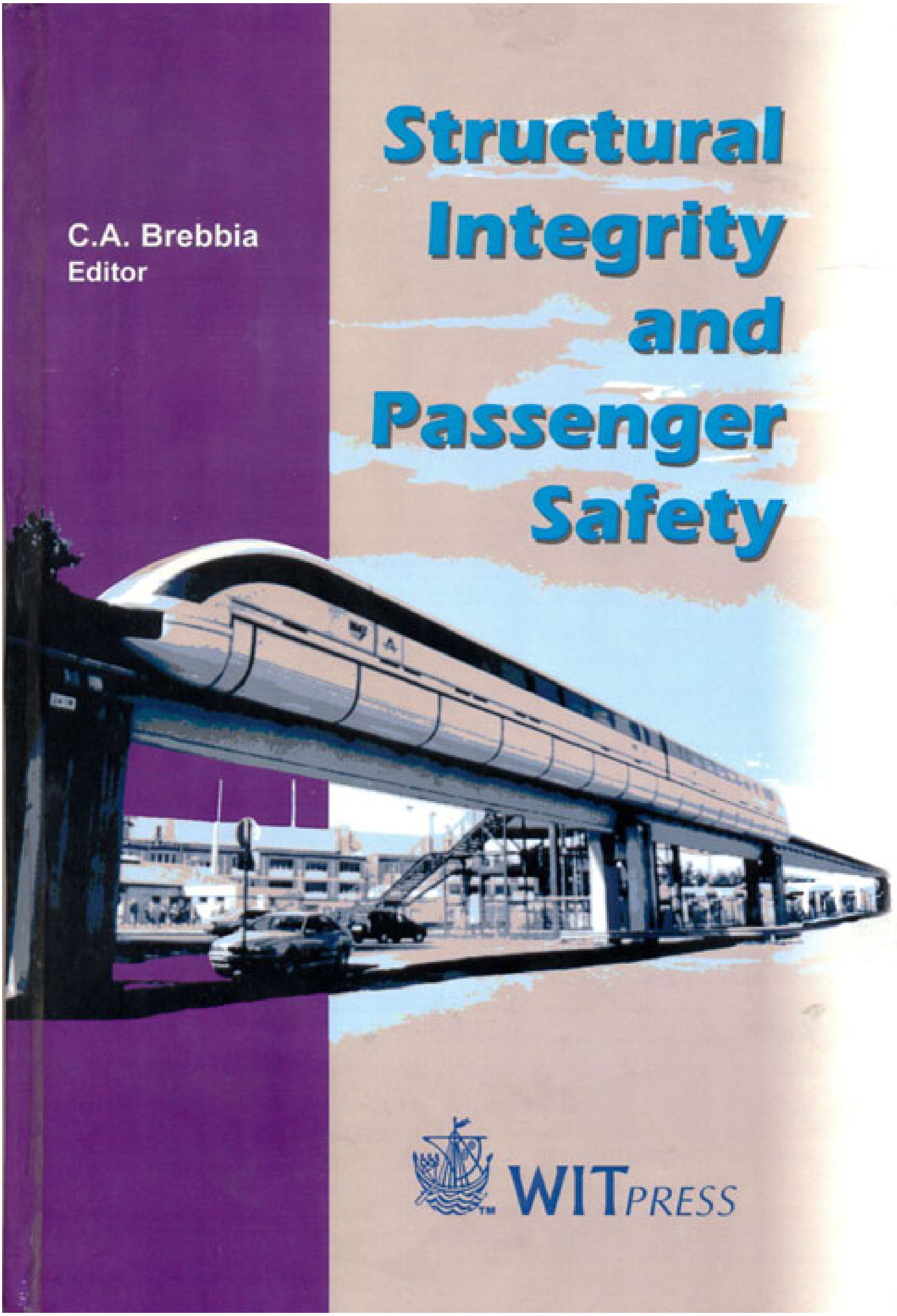

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Structural Integrity and Passenger Safety

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Contents

Preface

The safety of railways is of increasing concern to operators, particularly as velocities have risen considerably with the latest generation of high-speed trains. Accordingly, the magnitude of an accident arising from a relatively small fault is potentially far greater than ever before.

This book covers some important applications in the broad area of safety studies with contributions from experts in Japan, Sweden, Germany, France, Poland and the Czech Republic.

The first chapter deals with the integrity assessment of Shinkansen vehicle axles. The authors use probabilistic mechanics concepts to study the failure of the axles, which is assumed to occur as a result of the growth of cracks originating from fretting corrosion in a wheelseat. Cracks are considered to be randomly distributed in size, and cyclic stresses induced during train operations are used in conjunction with the crack growth characteristics of the material to predict the variation of the crack size with the distance travelled. The authors consider the effect of in-service inspection for different induction-hardened axles.

