1. Introduction

Deutsche Bahn’s track network is subjected to very high levels of operational stress. High train speeds and heavy axle loads are the critical factors affecting the service life of the rails. This places increasing demands on the rail technology used and has tightened the requirements that need to be met by non-destructive material testing techniques. For example, defects occurring at or near the surface of rails can be a major cause of component failure and therefore require a test method that is specially designed to detect rail defects of this type. A major consideration for safety inspections of the permanent way is the speed with which the rails can be scanned. Today, rail test vehicles are available which enable rail defects to be detected and analysed at speeds of up to 100 km/h.

2. The properties of near-surface defects in rails

Near-surface defects in rails have been gaining in significance for some time. In the past, the wear on the rails was so great that any surface defects arising were continuously removed simply by trains running over the rails during normal service. However, the new rail steels are of such high quality and are so resistant to abrasion that material wear is no longer sufficient to prevent the growth of cracks appearing in the rail surface.

The test method described here is well-suited to the detection and analysis of near-surface defects. Initially, however, our work focused on the detection of so-called head checks, i.e. defects occurring at the gauge corner of the rail. Head checks initially run into the interior of the rail at a very shallow angle of 15–30°. They are typically spaced between 2 and 7 mm apart (see Figures 1 and 2). The crack spacing may decrease to as little as 0.5 mm in rails in which the head of the rail has been hardened. If the head checks are not removed by processing the surface of the rail, for example by re-grinding, they will often grow to cause shelling at and around the gauge corner (see Figure 3).
In cases of strong growth, head checks may undergo a sudden change of orientation after which they grow vertically down into the rail inevitably leading to rail breakage. Indeed multiple rail breaks can occur because, as already mentioned, head checks can appear with a very small crack-to-crack spacing.

![Fig. 3 Shelling caused by head checks](image)

### 3. Test methods used to detect near-surface rail defects

Up until now, rails have been tested exclusively by means of ultrasonic detection using either hand-held inspection equipment or the rail test vehicle operated by the infrastructure manager DB Netz AG. As ultrasonic sensing is a full-volume detection technique, a large region of the cross-section of the rail can be examined. However, for reasons of geometry, the gauge corner of the rail is very difficult to probe using ultrasound methods. Another complicating factor is the fact that head checks enter the rail at a very shallow angle and with a very small crack-to-crack spacing. It is thus not possible, when working from the running surface of the rail, to align the ultrasonic beam in such a way that the tips of the cracks can be detected (see Figure 4). Knowledge of the location of the tip is, however, important in order to be able to assess crack length and the damage depth.

In contrast to ultrasonic inspection, eddy-current testing is purely a surface technique. For rail inspection purposes, it is thus a useful additional method which complements ultrasonic inspection.

Eddy-current sensing is capable of detecting very fine cracks at the surface of the specimen under test. With a suitably designed test system it is therefore possible to track damage evolution in the surface region, to optimise the planning of remedial measures and to check the results achieved. For these reasons, eddy-current detection was selected as the basis for developing testing technology which would be able detect surface defects in rails.
4. Preliminary investigations

A feasibility study was set up in order to investigate the ability of an eddy-current sensing system to detect and analyse near-surface defects in rails. The focus was placed upon achieving high spatial resolution because of the narrow spacing between the defects, obtaining a large penetration depth in order to be able to assess relatively large cracks, and on achieving a high inspection speed as the eddy-current technology is to be installed in automated rail testing equipment, in particular into rail inspection vehicles. The study involved performing a comprehensive programme of tests. As an example of the results obtained, we mention here the comparison of the eddy-current signals of a test rail recorded at a range of scanning speeds. The circular ‘test rail’ was clamped in a lathe in order to be able to reach high scanning speeds within the laboratory. As can be seen in Figure 5 the signals from both tests are almost identical and thus the test method can be applied at any speed in this range.
5. Calibrating the test equipment

In order to be able to make reliable measurements of the depth of damage in a rail, the inspection system must be calibrated. This was done by carefully grinding the surface of a rail with gauge corner defects at a specified low material removal rate (see Figure 6). After each grinding operation, eddy-current measurements and cross-sectional measurement were performed to determine exactly the amount of material removed. The result is a calibration curve which allows one to assign a crack length on the basis of the recorded eddy-current signal (see Figure 7). In order to determine the damage depth (cf. Figure 2) it is necessary to know the angle at which the crack is propagating through the rail material. If reliable conclusions are to be made, further investigations of material properties and fracture mechanics will be required.

6. In-situ examination of rails

6.1 Test equipment for rail inspection vehicles

In order to be able to use the eddy-current technology in the DB Netz rail inspection train, two different probe-holder assemblies were tested.
In the initial trials, the transducers were installed in a slide-type holder of the type used for ultrasonic detection (see Figure 8). With this type of holder, the rail inspection train could be equipped rapidly as no further conversion was necessary. The disadvantage is that the holder is mechanically coupled to the ultrasonic test system and thus cannot be guided continuously along the gauge corner of the rail because of the centring adjustments experienced by the ultrasonic probes. In addition, the vertical position is undefined as a result of the differing amounts of wear on the rail.

