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STRAIT STRAIGHTENING OF RAIL WELDS BY AUTOMATED ITERATION TECHNIQUES

IS 8.3

Innovative straightening of rail welds

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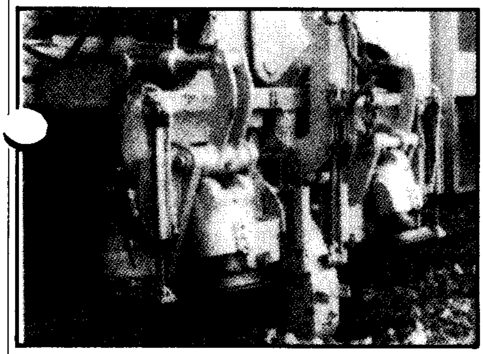
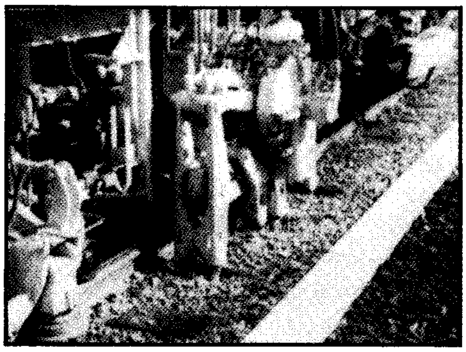
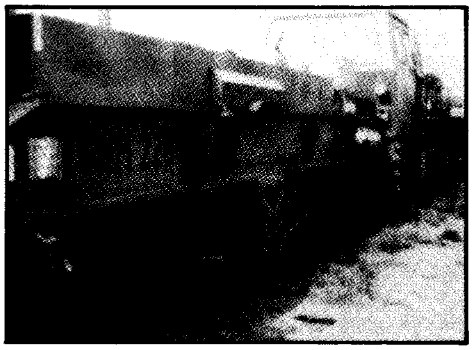


Straightening



Tamping



Grinding

This article describes a rail weld straightening method developed by NS and its practical application. The straightening method is based, in principle, on the stagewise loading and unloading of a weld according to the mathematically known Newton-Raphson iteration technique, designated as STRAIT (STraightening of Rail welds by Automated Iteration Techniques). The main advantage of this method is that neither the characteristics of the materials, nor their geometric properties need to be known. Particularly the characteristics of the materials in the vicinity of welds often display a high amount of scatter.

The STRAIT system has recently been installed on the stationary ROBEL rail straightening machine at the NS Rail Welding Depot. The mobile variant has lately been used on the Mailiner VI tamping machine.

This article is mainly focused on the mobile machine and on the experience recently collected in correcting poor flash butt welds on the Schiphol line. The stationary machine at the NS Rail Welding Depot will be discussed in a separate article.

One of the most important conclusions gathered from the straightening jobs on the Schiphol line is that the sequence of the various maintenance operations and their way of implementation are of essential importance. The following procedure is recommended: Straightening according to the STRAIT system, with an over lift of the weld of some tenths of a millimeter, followed by immediate tamping of the four sleepers on either side of the weld and grinding of the weld one day later by a rail grinding car (for instance the GWM 220) and, finally, on the occasion of a track renewal, grinding the entire track twice in succession.

continued

The correction of welds in the track according to this procedure has led to excellent results, and, after a traffic load of 2 million tonnes there has been no sign of any deterioration of the welds in question.

1. Dynamic response at welds

Practice has shown that even a relatively small number of geometric deviations of welds may lead to huge dynamic forces during wheel passages. This subject was referred to in earlier publications [1] and [2].

As far as the problems on the subject of thermit welding, and, to a smaller degree, of flash butt welding, are concerned, the report compiled by the ORE D 148 Specialists Committee is most illustrative. The report shows, inter alia, that the standard value of the vertical deviation, for which 0.3 mm on a 1 m base in adopted by most Railways, is hardly ever achieved.

Both practical measurements and theoretical studies [3] have, however, shown that the non-adherence to this limit value will, very soon, lead to problems with reference to track maintenance. These maintenance problems have also manifested themselves very clearly on the Schiphol line, where the flash butt welds often exceeded the above standard to an extremely high extent.

Figure 1 shows a striking example of two flash butt welds, where the dynamic wheel load was measured. These values were divided by the static wheel load, so as to obtain the dimensionless amplification coefficient. This proved to be very high: for weld 1, with a dip of 3 mm on a 3 m base length, the coefficient is about 2.5 at 130 km/h, while at weld 2, with a dip of 5 mm on a base length of 3 m, an amplification of more than 4 has been found.

Axle box acceleration measurements, recently performed by the NS, have shown that in the case of dipped welds of triangular shape without step, the acceleration amplitude is linear as a function of the irregularity. Figure 2 shows the results of a regression analysis made on the basis of these measuring data.

The theoretical calculation made in [3] leads to an identical linear behaviour. However, the behaviour of steps is quite different and this study, too, confirms once more the very aggressive nature of this defect, which, however small, is always unacceptable.

