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The performance of lining and tamping machines

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SUMMARY

In this paper, the performance of some modern type track maintenance machines is discussed for both lining and levelling operations.

After outlining the measuring principle, used in the automatic mode, theoretical transfer functions are derived according to the measuring system used.

The methods applied for determining actual transfer functions of maintenance machines are then discussed. This technique basically consists of recording the track geometry, before and immediately after maintenance, by special recording coaches, two of which are discussed here. A detailed survey of the spectral analysis methods for evaluating the recorded data are given.

These analyses have been applied to a large series of measurements carried out for ORE Committee D117. Those results which could be estimated sufficienly accurately from a statistical point of view are presented here.

Conclusions have been formulated with respect to the practical use of maintenance machines, special attention being focussed on the distinction between track lining using lining or tamping machines, and machine operation in the automatic mode and the design mode.

1. INTRODUCTION

Nowadays the planning of track maintenance is increasingly based on geometrical track data recorded by special coaches. In line with this philosophy, the track quality is expressed in statistical terms [1] such as standard deviations and exceedence levels, which are calculated on a computer from recorded geometry.

The question as to where to fix the track quality standards for which maintenance is required, cannot be easily answered as a correct choice depends on a considerable number of factors such as the relationship between riding comfort and track geometry, the rate of deterioration of track irregularities and the geometrical improvements attainable through lining and tamping.

The present paper primarily deals with the last aspect and describes a number of results from recent studies on the performance of track maintenance machines, carried out on behalf of the ORE Committee D117. The project was initially commenced with an examination of the measuring systems used with maintenance machines working in the automatic mode. The transfer function of this system gives the relationship between the geometry of the track before and after maintenance under ideal conditions, i.e. assuming that the machines establish perfect track correction and that the reaction forces on the track do not cause permanent track deformations. These calculations are given as regards lining in Chapter 2 and as regards levelling in Chapter 3. For a detailed account, reference should be made to sources [2,4,5].

The next step of the investigation consisted of conducting a test programme to determine the actual machine performances. Here the machines were applied both in the automatic mode, resulting in smoothing of track faults, and the design mode, in which case the machines rectify the track according to fixed points. The basic idea of the test set-up consisted of recording the track geometry before and immediately after the maintenance operation. From the applied recording coaches, the BR track recording coach and the SNCF Mauzin car are discussed in Chapter 4.

During track recording, the measurement data were stored on magnetic tape for subsequent processing on a computer. Special analysis procedures, based on the spectral analysis concept [2, 6], have been developed for analyzing the data and are outlined in Chapter 5.

The actual performance of the maintenance machines is also expressed by transfer functions, which represent the real amplitude reduction of the original track faults as a function of wave length. From these estimates, the different maintenance machines are assessed with respect to their effectiveness in Chap-

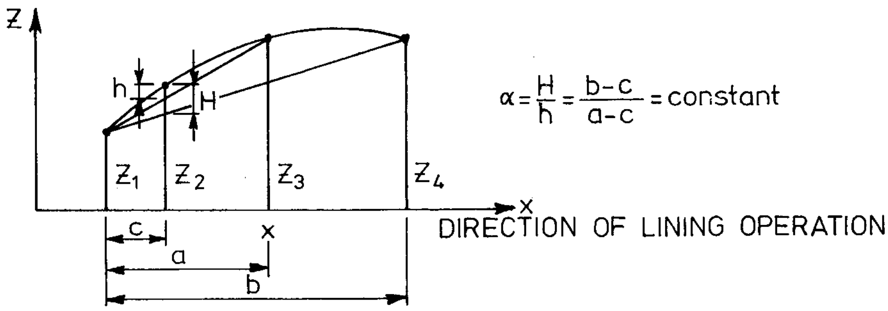

Fig. 1. The 4 point lining principle

ter 6. For a complete survey of all test results please refer to [3]. Finally, in Chapter 7, conclusions and recommendations are formulated concerning the practical applications of maintenance machines.

At the request of the publisher, it has been decided to omit firm names in this text, this being the reason why lining machines are referred to as LIN *i* and tamping machines are designated as TAMP *i*.(*)

2. THE LINING PRINCIPLE

With the present maintenance machines, the lining mechanism either consists of a 3-point or 4-point system. Only the 4-point system will be discussed here as the 3-point system is basically the same as the levelling system, outlined hereafter.

Broadly speaking, a circle is determined by the three ordinates Z_1, Z_2 and Z_4. The point of operation (number 3) is moved by the machine such that it coincides with the previously defined circle (Fig. 1). This operation is controlled by the fixed ratio of the versines *h* and H, depending on the chord length.

When the machine works in the automatic mode (smoothing), the leading point of the long chord (number 4) follows the old geometry. The reduction of faults in the geometry attained by this process has been studied for several types of machine [2, 4, 5].

Another way of applying maintenance machines is that of the fixed point mode (correction). Here the geometry must be calculated in advance, the results of which are fed into the machine. Two possibilities exist in this respect. First, the theoretical values can be assigned to point 4, i.e. to the leading point of the long chord. Small irregularities in the input data are smoothed by the machine. This way of proceeding is the same in fact as the one described above, except that now the leading point follows a theoretical value rather than the actual track geometry. This principle is also adopted in laser beam applications on straight track. The laser beam serves as theoretical track geometry reference. A second possibility in the correction mode is to adjust the point of operation directly according to the predetermined theoretical values. This seems to be the most logical way, but the disadvantage here is that all the inaccuracies of the input data are directly transferred to the track geometry since any smoothing mechanism now fails.

(*) These names can be supplied by the author on request.

The previous principle applies to almost all the machines of the test programme. Only the LIN 3 lining machine works slightly differently to the above; first, a preliminary recording of the alignment is made with the aid of the versine measurement from the reference base. Next, the desired geometry is chosen and the machine adjusted accordingly. Subsequently, the lining operation is carried out in smoothing the differences between the desired values and the existing values.

