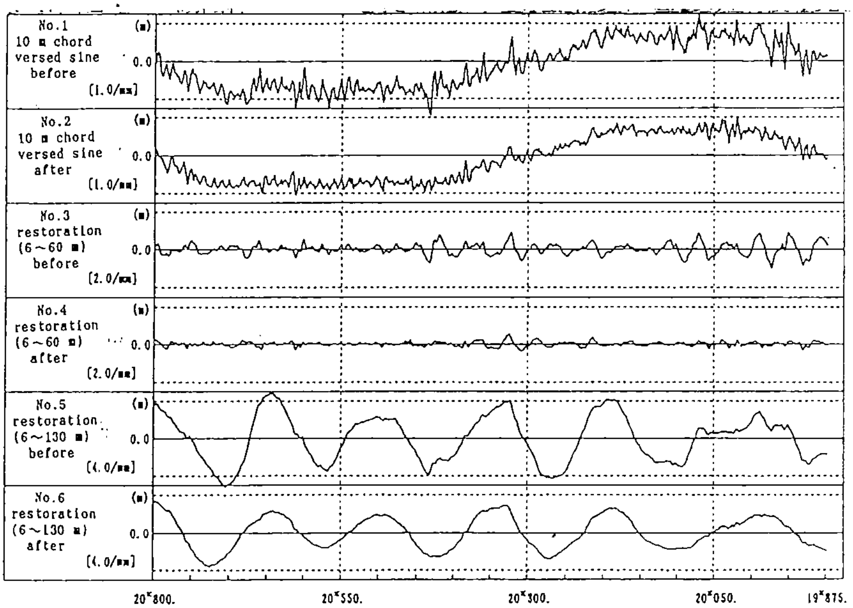
4.EVALUATION OF THE REPAIRING WORK OF A TRACK IRREGULARITY

In this section as an example of the application of the restoring method we give the results of data analyses for the repairing works of a track irregularity which were carried out at the field of Kosei line in West Japan Railway Company. The repairing works investigated here are lining and tamping with the absolute or relative reference points using the multiple tamper.

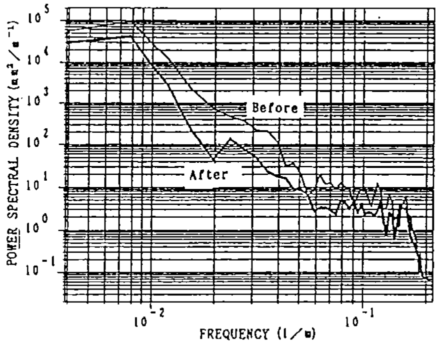
Graph 10 shows various waveforms obtained by processing appropriately the 10 m chord versed sine measured data of the track irregularity in alignment of right-rail before and after of the rapairing work, in this case, the lining with the absolute reference points. For example, data No.1 and No.2 in Graph 10 are the waveforms of the 10 m chord versed sine measured data before and after of the repairing work.

Now we use the two kinds of restoring inverse filters, as already shown in Graph 9. One is a filter restoring the components in the bandwidth over the wavelength of a track irregularity from 6 m to 60 m which have a great influence on the vibration of vehicles. The other is a filter of restoring the components in the wider bandwidth over the wavelength from 6 m to 130 m, so as to estimate an actual waveform of a true track irregularity.

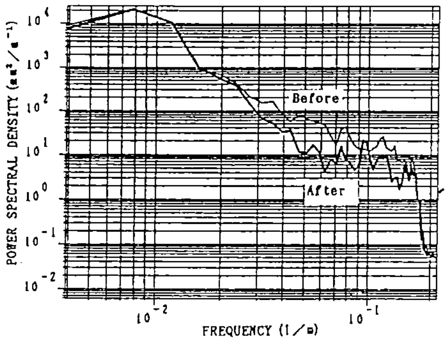
The waveforms of data No.3 through No.6 shown in Graph 10 were obtained by applying these two kinds of inverse filters to the measured data of data No.1 and data No.2 respectively. By observing and comparing these six waveforms in Graph 10 along the railway line we can grasp precisely the change of the state of the track irregularity between before and after of the repairing work.



Graph 10 Various waveforms obtained for the track repairing work



Graph 11 Spectral analysis of the lining work



Graph 12 Spectral analysis of the tamping work

In addition to these analyses, an ordinary spectral analysis is also very useful. In this case, as shown in Graph 11, we can tell good from bad of the rapairing work from a whole point of view, unlike the case of observing the previous restoring waveforms. Actually in this example we can say that the repairing work of the track irregularity has been· carried out satisfactorily over the wide range of wavelengths.

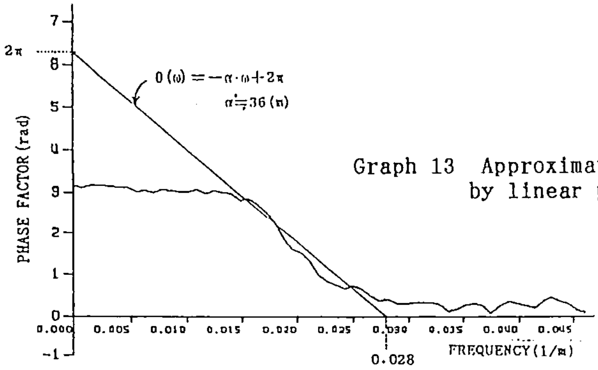
For the comparison we also give an example of the similar analysis of the repairing work with the relative reference points for a track irregularity in longitudinal level in Graph 12. We can see that concerning the effects of repairing work there is a difference between above two cases, coming from the way of whether using a absolute reference ponts or relative ones.