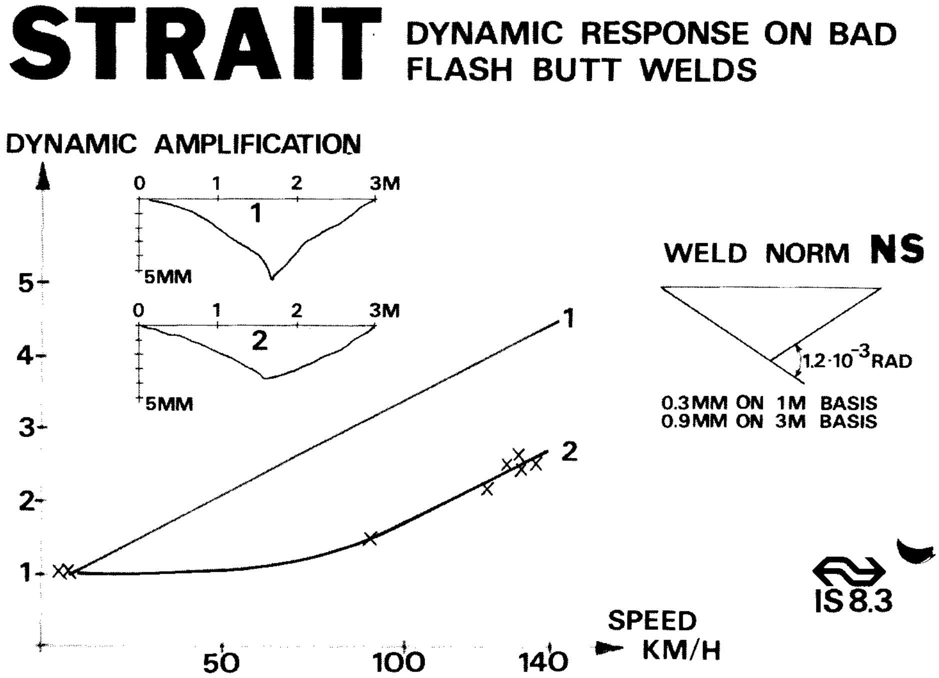
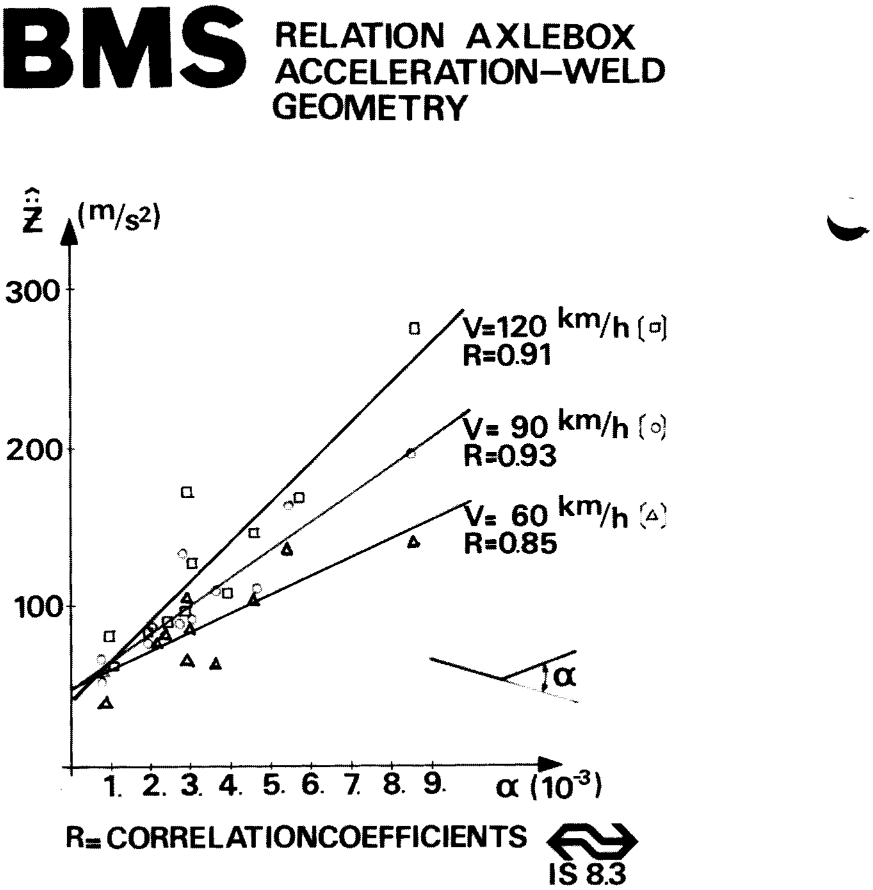


Fig. 1. Dynamic response at the site of poor welds

Fig. 2. Amplitude of axle box acceleration versus weld dip



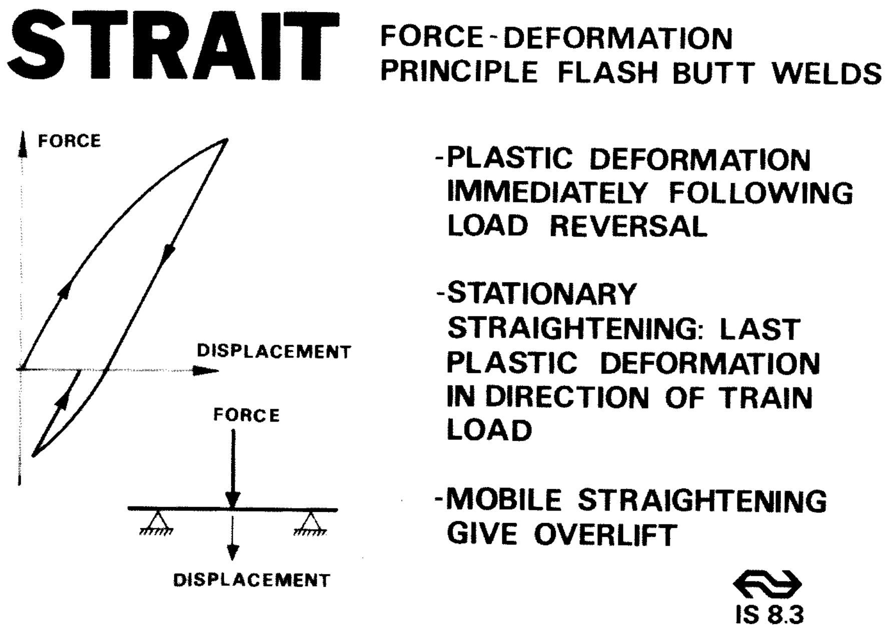
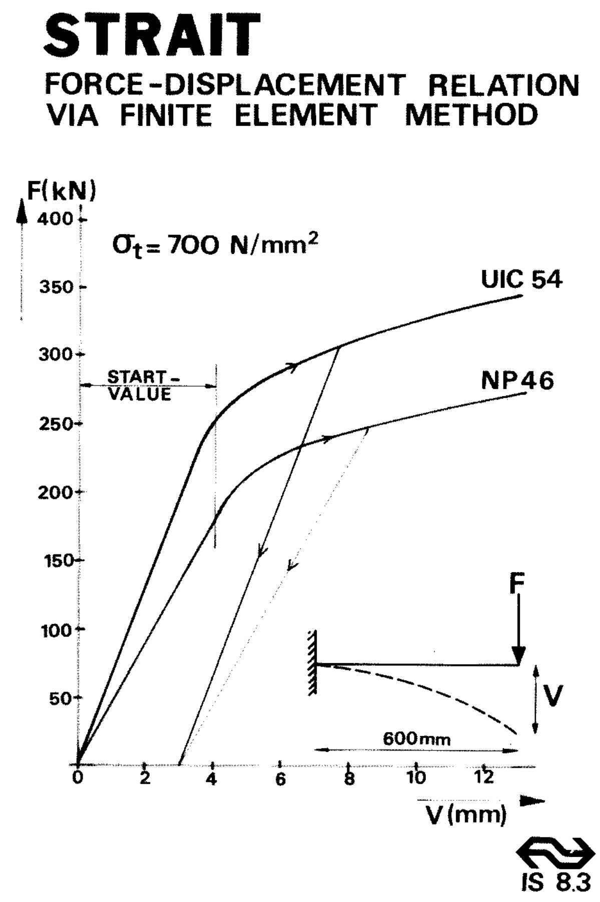