When a maintenance machine operates in the automatic mode, the track faults are reduced by virtue of the machine's measuring system. Under ideal conditions, assuming perfect correction, the transfer function of the measuring system will give the relationship between the geometry before and after maintenance. This theoretical transfer function can be derived from the schematic representation of figure 2.

The points A, B, G and E are corrected points for which the ordinates are denoted by Z_n (new). Point D is an auxilliary quantity with a value Z_r and the level of the uncorrected point C is referred to as value Z_o (old). When the values, *a, b* and *c* are known, the ordinate of point D can be expressed in terms of the ordinates of A, B and C.

Alternatively, there exists a fixed ratio between the versines *h* and H, given by the following expressions

$$H = \frac{c\,(b-c)}{2R}, \quad h = \frac{c\,(a-c)}{2R}, \qquad (2.1)$$

$$\alpha = \frac{H}{h} = \frac{b-c}{a-c} \quad \text{and} \quad S = \frac{a}{c}\,H\,\frac{\alpha-1}{\alpha}$$

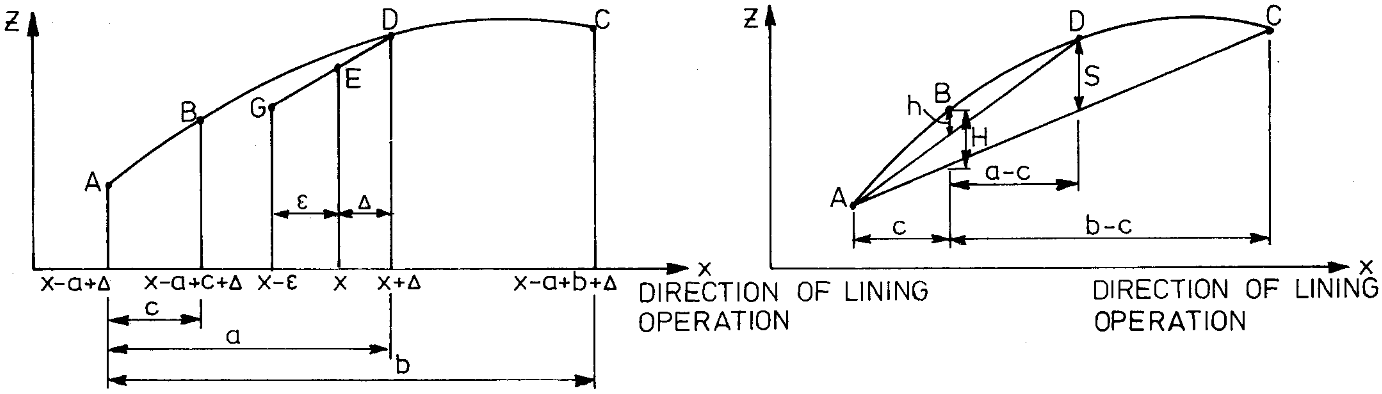

Fig. 2. Lining system schematic

With the aid of the previously derived formulae, the displacement of E can be expressed in terms of the other ordinates, resulting in the following relationship :

$$\frac{\varepsilon + \Delta}{\varepsilon} Z_n(x) = \frac{\Delta}{\varepsilon} Z_n(x - \varepsilon) + \frac{a}{c}\frac{\alpha - 1}{\alpha}$$

$$Z_n(x - a + c + \Delta) + \left\{\frac{b - a}{b} - \frac{a(b - c)}{bc}\frac{\alpha - 1}{\alpha}\right\}$$

$$Z_n(x - a + \Delta) + \frac{1}{\alpha}\frac{a}{b} Z_0(x + b - a + \Delta) \qquad (2.2)$$

This is a so called recursive expression, relating a new value to an old one and to some previously determined new values. This technique is well-known from, for instance, the theory of digital filters [15]. After carrying out the Fourier transform for this equation and collecting terms, the result can be written in the form :

$$FT\{Z_n\} = H(F)\, FT\{Z_0\}$$

in which the transfer function H (F) becomes :

$$H(F) = \frac{\frac{a}{b}\frac{1}{\alpha}\zeta^{b - a + \Delta}}{\frac{\varepsilon + \Delta}{\varepsilon} - \frac{\Delta}{\varepsilon}\zeta^{-\varepsilon} - \frac{a}{c}\frac{\alpha - 1}{\alpha}\zeta^{-a + c + \Delta} - \frac{c - a}{c}\frac{\alpha - 1}{\alpha}\zeta^{-a + \Delta}} \qquad (2.3)$$

with :

$$\zeta = e^{i 2\pi F} \quad \text{and} \quad F = \frac{1}{L}, \quad L = \text{wavelength.}$$

For the machines of the test programme, the theoretical transfer functions with respect to lining are given in figure 3. The shape of these curves obviously shows strong resemblance. It may therefore be