Chapter two studies the use of stainless steel carbodies for high structural integrity and safety. Comprehensive studies of railway accidents have shown that serious injuries occur particularly when the carbody structure is demolished or when people are thrown out of the vehicle. The authors study a number of measures which have been taken to minimise risks as far as possible. Carbodies are, for instance, designed with an extra strong "cage" surrounding passenger compartments, while the ends of the body have weaker zones for controlled deformation. Stainless steel is judged to be a suitable material for these requirements as it has a high yield strength and because its ductility can sustain large plate deformation before ultimate fracture.

Chapter three on the safety of high-speed Maglev trains discusses the safety and reliability problems related to these systems, including vehicle-based active subsystems such as levitation and guidance, braking and power supply. A potential safety issue is maintaining an obstacle free clearance profile and as a result of extensive trials on the Transrapid test facility, the safety and reliability of the key Maglev functions are judged by the authors to have been successfully tested and proved.

The fourth chapter deals with the development and use of a capacity model for railway networks. The resulting computer program can be used in the strategic planning process when the exact infrastructure and timetable are not yet determined. The model is described in detail in this chapter together with calculations illustrating its practical use.

Chapter five relates to the need to use reliable testing equipment in the verification of the quality of track and rolling stock components or systems. A general view of the testing requirements is presented along with a description of the hardware and software tools developed for these needs. The aim of chapter six on passenger and equipment safety in railway transport is to improve safety by automatically detecting people or objects on the tracks.

Chapter seven on train real-time position monitoring trials, analyses several current safety issues which have to be resolved on high-speed lines. These analyses cover the monitoring of safety separation distances among trains; train integrity monitoring and efficient grade crossing control depending on the velocity of the approaching trains. The author discusses the advantages of using an automatic train position monitoring systems based on a DGPS (Differential Global Position System) and INS (Inertial Navigation Systems) combined with more conventional train position networks.

Finally, chapter eight analyses the cycle of stress intensity factors for cracks in wheels using boundary elements. The model developed allows for the accurate computation of friction between the faces of the cracks, including the presence of fluid.

The valuable contributions of the authors make this volume an essential addition to the literature dealing with rail safety, a topic that is becoming increasingly important in view of the requirements imposed by modern high-speed trains.

The Editor
Southampton, 2000

Chapter 5

Track and rolling stock quality assurance related tools

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Abstract

Safe operation of railways calls for reliable testing equipment that should be employed for verification of the required quality of components and systems or whenever a chance arises that safe operation conditions might be compromised, irrespective of the source of this threat. A general overview of the testing needs is presented along with descriptions of the hardware and software tools developed to satisfy these needs. Measurement results are presented, collected in field conditions, obtained during testing and investigation projects carried out for the Polish State Railways. The systems described range from the stationary rail measurement system deployed in a steel plant, through the portable wheel profile measurement gauges up to a family of computerised track testing vehicles.

1 Introduction

Problems connected with safe operation of railways are as old as this means of transportation. Cornish inventor Richard Trevithick built in 1801 the first steam-driven road carriage to carry passengers, and later it was his locomotive that made history on 21 February, 1804, when it undertook the journey from Merthyr to Abercynon - the first in the world by a steam engine on iron rails (*New Scientist*[1]). Since that time rails and steam engines were brought together and this immediately gave rise to many problems. One of them was that the track could not support the load of the heavy locomotive and carriages that would run on it for longer periods of time. The same problems are faced by every railway in the world nowadays as well, so there is a need to assure the quality of each and every component of the railway system. Quality Assurance goals of the track and rolling stock are to forecast the possible faults before they take place, by implementing the effective measurement and analysis procedures. It is evident that any faults that might occur during operation have to be effectively detected or forecast - see Figure 1.

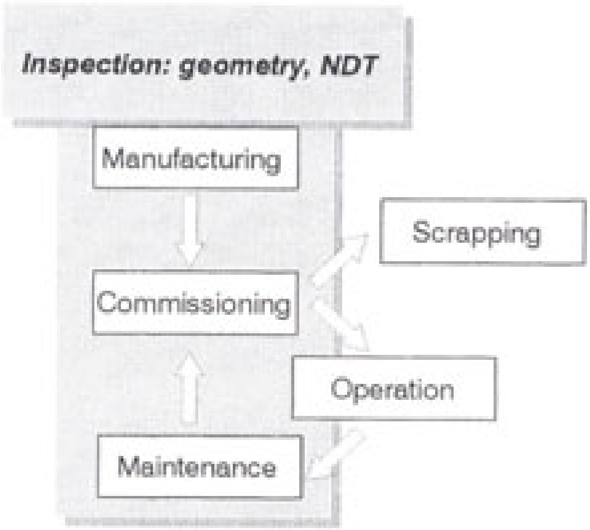

Figure 1: Life cycle of railway elements.