Fig. 3. Principle of force deformation relationship for fusion welds

Fig. 4. Force deformation analysis through the finite element method



2. Weld correction

Before taking a final decision as to the straightening principle to be adopted for fusion welding, the Research Department of the NS (CTO) has carried out some laboratory tests, in order to determine the relationship between force and deformation. This relationship is, in principle, similar to that illustrated in figure 3. The structural changes during the welding process in the heat affected zone lead to a relatively high amount of scatter in the properties of the material. This also applies, therefore, to the relationship between force and deformation; outlined in figure 3. As mentioned in [1], the last plastic deformation should, by preference, occur in the direction of the train load, so as to create the largest possible elastic range. On the recently completed stationary automatic rail straightening machine at the Rail Weld Depot of the NS, the final shape of the weld is, in fact, realized in this way. In case of the mobile STRAIT machine, this was not possible, so that on that occasion, an over lift of some tenths of a millimeter is given.

Simultaneously with the laboratory tests, the plastic behaviour of welds was subjected to a theoretical examination, having recourse to a model composed of finite elements [6].

The results obtained in the case of the UIC 54 and NP 46 rail profiles, both having a tensile strength of 700 N/mm², are given in Figure 4. This theoretical simulation aimed, above all, at examining the influence of the measuring principle, based on a displacement measurement at 0.10 m on either side of the weld relative to a base length of 1.20 m and at estimating the maximum values to be anticipated under practical conditions.

It became apparent that for a base length of 1.20 m and a position of the measuring transducers 0.10 m away from the center of the weld, as experimentally determined from numerous measurements using a 3 m straight edge, the plastic behaviour lent itself very well to be described during the theoretical simulation.

3. The STRAIT principle

The strongly non-linear relationship between force and deformation, shown in figures 3 and 4, together with the high amount of scatter of the measuring constants to be anticipated, both in describing the elastic behaviour of the weld, led to the assumption that a simple straightening principle, according to which the weld is pressed at the correct value by one single load step, would not be possible, nor did the adoption of all kinds of profile data and material properties seem of much practical use. Therefore, a method utterly independent of profile and material properties was studied, which led to the adoption of an iterative straightening principle, designated as STRAIT

continued

(STraightening of Rail welds by Automated Iteration Techniques). This principle, elaborately described in [1], is once more outlined in figure 5 for the mobile system, installed on the Mainliner VI tamping machine. As the structure to be loaded in the mobile situation is not only composed of a rail, but also of sleepers embedded in the ballast and suspended from the rail, it would appear, in practice, that the very first iteration stroke will result, somehow, in a small residual «settlement».

As initial value, a displacement of 4 mm is taken, which, according to the data in figure 4, must lie just at the limit of the elastic range of the rail. Subsequently, the load is reduced to zero. The difference with the maximum overlift admissible for the weld (a value of 0.5 mm has been adopted so far) is added to the earlier mentioned initial 4 mm value, after which the weld is deformed again over this increased range.

This process converges very quickly to the desired ultimate value, at which usually, not more than 2 to 3 iterations prove to be necessary.

It is of essential importance for the sleepers surrounding the weld to be tamped immediately after this straightening operation. For this, NS retains 4 sleepers on either side of the weld.

Subsequently, the surplus material, and of course above all, the steps must be eliminated by grinding. So as to allow possible plastic deformations to be developed, which have not been found so far, and also for considerations connected with planning technology, grinding is done after one day's train traffic, i.e. during the next night. The grinding methods applied by NS and the experience collected on the subject are described in Chapters 5 en 6.

4. Realisation mobile machine

NS have entrusted Plasser & Theurer with the installation of the STRAIT principle developed by NS on the type 07-16 Mainliner VI tamping machine. The design of the hydraulic straightening device with the corresponding measuring system and also the electronic control unit have been designed and implemented by Plasser & Theurer on the basis of NS specifications.

Figure 6 contains a photograph of the hydraulic straightening device, composed of a block and fitted on the extremities with a hydraulic cylinder, with a hook in the center.

After the hook has been swung under the rail foot, for which purpose some ballast has to be removed before, the load is applied by means of the two cylinders. Together with the hook they constitute a three-point bending system. The bending mechanism is controlled on the basis of two displacement transducers, linked with a measuring frame of 1.20 m length. The principle is illustrated in figure 7.