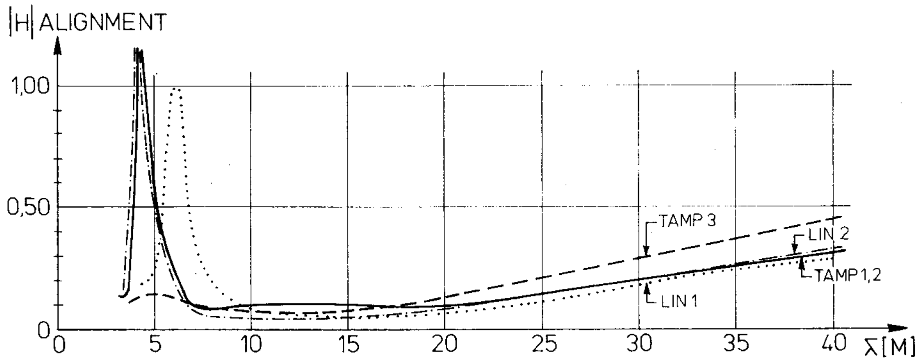

Fig. 3. Theoretical transfer functions for lining

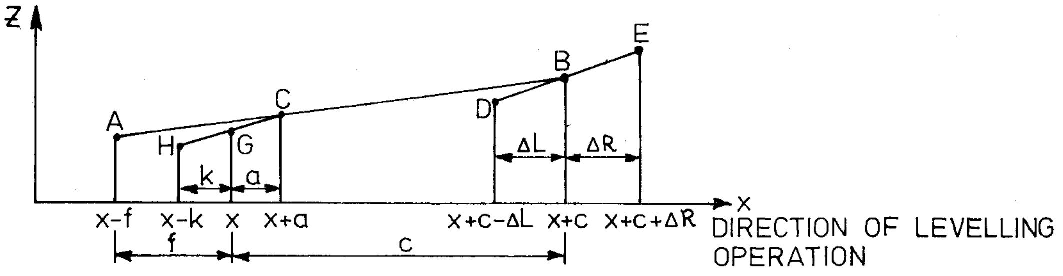

Fig. 4 Levelling principle

assumed that the performance will also be similar. From the experimental results, discussed afterwards in Chapter 6, it will be clear however that the actual improvements of the track geometry are in general less favourable, while moreover much larger discrepancies are found among the different machine types than is suggested by the theoretical graphs.

3. THE LEVELLING PRINCIPLE

In the case of levelling, the principle of which is outlined in figure 4, the sensing mechanism basically consists of two points, namely, A at the rear, measuring already corrected geometry, and B in front, recording uncorrected values. Point C, at some distance from the rear, is lifted in such a way that it tallies with the line connecting A and B. A more sophisticated system is that with two sensing points in front, from which the average value is assigned to B. In reality, the actual point of operation is not C in fact but a point G between C and the adjacent left wheel H. In that case, the assumption is made, as for lining, that G lies on the line connecting C and H.

For the automatic mode, the theoretical transfer function follows from the principle sketched in figure 4.

The points A, G and H refer to corrected track level, denoted by Z_n, while D and E concern the uncorrected track. The points C and B are auxiliary points. Point G can be related to all other ordinates by the recursive expression

$$Z_n(x) = \frac{a}{a+k} Z_n(x-k) + \frac{k}{a+k} \left\{ \frac{a+f}{c+f} \, \frac{1}{\Delta L + \Delta R} \left[\Delta R \, Z_0(x+c-\Delta L) + \Delta L \, Z_0(x+c+\Delta R) \right] + \frac{c-a}{c+f} Z_n(x-f) \right\} \quad (3.1)$$

After applying a Fourier transform, making use of

$$FT\{Z_n\} = H(F) \, FT\{Z_0\}$$

and after re-arranging the terms, the following expression for the transfer function is found

$$H(F) = \frac{k(a+f)\,\zeta^{c} \frac{1}{\Delta L + \Delta R} \left(\Delta R \, \zeta^{-\Delta L} + \Delta L \, \zeta^{\Delta R} \right)}{(a+k)(c+f) - a(c+f)\,\zeta^{-k} - k(c-a)\,\zeta^{-f}} \quad (3.2)$$

with:

$$\zeta = e^{i 2\pi F} \quad \text{and} \quad F = \frac{1}{L}, \quad L = \text{wavelength.}$$

The theoretical transfer functions for levelling, as far as the machines of the test programme are concerned, are given in figure 5. In the same way as

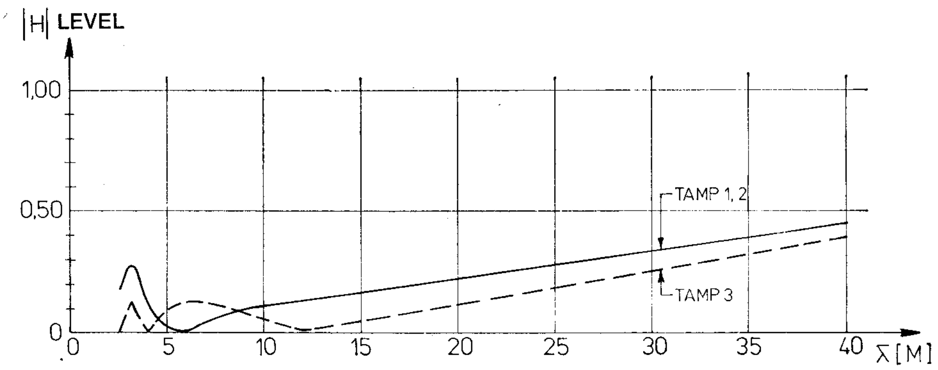

Fig. 5 Theoretical transfer functions for levelling

for lining, the theoretical transfer curves suggest rather a large improvement in vertical geometry. Especially in the waves below 20 m, this is not confirmed by the experimental results presented in Chapter 6.

4. TRACK RECORDING COACHES

The principle adopted for assessing the performance of maintenance machines is to record the track geometry before and after the maintenance operation. For this purpose, the French Mauzin car and the BR recording coach have been used. Their respective measuring systems are briefly outlined below.

The French Mauzin car measuring system is based on a mechanical transducing principle [7, 8]. The vertical profile is measured as the difference of a wheel displacement with respect to a reference frame composed of eight wheels. The mechanical displacements are directly plotted and are converted into an electrical signal, which is stored on magnetic tape. To obtain true displacements from these data, compensation for the transfer function, shown in figure 6 and normally referred to as recolouring, is necessary. Up to a wavelength of 10 m, the transfer is approximately equal to unity, and then diminishes rapidly. The technique adopted for the measurement of the lateral track irregularities (alignment) is a so-called three point system. In taking a 10 m base, the versine at the midpoint is recorded. The equation for the governing transfer functions reads :

$$H = 1 - \cos\frac{b\pi}{\lambda}$$

b = reference base = 10 m

λ = wavelength (4.1)

and is plotted on Figure 6. This measuring technique has the major drawback that information corresponding to wavelengths of $b/(2n)$ (n = 1, 2, ...) is not recorded. From a practical point of view, this means that wavelength information below 6 m is strongly mixed-up with noise and is therefore rather unreliable. This is also confirmed by the analysis results, where for alignment, the coherence normally shows a very low value at wavelengths below 6 m. For obtaining information about the actual lateral displacements, recolouring is inevitable because wave information at 10 m is overestimated by a factor of 2, while beyond 20 m the transfer function rapidly attenuates from unity to zero.