This is the more applicable with increasing speeds of trains, resulting in different conditions of work and wear of the joint elements of the track and rolling stock. This attitude is being currently adopted by the Polish State Railways (PKP). We shall limit our discussion to activities connected with controlling the geometry of rails: Grabczyk and Madejski [2-3], track: Madejski *et al* [4], Zając and Jasiński[5] and Burghardt *et al* [6], wheel and rail profiles: Madejski and Grabczyk[7], and wheel sets: Grabczyk *et al* [8], in which we participated in the last few years.

Relevant measurement methods and equipment were developed for railways' suppliers and for their in-house use. This in-house use incorporates maintenance jobs carried out by the railway's own staff for verifying quality of work done by external service providers (P.U.T. Graw[9-11]). Moreover, it is essential to bear in mind that the Polish State Railways are facing restructuring at present, so that in future they will own the current - and developed - infrastructure, which will be used by numerous transportation service providers. The most probable future organization of what constitutes the present Polish railway infrastructure is shown in Figure 2.

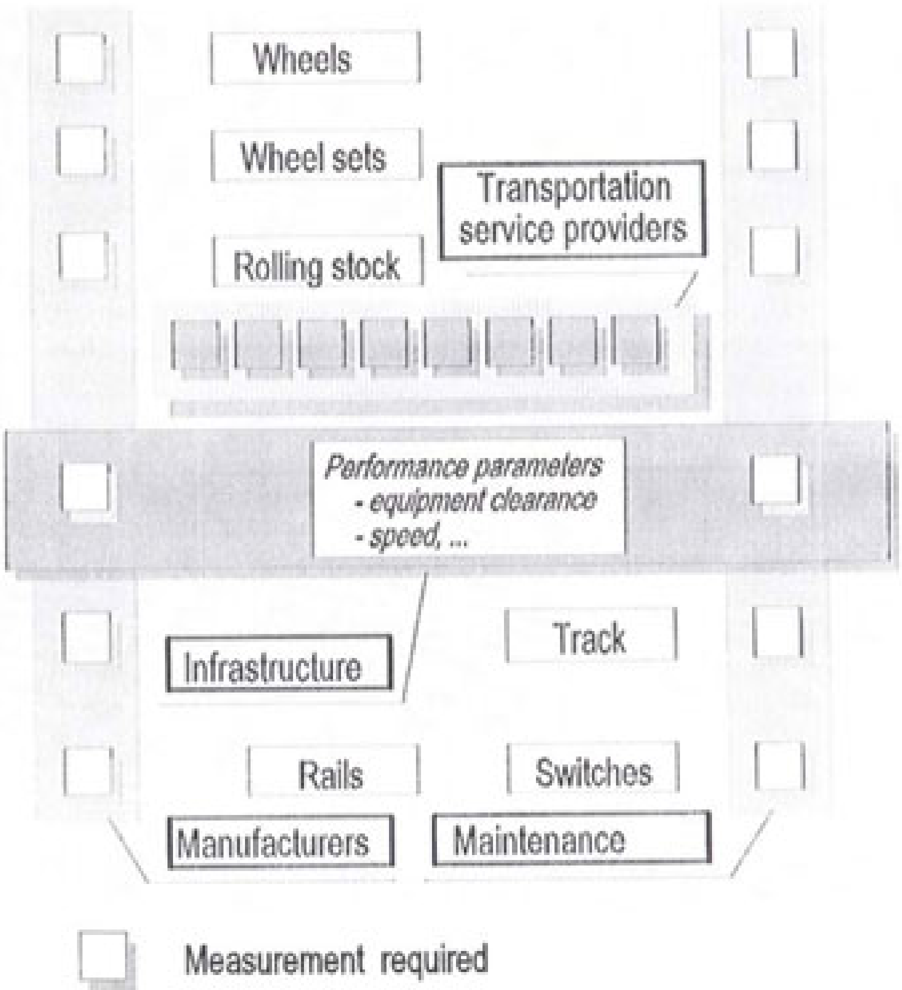

Figure 2: Responsibilities of particular parties involved.

We shall concentrate now on such safety factors as: rail quality, as commissioned from their manufacturer, track condition, and the automatic verification of the state of the rolling stock wheel sets. Any attempt to introduce quality control has to be accompanied by provisions for easy and reliable storage of measurement results. Fast data retrieval - when necessary - is also necessary. Therefore, all gauges and systems we developed have database links designed in. These may be fully-fledged databases, as in the stationary measurement data analysis systems (Grabczyk and Madejski[2], Grabczyk *et al* [8], Graw[12]) or rather simple flat file packages (Grabczyk *et al* [13]). All databases make use of the relational model and the main requirement in selection of the suitable PC software development tools has been compatibility with DOS, Win 9x, QNX 4.2x and WATCOM 10.x.