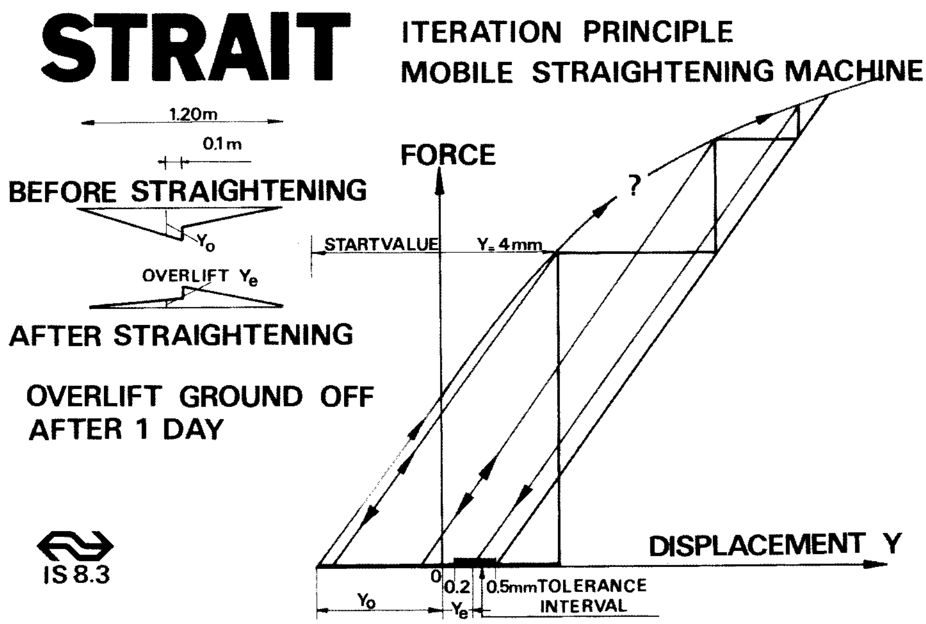


Fig. 5. STRAIT iteration principle for the mobile machine

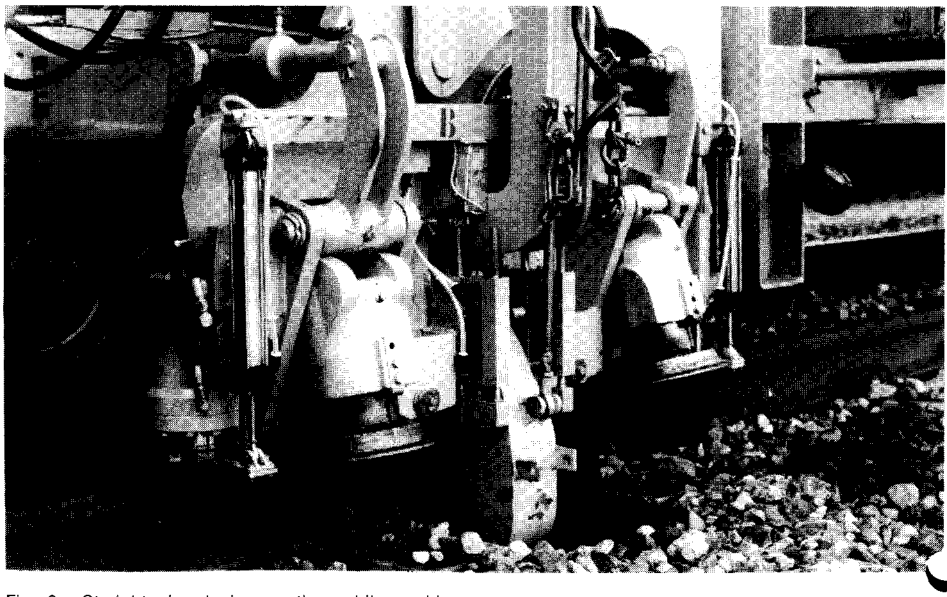
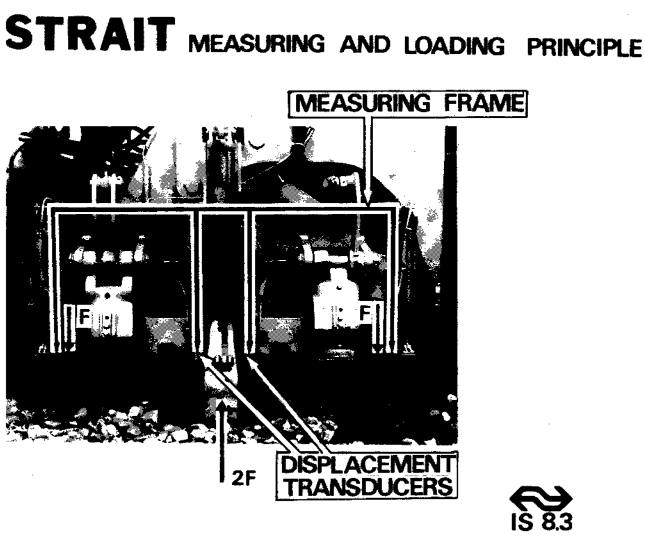
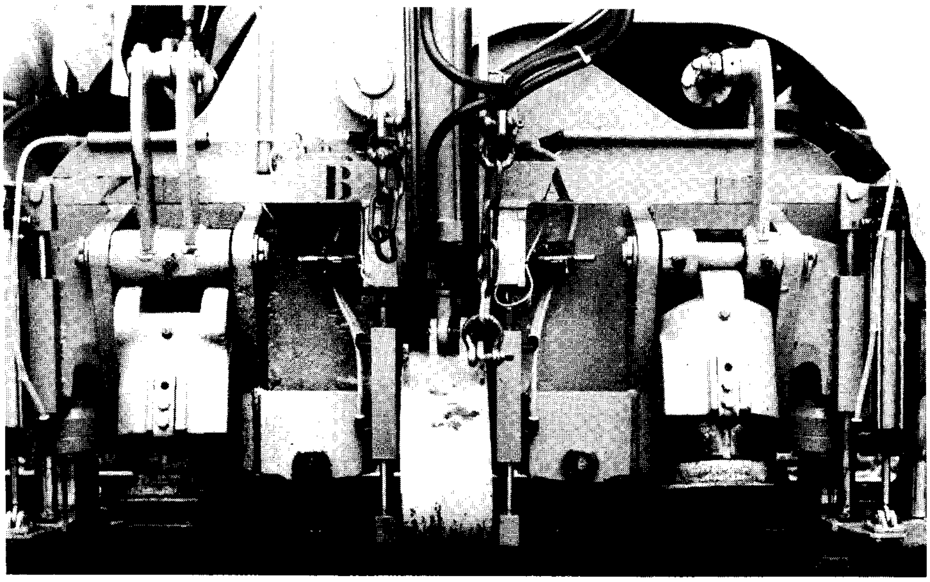


Fig. 6. Straightening devices on the mobile machine

Fig. 7 Measuring and loading principle

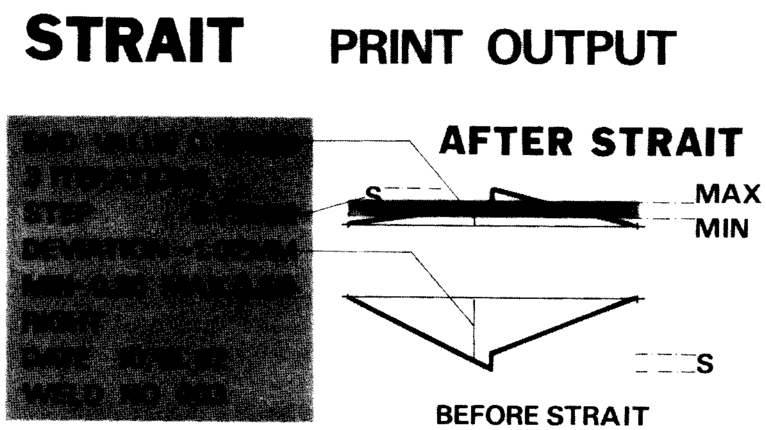




8. Calibration of measuring instruments

Fig. 9 STRAIT control unit

Fig. 10. Print output



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The difference between the transducers furnishes the size of the step, which is an essential piece of information on behalf of the grinding process to be made later on, while the transducer with the initially highest displacement in terms of absolute values being used for the control of the iteration process.