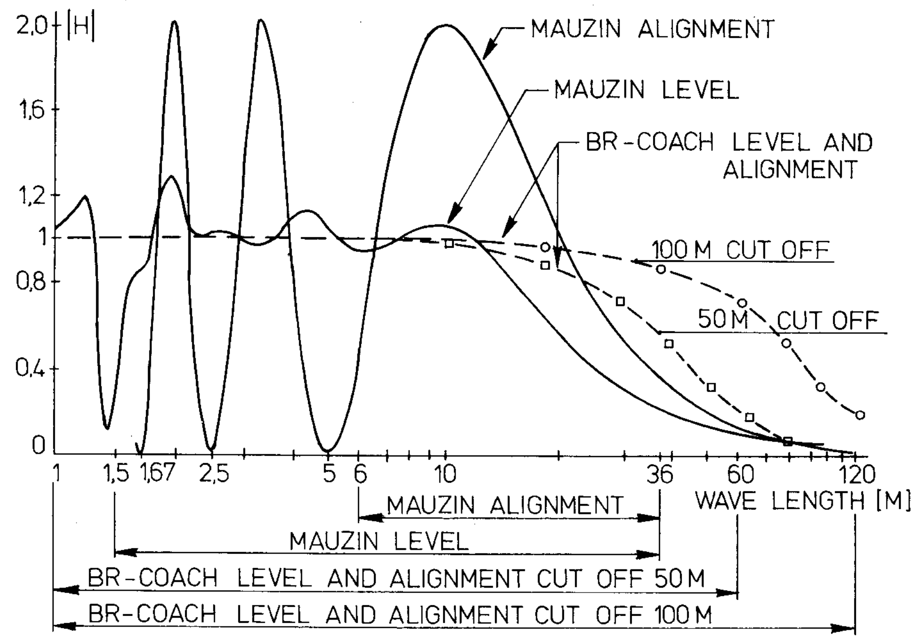

Fig. 6. Transfer functions of the Mauzin car and the BR recording coach

The BR high speed track recording coach measures the vertical profile, as is schematically illustrated in figure 7 [9, 10]. The accelerometer senses the vertical coach body motion, and this is integrated twice to give the displacement. By combining this with the suspension displacement, the required vertical profile can be obtained. The integrators are combined with high-pass filters, which carry out the dual function of stabilising the processing system and limiting the measuring bandwidth to accentuate those wavelengths that are important from a track quality viewpoint. The bandwidth is maintained at a

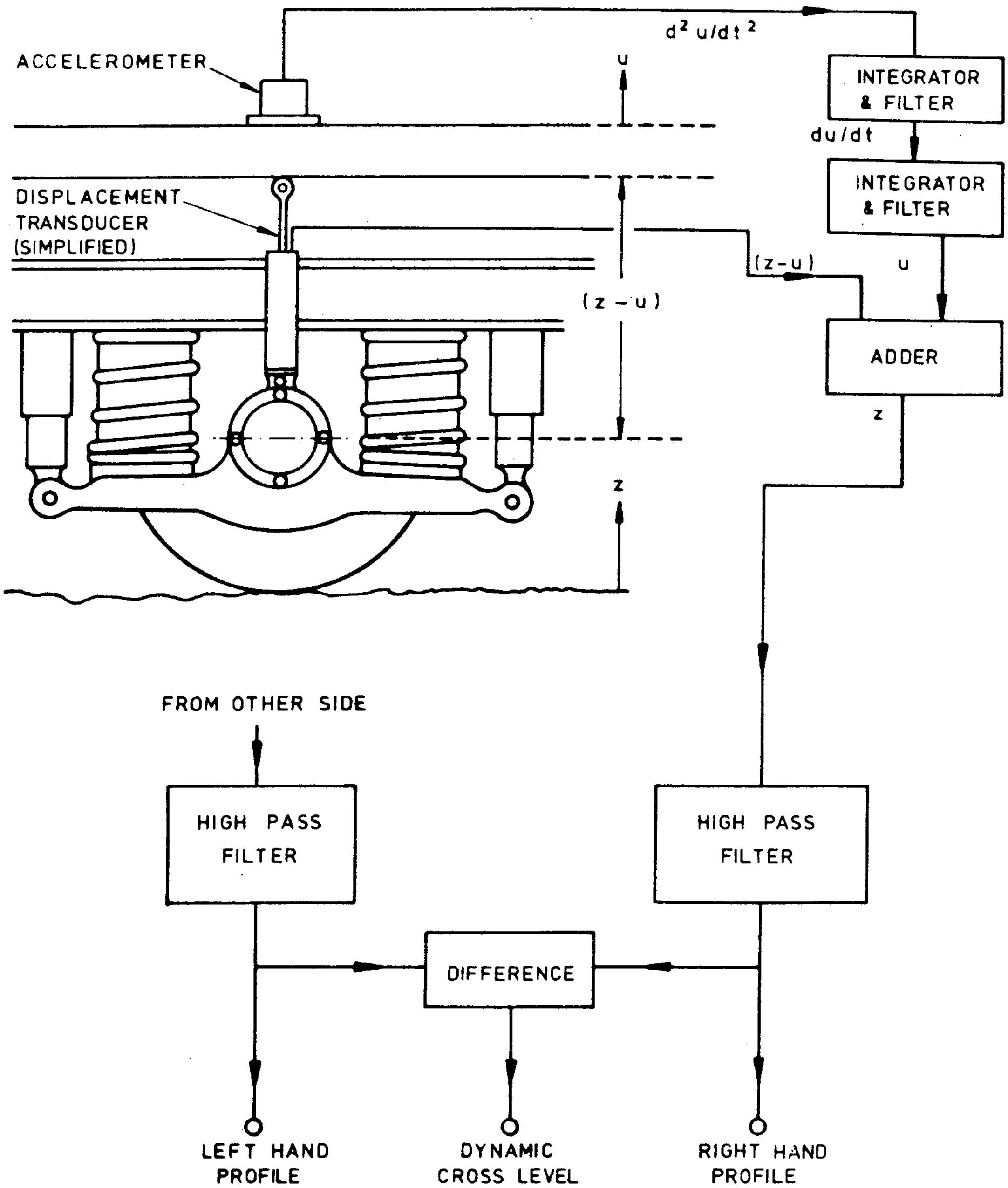

Fig. 7. Vertical profile system schematic BR recording car

constant spatial value by parametrically varying the filter cutt-off frequency as a function of the speed. The applied filter characteristic is shown in figure 6.