As evaluated from these examples our techniques of the repairing work in the track maintenance have been remarkably improved in recent years.

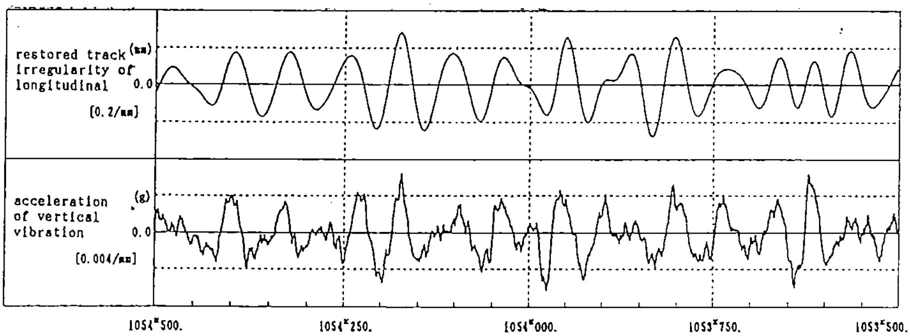
5. CORRESPONDENCE BETWEEN A TRACK IRREGULARITY AND A VEHICLE VIBRATION

As described already in the section 2, there is a relationship of a strong linear dependence between a track irregularity in longitudinal level and a vertical vibration of a vehicle. Taking advantage of this fact we can give some useful applications in the railway track maintenance management.

Firstly, as illustrated in Graph 13, a phase characteristic in the frequency response can be partly approximated with the linear phase. This part of the frequency band corresponds to the one having a large influence on a vehicle vibration. Therefore if we restore the components of a track irregularity lying in this frequency band, we can expect that its restoring waveform should have a similar one as



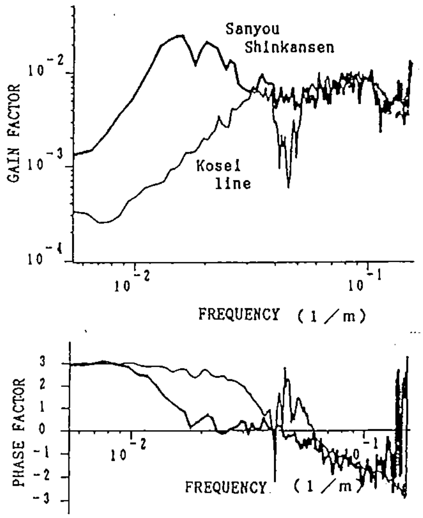
Graph 13 Approximation by linear phase

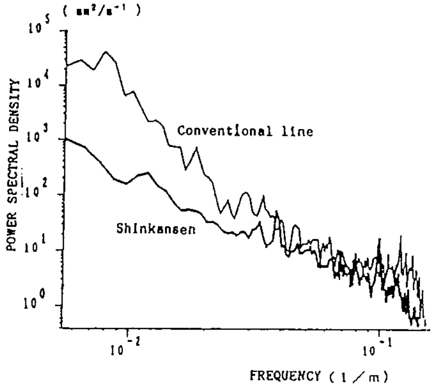


Graph 14 Correspondence between a track irregularity and a vehicle vibration by the linear phase approximation

a vehicle vibration. Actually we can confirm this prospect, as shown in Graph 14. Such an interpretation for the relationship between a track irregularity and a vehicle vibration serves for giving a reasonable explanation for the cause of giving rise to a large vehicle vibration.

Secondly again utilizing the linear relationship we can find the correspondence between the track irregularity measured in the track inspection car and the vehicle vibration measured separately in an ordinary passenger train, under the condition that a state of the railway track irregularity does not vary suddenly. An algorithm of taking this correspondence is divided into the following two steps. In step 1, a very longer wavelength components of , for example, more than 100 m for which a phase characteristic has no delay in a response, are restored for both data of a track irregularity and a vehicle vibration and then a correlation between them is computed. By this result we can obtain an approximate correspondence between both data.





Graph 16 Comparison of power spectra

Graph 15 Example of frequency response analysis after processing of the correspondence

Next in step 2, a frequency response analysis is carried out repeatedly in the neighborhood of the corresponding data point obtained in step 1, while shifting a corresponding position of data points to back and forth, until the satisfactory phase characteristic is obtained. Graph 15 is an example of the frequency response analysis between the track irregularity in longitudinal level and the vehicle vibration obtained after having gotten the correspondence by applying the above algorithm to the data in Sanyou Shinkansen and Kosei line respectively, in West Japan Railway Company.

And we also give the comparison of the power spectra of Shinkansen and Kosei line in Graph 16.

CONCLUDING REMARKS

In this paper we described various data processing techniques useful to the railway track maintenance management in the days of a speed up of trains. We hope our Micro LABOCS system serves for the improvement of its related technology.

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