Before starting on the actual straightening process, the measuring system is calibrated. For this purpose a straight edge, as shown in figure 8, is fixed to the measuring frame. The transducers should now indicate a value of about 0.04 mm, which corresponds to the elastic displacement of the straight edge under the load of the transducers, the latter being pneumatically pressed down with a force of about 100 N.

At the front of the control unit depicted in figure 9, there are four bolts for the adjustment of the transducers. The experience collected hitherto shows that a single calibration, limited to once a night, is sufficient. This is to be done before the start of the activities.

The operation of the STRAIT system is extremely simple and is fully effected in the cab. It will only be necessary to remove some ballast beforehand, so as to enable the hook to be swung under the rail. NS does this in the daytime. An additional important advantage is that the fastening devices can be left in place.

The hook is swung pneumatically under the rail foot. A safety device controlled by terminal switches prevents the start of the bending operation before the hook is accommodated at the right place. The machine can only be moved on when the hook has been pushed up.

The minimum pressure on the straightening cylinders is 8 bar, which corresponds to a force less than the dead weight of the block. This means that the effective force equals zero at the end of each iteration step.

After the system has been put under pressure and the keys LEFT/RIGHT and AUTO have been pressed, the straightening process is started by simply pressing the key START/STOP, upon which the rest of the process is completed fully automatically. For experimental purposes, the system has been designed such, that with the key MANUAL engaged, the machine will stop, after each iteration step, until the key START/STOP is pressed again.

If, at the start of the process, it becomes apparent that the weld has a positive hump and thus an overlift, the straightening process is automatically discontinued.

The system has been fitted with a printer, on which all the relevant data are printed out. Figure 10 shows an example of this output..

5. The Plasser GWM 220 rail grinding car

In the middle of 1982, NS carried out a number of tests with the GWM 220 car.

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The object of these tests was to examine the suitability of this car for selective grinding of welds in track. Furthermore, these tests should answer the question whether the grinding principle applied on the GWM 220 would also be suitable for an automatic stationary grinding machine on behalf of the Rail Welding Depot. For this study, approximately 30 flash butt welds in NP 46 90 B rails in the quality new and used were made. They contained ramps and steps of various sizes. After installation in a marshalling yard, these welds were ground with the GWM 220. For this purpose, the machine was run at approximately zero speed visa versa over the weld, during which the stones, mounted in a frame of about 2 m length, ground the weld. The grinding unit is illustrated in figure 11.

A characteristic flash butt weld, as may be anticipated after welding and straightening at the Rail Welding Depot, is shown in figure 12. The welding burr, clearly discernible in the recording prior to grinding, is removed by the GWM 220 in about half a minute.

After regrinding for another 1 1/2 minutes, the condition shown in figure 12 is obtained. Under normal conditions, the grinding time of 2 minutes, required for this example, proved to be sufficient in all cases.

A somewhat less usual situation is encountered in the case of the weld shown in figure 13, which has a step of 1 mm. The result achieved with the Plasser GWM 220 car in this case after a grinding time of 6 minutes is, however, satisfactory in every respect. In the case of the present production process it would certainly be necessary to cut out a spot containing such a grave defect. However, the GWM 220 proves to be fully capable of dealing with it.