For the horizontal reference frame, a non-contacting optical system, sketched in figure 8 is used. Light projectors are mounted on the bogies and so arranged that a small area of each railhead is illuminated. The reflected illumination from the railhead is converted into an electrical (video) waveform by linescan cameras mounted in the floor of the vehicle directly above the illuminated parts of the rails. The illumination intensity will change rapidly at the gauge face, which can therefore be detected electrically by means of a threshold detector. The output from linescan cameras is principally a function of the relative position of the railhead and the roll of the vehicle. Since the roll effect is common to the scanners on each side of the vehicle, if the signals are subtracted this will then give the gauge.

To calculate alignment, some additional transducers are used. From lateral accelerometers, a measure of the lateral position of the coach can be determined by double integration. Bogie displacement transducers are used to derive a correction signal for the roll effect on the lateral accelerometer. Vertical accelerometers are employed to derive an angular acceleration signal to compensate for the roll component in the linescan camera signal. The

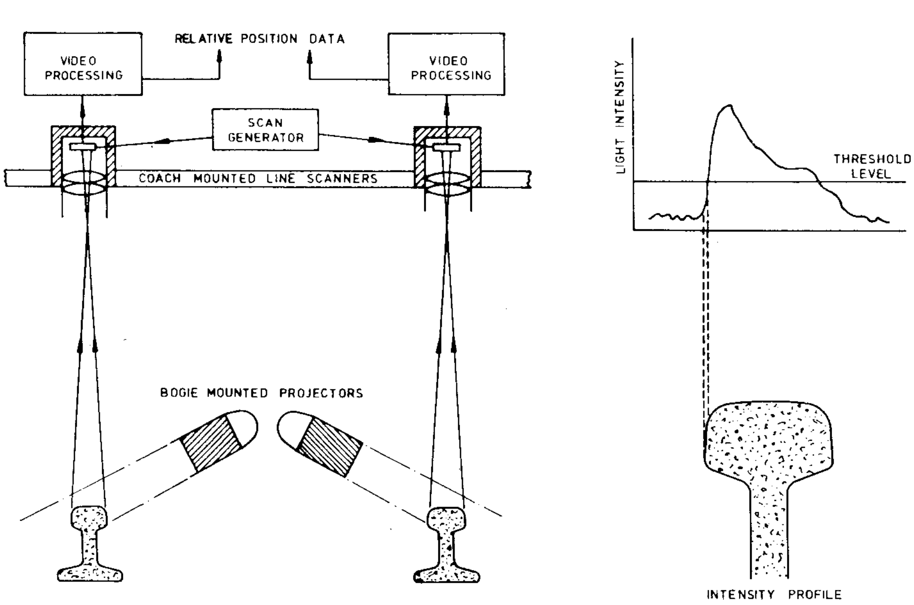

Fig. 8. Lateral sensing transducers BR recording car

alignment signal, which is substantially independent of the track curvature, as in the case of vertical profile, is filtered to conform to the system response shown in figure 6.

In figure 6 also the measuring range of the recording coaches is represented. The longest wavelength which can still be read from the output is determined by a transfer value of approximately 0.7 times the maximum transfer Hm without recolouring. This wavelength can be increased to correspond to a value equal to 0.2 Hm if recolouring, i.e. compensating for the transfer function, is carried out. For the Mauzin car, λ_{max} is about 35 m. In case of the acceleration principle, the speed serves as relative base and obviously any system-bandwidth can be set here. The measuring range of the BR system is given for a filter cut-off corresponding to 50 m and 100 m.

5. THE EVALUATION OF RECORDED DATA

During the coach measurements, the recorded information is stored on magnetic tape for subsequent processing on a computer. Basically, the evaluation of the test data consists of applying the theory of random data analysis [2, 11], briefly discussed hereafter.

The objective of the analysis is to determine the relationship between an input *x(t)*, representing the geometry before maintenance, and an output *y(t)* representing the position after the maintenance operation (Fig. 9). When the input function *x(t)* is Fourier transformed, the result can be expressed as

$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{-i 2\pi f t} dt \qquad -\infty < f < \infty \qquad (4.2)$$

and *y(t)* can be similarly established.

The cross-spectral density function between input and output follows from

$$S_{xy}(f) + \lim_{T \to \infty} \frac{1}{T} \bar{X}(f)\, Y(f) \qquad (4.3)$$

$\bar{X}(f)$ is the complex conjugate of $X(f)$

It is easy to show that Sxx (= Sx), the psd-function, is found by replacing *y* by *x*.