For this reason a mechanical solution was sought which would ensure that the probe was able to track the gauge corner of the rail exactly and which would maintain a constant air gap between the transducer and the gauge corner of the rail. The carriage that was developed is shown in Figure 9. It is equipped with rollers enabling the probe holder to be guided along the rail. The holder can be raised pneumatically so that the transducers are not damaged when passing over switch zones (e.g. over the gap at the nose of the crossing). The rollers ensure that the eddy-current transducers are guided along the gauge corner of the rail with a constant air gap of 1 mm. The rollers are designed to cope with scanning speeds of up to 70 km/h.

Each system was mounted on the DB Netz rail inspection train for a trial run. During these trial runs, the advantages of the roller-guided system compared to the slide-type carriage became very apparent. However, as the roller-guided carriage must be lifted before each cross-
inge gap, this design will need to be re-appraised before it can be used for scheduled rail inspection work.

6.2 Manual detection of head checks

An inspection trolley was designed and built for the manual examination of head checks. The purpose of the manual system is, on the one hand, to provide a means of verifying the results obtained with the rail inspection train and, on the other hand, to make available at short notice a versatile system for inspecting damaged sections of rail. The critical design factor is once again the uniform tracking of the gauge corner by the eddy-current transducers so that comparable data is acquired. The first trolley did not permit ‘real’ manual rail inspection to be carried out as it proved very difficult to transport all the necessary test equipment on the rails (see Figure 10). The accurate guidance of the trolley on the rails was achieved using rollers (see Figure 10).

![Fig. 10a Using the original manual inspection trolley](image1)

![Fig. 10b Guiding the manual inspection trolley along the rails](image2)

The prototype inspection trolley for manual rail inspection by eddy-current probing is shown in Figure 11. This system has been constructed to enable the measurements to be conducted by one person. Two eddy-current transducers are used which can be guided over the surface of the rail head in 14 different lanes thus enabling the running surface of the rail to be examined for near-surface defects.

![Fig. 11a The prototype manual test system](image3)

![Fig. 11b The prototype manual test system stowed for transportation](image4)
A further criterion that was applied to the design of the inspection trolley was the need to be able to transport the measuring technology in compact form. As can be seen in Figure 11, the entire manual testing system can be stowed away without difficulty in a small car.

6.3 Results

The first trial section of track was selected near Magdeburg in Germany. The rails were examined with the rail inspection train (cf. Figure 9b) and the manual inspection trolley (cf. Figure 10a) in order to be able to compare the results obtained. As these were the first trials, the speed of the rail inspection train was restricted to 43 km/h.

The trial section of track contained both reprofiled and untreated rails. If one compares the eddy-current signals shown in Figure 12, which were recorded at different scanning speeds, it is apparent that there is an extraordinarily high degree of reproducibility, which demonstrates the reliability of the eddy-current measuring system used. It is also noticeable that head checks are still present in the reground section of rail. This indicates an important area of application for eddy-current testing: assessing the quality of regrinding work by checking whether the reprofiling operations have indeed been successful in removing all the head checks.

Figure 12: Eddy-current signals of a reprofiled rail (left) and an unground rail (right) at different inspection speeds

At present, trials are being run with the rail inspection train equipped with the slide-type probe holder shown in Figure 8b. The aim of these trials is to examine the behaviour and the reliability of the system during the scheduled inspection of rails. The test system in use in these trials is not, however, the final version and a redesigned system to be installed in the
inspection vehicle is planned for end of the year. Nevertheless, interesting results have already been obtained with the current system. Figure 13 shows selected results from one trial run. As well as signals indicating the occurrence of head checks (Fig. 13a), signals were also recorded which indicated the presence of grinding marks (Fig. 13b). The latter can be recognised by the very uniform spacing and amplitude of the eddy-current signals compared to the head check signals. In addition, eddy-current sensing is able to detect weld seams. Whilst this is not defect detection, such signals could be usefully used in subsequent rail inspection work to accurately locate rail defects.
7. **Outlook**

The study has shown that results of excellent quality can be achieved using eddy-current sensing methods. Head checks on the gauge corners of rails can be unambiguously detected. The tests have also demonstrated that the eddy-current technique is also capable of recognising other types of surface defects (e.g. Belgrospis, wheel burns, short-pitch corrugations, etc.). At the end of 2001, the DB Netz rail inspection train will be equipped with a ‘production-model’ eddy-current detection unit. This unit, which will contain four eddy-current transducers for each rail, will enable the gauge corner and a large part of the running surface to be examined at inspection speeds of up to 100 km/h.

The inspection trolley for manual testing, whose prototype is currently undergoing trials, will soon be transferred to DB Netz AG so that eddy-current detection can be incorporated into the scheduled rail inspection programme.

A third area of application is equipping rail grinding trains with eddy-current sensing technology. This would allow the results of the rail regrinding operations to be subjected to immediate quality checking. In addition, the ability to precisely control the regrinding process will bring economic benefits, as quantitative information on damage depth can be used to specify the exact amount of rail material to be removed.