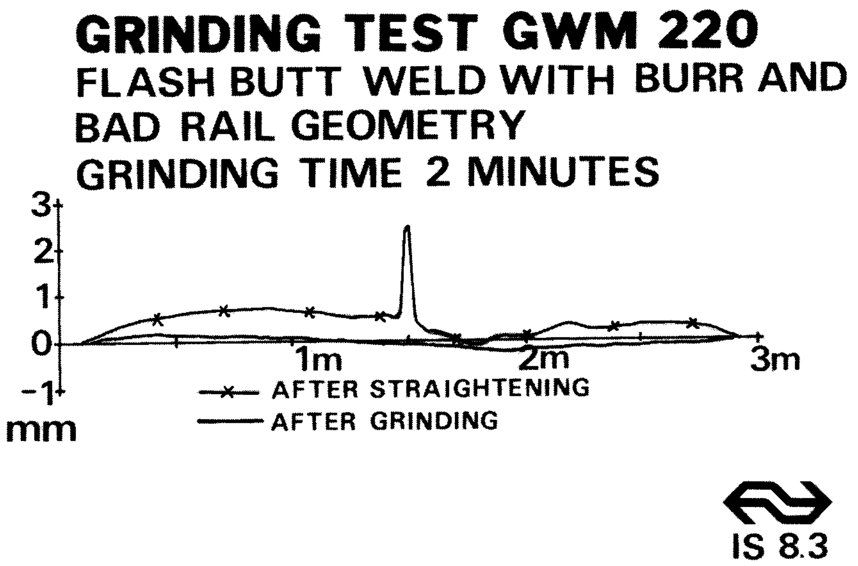


Fig. 12. Grinding test with GWM 220 on a characteristic flash butt weld

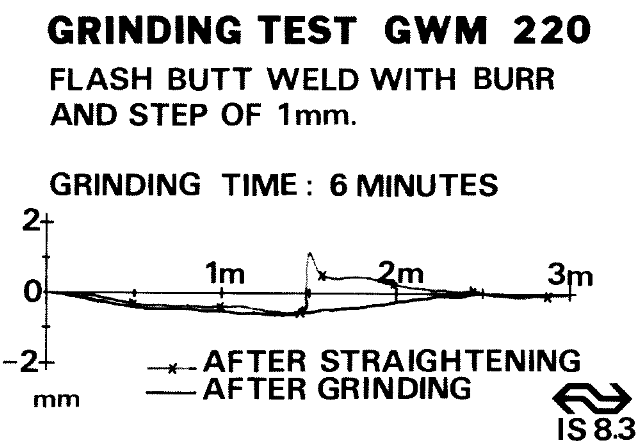
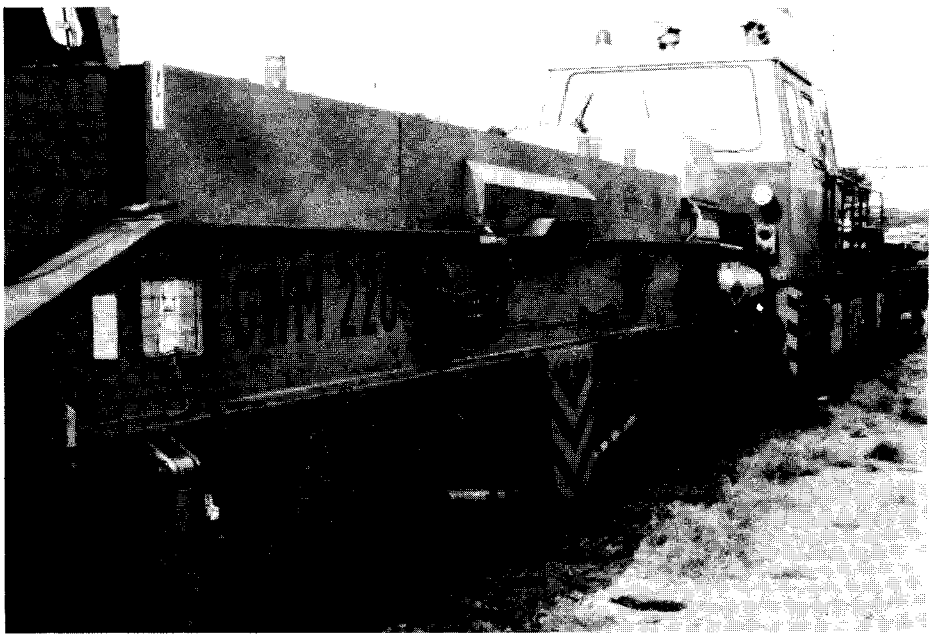


Fig. 13. Grinding test with GWM 220 on a flash butt weld containing a step of 1 mm

Fig. 11. Plasser GWM 220 grinding unit



These results have induced NS to use the GWM 220 in combination with the STRAIT system for the correction of flash butt welds on the Schiphol line. As will be shown in the next chapter, this work method leads to excellent results.

6. Recent experience

For some time past, NS have acquired the necessary experience on the straightening of welds. Before the introduction of the STRAIT system, the welds were straightened by means of hand jacks, for example made by Permaquip or by heat treatment.

In most cases, the results of the two methods are rather disappointing in practice because, in the absence of good measuring instruments, the processes can hardly be kept under control and also because tamping of the sleepers around the weld by means of hand tampers is not fully effective. Figure 14 shows an example of a weld straightened by means of hand tools. After a traffic load of about 1.5 million tonnes, the weld appears to have sagged

STRAIT OPERATIONAL SEQUENCE
FOR INTRACK STRAIGHTENING

1. STRAIGHTENING	MAINLINER VI STRAIT OVERLIFT 0.2 - 0.5 mm
2. TAMPING	MAINLINER VI 8 SLEEPERS
3. GRINDING	PLASSER GWM 220 GRINDING TIME ± 2 MINUTES

PRODUCTION MAINLINER VI (1+2) AND GWM 220 (3) ± 15 WELDS PER HOUR

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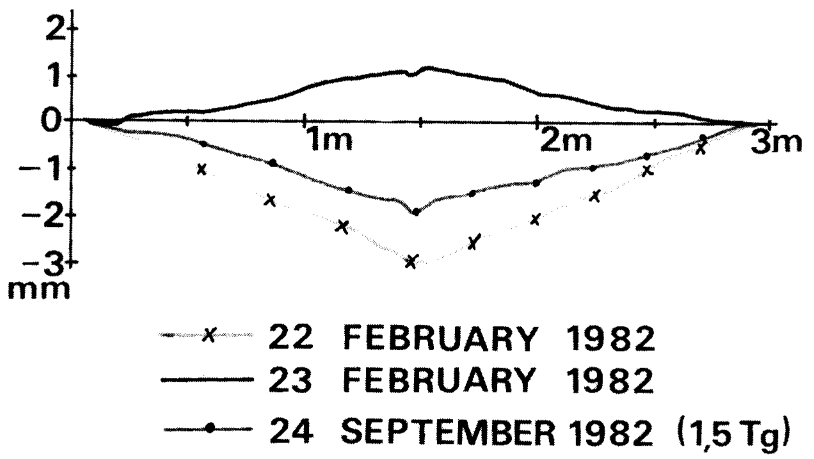
Fig. 15. Work sequence in straitghtening welds in the track

Fig. 14. Deterioration due to inadequate tamping of sleepers

STRAIGHTENING WITH MANUAL EQUIPMENT

DETERIORATION DUE TO INSUFFICIENT TAMPING



again to its previous level.
The corrective grinding of welds by means of hand tools has not been found very effective either in the practical NS experience. A great number of measurements with the 3 m straight edge has shown that the result remains limited to the elimination of burrs; it is hardly possible to obtain a correct weld profile by manuel grinding.

During all the straightening operations it appeared again and again, that a successful outcome fully depends on the accuracy, i.e. the possibility of keeping the process under control and the nature of the procedure applied. The sequence ideal in the experience of the NS, namely straightening, tamping and grinding, is shown in figure 15.

It stands to reason that the crucial point consists in finding an answer to the question whether the result is durable as a function of time or rather of the tonnage borne. So far, the NS have corrected some hundreds of welds on the Schiphol line according to the sequence outlined in figure 15. Many records have been taken with the 3 m straight edge prior to and after the operation, so as to obtain an insight into the effectiveness and durability of the result. The results hitherto on the Schiphol line, though bearing on low traffic loads, with axle loads of 13-14 tonnes may yet be considered very positive.