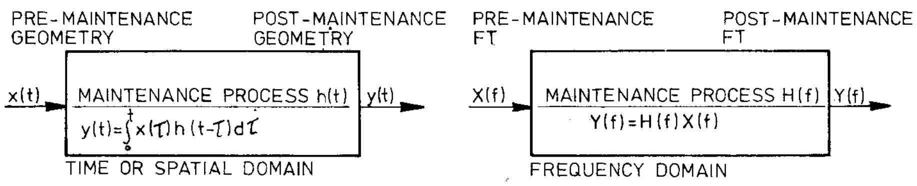

Fig. 9 Input - Output model for track maintenance

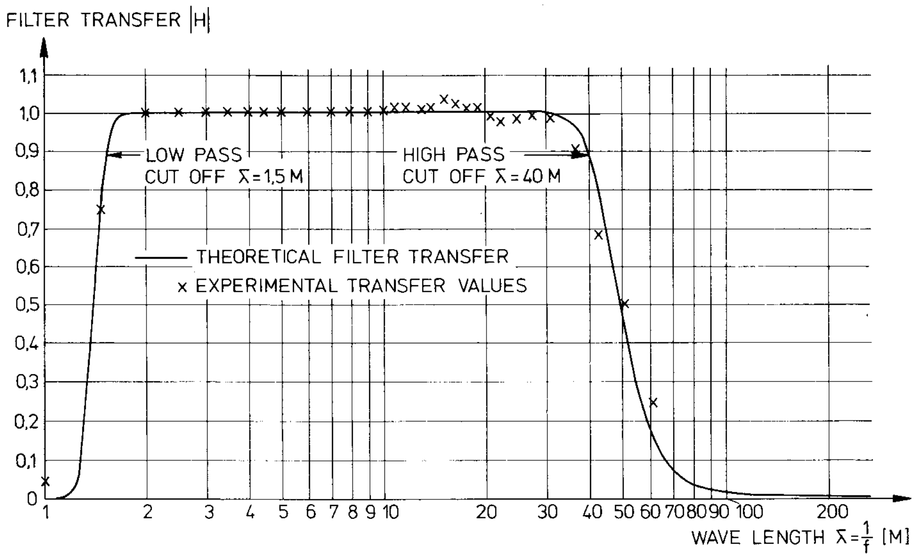

Fig. 10. 6th order digital Butterworth band filter

A very important property of power spectral density functions is that the area under the function is equal to the variance σ^2, so that:

$$\sigma_x{}^2 = \int_{-\infty}^{\infty} S_x(f)\,df = 2\int_0^{\infty} S_x(f)\,df = \int_0^{\infty} G_x(f)\,df \quad (4.4)$$

in which $G_x(f)$ is the one-sided power spectral density function. The cross-correlation function $Rxy(t)$ is defined by

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_0^T x(t)\,y(t+\tau)\,dt. \quad (4.5)$$

Sxy and Rxy are related by the Wiener-Khintchine equations

$$S_{xy}(f) = \int_{-\infty}^{\infty} R_{xy}(\tau)\,e^{-i2\pi f\tau}\,d\tau$$
$$R_{xy}(\tau) = \int_{-\infty}^{\infty} S_{xy}(f)\,e^{i2\pi f\tau}\,df \quad (4.6)$$

In the computer analysis, Rxy is calculated by transforming Sxy as this computation, using the Fast Fourier Transform (FFT) [12, 13], is much cheaper than the direct evaluation.

Now, the transfer function H follows from

$$|H(f)| = \sqrt{\frac{S_y(f)}{S_x(f)}}; \quad H(f) = \frac{S_{xy}(f)}{S_x(f)} \quad (4.7)$$

The coherence, giving the dependence of the compared data per frequency component, follows from the equation

$$\gamma_{xy}(f) = \frac{|S_{xy}(f)|}{\sqrt{S_x(f)\,S_y(f)}} \quad 0 \leq \gamma_{xy} \leq 1 \quad (4.8)$$

The overall correlation is calculated by enumerating the expression

$$\rho_{xy}(\tau) = \frac{R_{xy}(\tau)}{\sqrt{R_x(0)\cdot R_y(0)}} \quad -1 \leq \rho_{xy} \leq 1 \quad (4.9)$$

These expressions have been evaluated by digital methods.

The analog input, stored on the recording tape, is sampled at intervals of 0.5 m, thus resulting in a shortest significant wavelength of 1 m, according to the Nyquist theorem. The total number of samples per record has been fixed at $2^9 = 512$. A power of 2 is required by the FFT subroutine.

A record length of 250 m has been chosen firstly because of the limited storage capacity of the computer (PDP 11/20, core size 20 K) and secondly because of computational time, while also bearing in mind that the longest wavelength which can be derived from recording coaches (Mauzin) is about 40 m. The accuracy ε of the sample mean, based on

Actual improvement of alignement due to lining and tamping machines, expressed by transfer functions | H | estimated from Mauzin records.

Postrecordings taken after passage of ∼ 0.1 TG following maintenance.