As far as durability is concerned, not any deterioration could be observed after a traffic load of about 2 million tonnes. Figures 16 and 17 contain some examples on the subject. The weld illustrated in figure 16 showed an irregularity of about 4 mm at first. After straightening, tamping and grinding, it was found to be fully eliminated and this situation persisted after a traffic load of about 2 million tonnes. The same pertains to the weld with the step, shown in figure 17. Such a geometric defect would, in the past, certainly have required the elimination of the affected spot by cutting it out. It can now be restored to a perfect weld.

All the straightened welds hitherto on the Schiphol line have recently been subjected to ultrasonic testing, during which no defects were observed.

In correcting welds, one should be well conscious of the fact that straightening reduces the defects from millimetres to tenths of millimetres and that corrective grinding raises the quality once more by another order of magnitude. However, steps can only be eliminated by grinding. Also in view of the aggressive character of this type of defect, grinding is an essential and even indispensable part of weld correction. This is also very clearly demonstrated in the records shown in figure 18, made by the French track recording car, prior to and after the treatment of welds on the Schiphol line. Figure 18 shows the longitudinal level of the track section between Leiden and Schiphol between km.p. 20 000-24 000. At those places where only the STRAIT system was used, the improvement was

continued

only slight, mainly due to the presence of steps. The areas where the welds were ground after the STRAIT process, with the GWM 220, show a very pronounced improvement. The best results are, however, achieved by additionally grinding the whole track twice. The level obtained in this way is virtually perfect.

The financial economic section of the Permanent Way Department has calculated the cost per weld, when made according to the work method in figure 15. On basis of the 1982 price level and an effective possession time of 3 hours, it is found to be approximately DFL 240, which corresponds to about 75 % of the cost of a thermit weld.

If the same straightening/grinding operation is carried out by the Rail Welding Depot, the additional cost per weld, as a result of the automation of the existing straightening press and the installation of a stationary grinding machine, will amount to about DFL 25 (1982 price level). This corresponds 8 % of the cost of a thermit weld and to 13 % of that of a flash butt weld.

7. Final remarks

The newly introduced STRAIT system, in combination with the GWM 220 rail grinding car, enables the geometry of poor flash butt and thermit welds to be restored to virtually ideal values. With a view to steps and battered rail ends, this result can only be achieved by making use of a good rail grinding car, such as for instance the GWM 220.

Measurements on the Schiphol line using the French Mauzin car have shown that a track containing very poor welds, manifesting themselves as in the case of a worn fishplated track, can be restored to a track with almost perfect geometry.

Meanwhile, NS have installed the STRAIT principle on a stationary straightening machine at the Rail Weld Depot. In view of the good experience, NS now contemplate adding an automatic stationary grinding machine derived from the GWM 220 to the Rail Welding Depot. Continuation of the operations with the mobile STRAIT system, installed on the Mainliner VI tamping machine, in combination with the GWM 220 grinding car, is considered very desirable. For this specific purpose, NS contemplate purchasing a GWM 220. The use to be made of this mobile straightening/grinding assembly is explained in Figure 19.

These activities will mainly be focused on track renewals. Once the stationary straightening/grinding assembly for the treatment of flash butt welds has become operative, the mobile combination can be used primarily for renewals, i.e. for the straightening and grinding of thermit welds and also for grinding the whole track. The hourly capacity is about 15 welds (straightening and grinding) plus grinding a