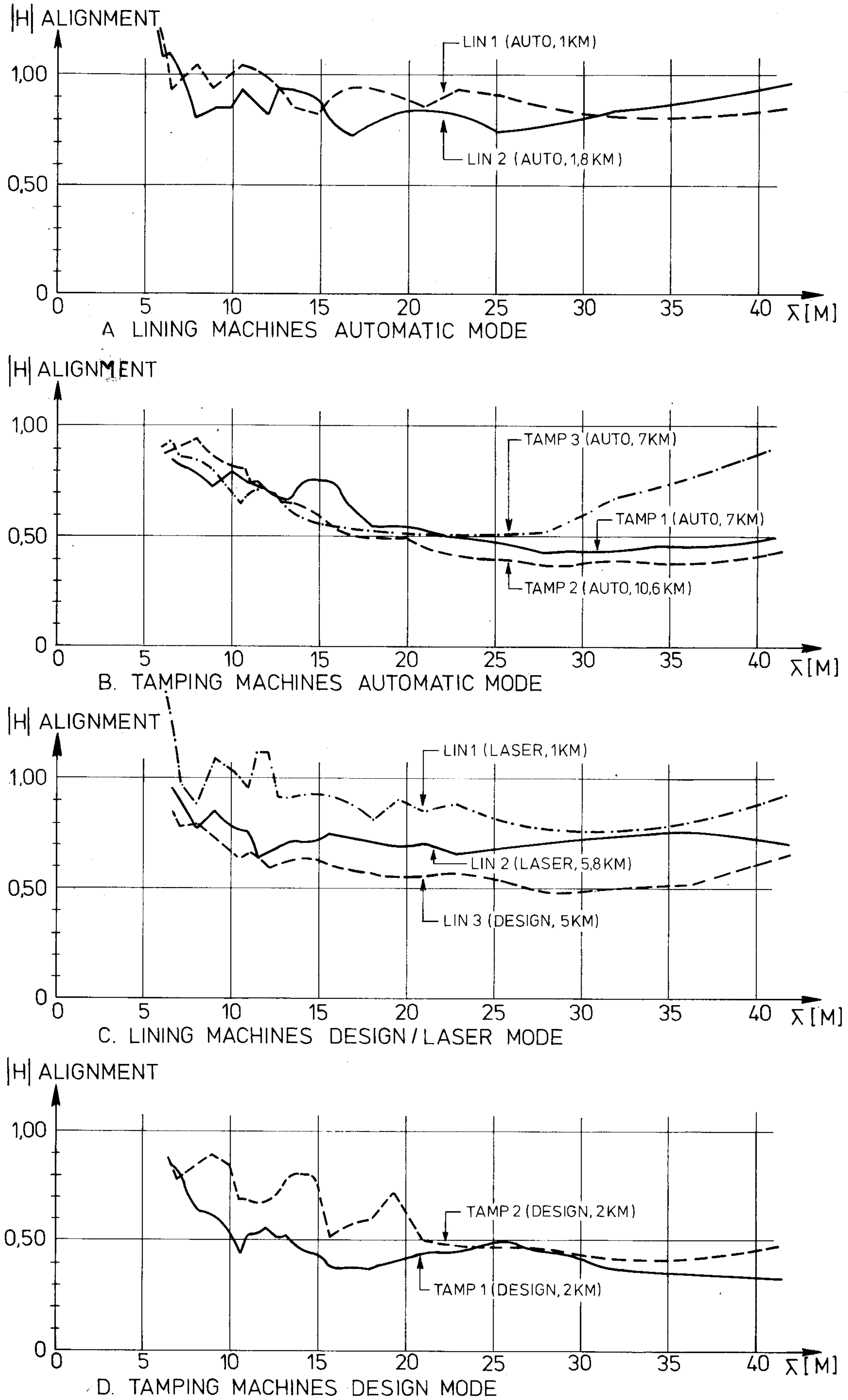

Fig. 11. Actual transfer functions for lining

a sampling number N = 2048, a $(1 - \alpha)$ confidence level of 0.975, and a pre-estimated standard deviation σ of 1 mm, is given by [11]

$$\varepsilon = \frac{t_{n;\,\alpha}\ \sigma}{\sqrt{N}} = 0.043 \text{ mm} \qquad (4.10)$$

where $t_{n};\ \alpha$ is the α percentage point of a Student t distribution.

Condensed information for the wave bands 0-5 m, 5-10 m, 10-20 m, and > 20 m is also calculated. These intervals are chosen such that the number of estimates per band, i.e. the degrees of freedom per interval, are approximately the same.

Before transforming the digitized data to the frequency domain, the records are filtered numerically [14], primarily to remove unwanted long waves as otherwise completely erroneous results could be obtained. This is necessary in particular for the analysis of the alignment signals and the evaluation of manually recorded data [2]. At present, a sixth-order Butterworth band filter [13, 15] is used, which has the advantage that the cut-off wavelengths can be chosen independently. An example of the filter shape is given in figure 10.

In order to compensate for the finite record length, each record is tapered using a cosine bounded window [6, 11].

The records are subsequently transformed to the frequency domain, using a FFT subroutine. Next, the records are recoloured with respect to the transfer function of the recording system, after which spectral density functions are calculated. To satisfy the reliability aspect, it is necessary to reduce the standard error by ensemble averaging and smoothing [6, 11]. The representative transfer functions can then be calculated, while the statistical reliability of the estimates is represented by coherence functions and the coefficient of correlation.

6. DISCUSSION OF THE TEST RESULTS

For a detailed account of the measuring results of the ORE-D117-test reference might be made to [3]. The presentation in this paper is restricted to a number of representative results which have been assembled in figures 11 and 12. The data processing and analysis have been carried out according to the previously discussed procedures. It should be emphasised that, due to the limitations of the Mauzin track recording coach, the estimated transfer values are only valid in the range of wave lengths between ~ 6 and ~ 40 m. The record length to which a particular estimate relates is also indicated in the figures. Such information is vital from the statistical reliability point of view: the results estimated over several kilometres can be considered as representative for the particular machine, whilst the estimates originating from a record of only 1 km possess a less general validity.

Lining

Strictly speaking, two different aspects of lining are distinguished here, namely, the machine type i.e. lining machine or tamping machine, and the mode of operation of the machine i.e. automatic mode or design/laser mode.

Actual improvement of level due to tamping machines, expressed by transfer functions | H | estimated from Mauzin records.

Postrecordings taken after passage of ~ 0.1 TG following tamping.