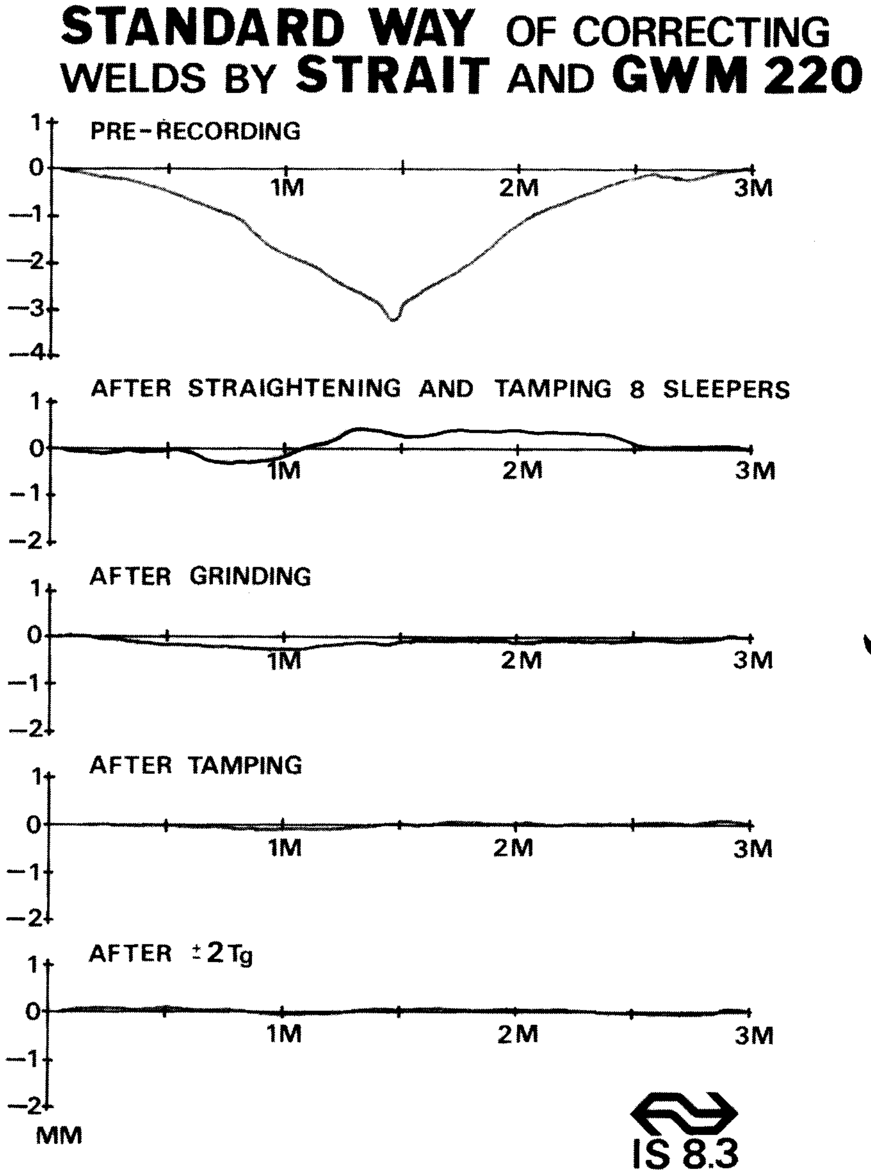


Fig. 16. Durability after dip correction

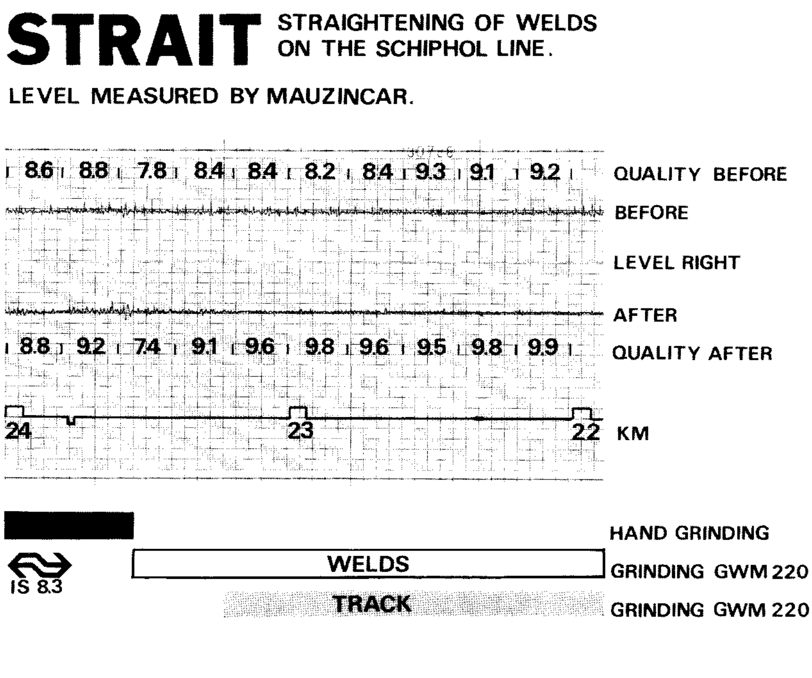


Fig. 18. Mauzin records prior to and after straightening of welds on the Schiphol line

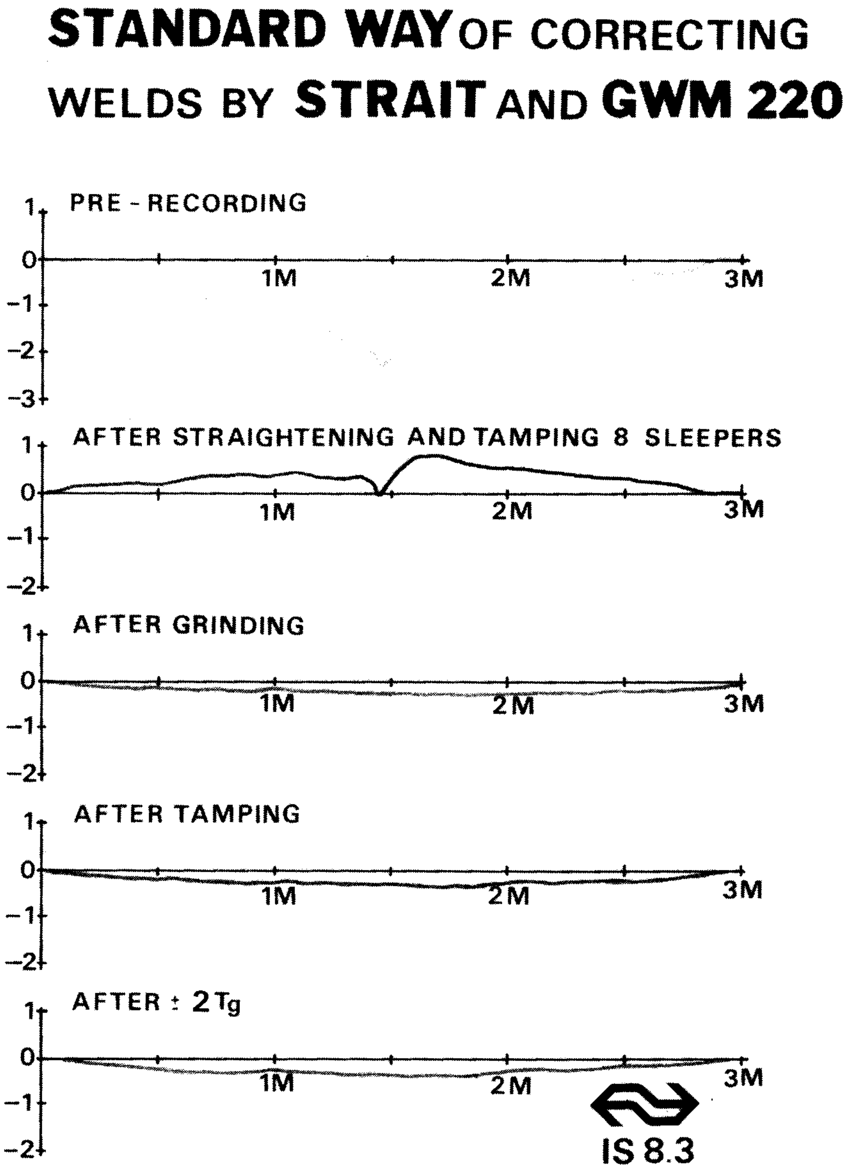


Fig. 17. Durability after step correction

STRAIT PRODUCTION

1. RENEWALS
   THERMIT WELDS ±50 NIGHTS/YEAR
   ± 2500 PER YEAR
2. OLD WELDS
   TOTAL ± 20.000 ±100 NIGHTS/YEAR

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Fig. 19. Desired application of mobile straightening and grinding machine

track length of 300 m. The remaining capacity can be used for the elimination of poor welds still persisting.

The improvement of the weld geometry, realized as above, will, in all probability, lead in the long run, to a considerably reduced need for track maintenance with both hand tools and tamping machines.

For assessing the geometric quality of flash butt welds and thermit welds in track and for the detection of rail corrugation, the NS are studying a system for measuring axle box accelerations, which will form part of the NS track recording system BMS.

The results now available, including, inter alia, the data shown in figure 2, lead to the assumption that this procedure will result in a practical detection system.

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