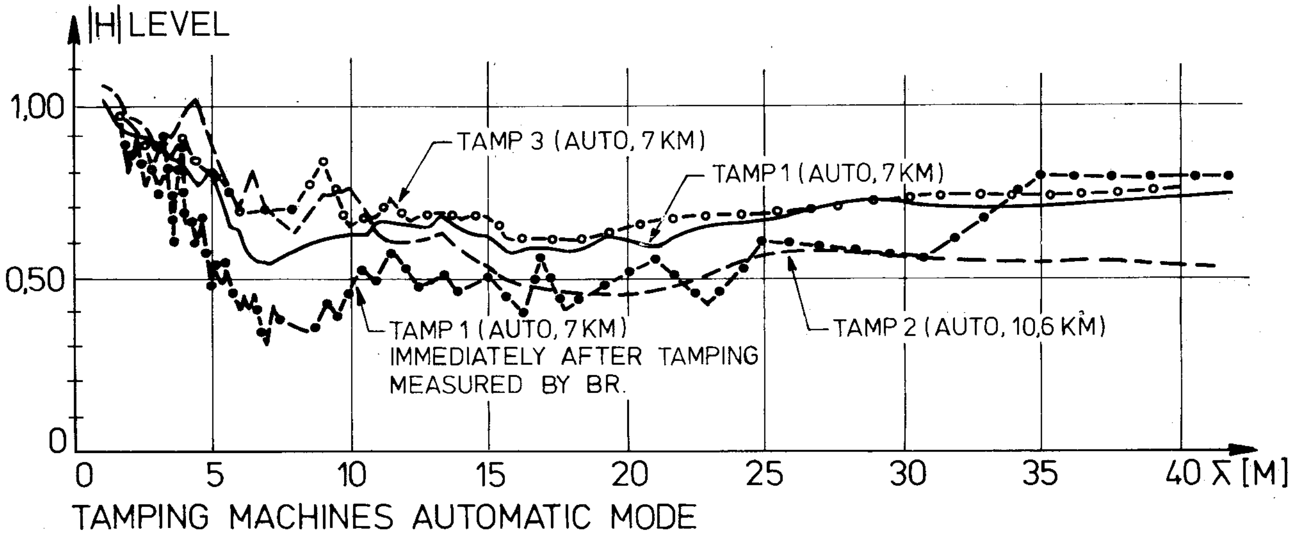

Fig. 12. Actual transfer functions for levelling

The lining results from the automatic mode are given in figure 11.A for lining machines and in figure 11.B for tamping machines. Obviously, both LIN 1 and LIN 2 (Fig. 11.A) exhibit rather poor results in the entire wave length range. The improvements in alignment attained by the TAMP 1 and TAMP 2 (Fig. 11.B) are quite similar and their performances are at any rate substantially better than those of the lining machines. The TAMP 3 is practically identical to the other tamping machines up to wave lengths of 25 m, but the waves beyond 25 m are less successfully reduced.

In figure 11.C the results of design lining and laser lining attained by different lining machines are displayed. In this case too, LIN 1, operated in the laser mode, furnishes poor results. The LIN 2 (laser mode) is better than the LIN 1, especially in correcting waves shorter than 30 m, but is worse than the LIN 3, operating according to a kind of design mode as outlined earlier. However, the performance of the tamping machines TAMP 1 and TAMP 2, used in the automatic mode, is much more favourable than the performance of the LIN 1 and LIN 2 in the laser mode, and is slightly better than the LIN 3 lining machine.

The graphs of figure 11.D show some measured transfer functions of design lining with tamping machines. Comparison with the graphs of figure 11.B reveals that with the TAMP 1 and TAMP 2 the lining results from automatic mode and design mode show little difference.

Levelling

Figure 12 shows some measured transfer functions for the vertical profile, relating to previously treated tamping machines operated in the automatic mode. Here it can be seen that all the machines are very similar. In this case too, no advantages can be seen for working in a design mode used for rectifying the level [2].

For those sections on which maintenance has been applied, coherence functions have been computed according to (4.8), showing in general a behaviour similar to the absolute value of the transfer function $|H|$, as is illustrated in figure 13. Obviously, the maintenance operation not only results in a reduction of the psd-function but is also responsible for a drop in coherence and correlation. Apparently, the coherence is reduced proportional to the value of $|H|$. From this observation it is clear that the maintenance operation is governed by non-linear factors, which phenomonon is observed throughout the test results.

7. CONCLUSIONS AND RECOMMENDATIONS

The performance of the LIN 1 lining machine exhibits poor results in all wave bands for both automatic mode and laser mode. The LIN 2 furnishes poor results in the automatic mode but the improvements found with the laser mode are somewhat better. The improvements found with the LIN 3, operating according to a kind of design mode, are the best as far as lining machines are concerned. The most favourable lining results are achieved however by tamping machines. These machines show an almost identical performance for lining waves in the range between 5 and 25 m. The performance of TAMP 3 is worse for waves beyond 25 m.

Also for levelling, the results achieved by the different machines are rather similar.

From recent tests on track deterioration [2,3], it has been found that the vertical geometry deteriorates much more rapidly than the alignment. Consequently, in this respect no need exists for separate lining between two successive tamping operations.

Transfer and coherence calculated from data recorded by the Mauzin car.

Intermediate maintenance by a TAMP 3 tamper. Record length 7 km.

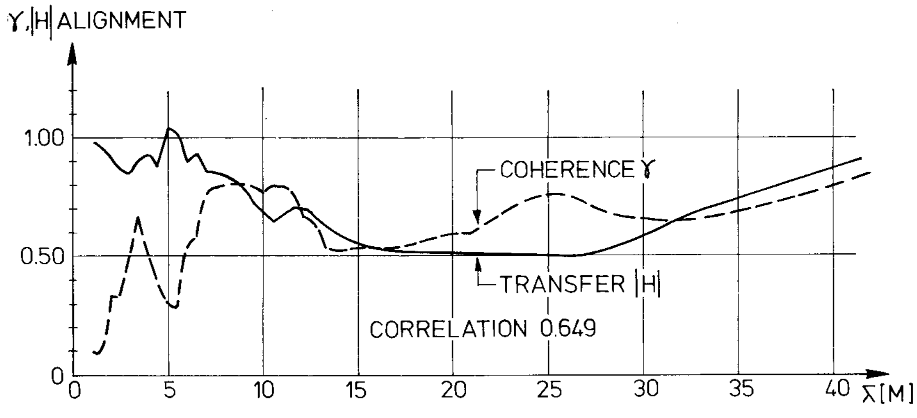

Fig. 13. Drop in coherence due to maintenance

On the basis of these findings, substantiated by the relatively poor performance of lining machines, the application of lining machines should be strongly dissuaded.

With both tamping machines of figure 11.D the results from the automatic mode and the design mode show little difference either as regards lining or tamping. As, theoretically, the design mode should be much more effective, especially at correcting long-wave-lengths, the methods of pre-recording the track and controlling the machine should be investigated and improved to give consistent results.

Throughout the results, a reduction in coherence and correlation more or less proportional to the absolute value of the transfer function is observed. This points towards significant non-linearities in the system relating the geometry before and after maintenance. Another remarkable feature, closely related to the previous one, is the large discrepancy between theoretical and actual transfer values in the wave band from 5 - 20 m, both for lining and levellling. The latter reveals in fact, that only about half the potential available for improving the track geometry is used, the other half being lost on account of permanent deformations of the ballast as a result of reaction forces during the maintenance operation. Machine tolerances also adversely affect the result [2].

Further research will be required, especially with respect to the details of the maintenance operation, to further investigate the track parameters causing the observed discrepancies [2].

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