2 Rail quality verification

The development of the first rail designs dates back to the 1830s and is credited to an English engineer, Charles Vignoles, and to Robert L. Stevens, president of the Camden and Amboy Railroad in the United States. Railroads have used hundreds of various rail cross sections since that time, however, with much study and research work resulting in new rail designs minimising internal and contact stresses of the wheel-rail head pair and thus extending rail life.

There is a strong tendency towards standardising on a few selected optimised sections and defining them more precisely, so that the resulting profiles should have better working properties than the present ones. The most commonly used rail section in Europe nowadays - UIC60 - has a transverse rail head profile made up of three different radii and two straight inclined gauge faces.

2.1 Quality control of rails in the steel plants

Rail manufacturing process is a complex one as the rail cross section is being formed during hot rolling at temperatures changing from 1200°C to 950°C, with succeeding modifications due to cooling to ambient temperature, involving the increase in volume by the γ to α phase transformation, scaling on the cooling banks, and mechanical deformation during roller straightening - additionally reducing for instance the overall rail height and deforming its head.

Simultaneously, increasing trains' speeds and loads calls for the significant improvement of the rail geometrical accuracy, especially for speeds over 160 km/h.

beam is positioned automatically in one of the two positions: working position and a base one at 500 mm distance from the rail surface (Wick *et al* [17]).

Thyssen Stahl AG measures the vertical waviness of rails using four transducers, touching the rail surface, mounted on a hydraulically lowered beam. This system was designed for rails of 30-67 kg/m with lengths varying in a range of 14-62.5 m running at speeds ranging from 0.4 to 1.5 m/sec (Becker *et al* [18]). Measurements of waviness have been carried out since 1978, and detailed examination of results has revealed that essentially the roller straightener and the rail height variations caused by the rolling-mill rolls exert an influence on the overall rail straightness error. Therefore since 1982 both parameters are measured simultaneously to evaluate the influence of both factors on the rail waviness, height being measured by a set of two laser probes.

Pennsylvania Steel Technologies undertook the development and installation of a PC based machine vision system designed to dimensionally inspect rails. This series of lines overlaps to form a continuous line that circumferentially surrounds a rail as it passes through the centre of the gauge head. Matrix array cameras, each with a very limited field of view, are then used to measure the changes in the shape of the laser line (Feldman[19]).

All features of rail measurement systems described above lack one capability - they cannot derive the true rail profile. The true - real - rail profile is necessary for the detailed and exact analysis of the running surface of the rails because they should be treated as individual products. Discovering any irregular "wavy areas" and kinks must result in elimination of the rail as a faulty one. Therefore there was a need to develop a rail measurement system which would check all standard geometric rail parameters and encompass all the above mentioned design requirements (Lindstrand[20]).

Huta Katowice S.A. has installed a system for inspection of all rail transverse section geometrical parameters, and the rail waviness evaluation by analysing a true rail profile - Figures 3 and 4. All measurements taken are used to verify conformity of the rails' geometry with the customers' specifications.

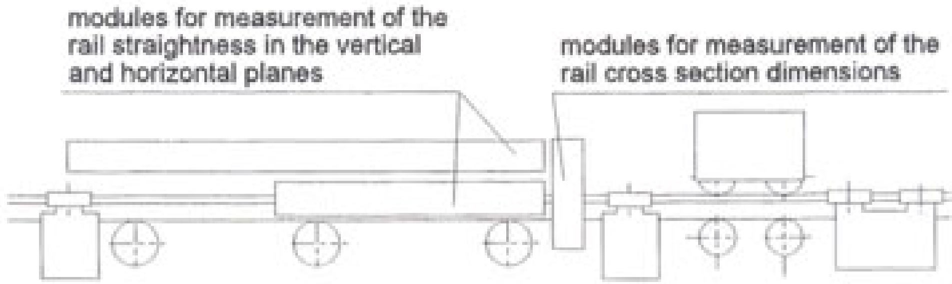

Figure 3: Overall measurement system layout.

The rail measurement system presented has been developed by P.U.T. Graw[2,3] following all available industrial experience in this area. It has been decided that:

- only the non-contact measurement methods should be employed for inspection of the rail height, rail head width, web thickness, foot width, foot flatness, rail asymmetry, rail foot twist, and straightness in vertical and horizontal planes,
- cycle time must not exceed 60 seconds,
- all rail cross section geometrical parameters should be measured,
- calibration procedure is simple, with most of it being carried out by the system software,
- visual and hard copy presentation of the measurement results was required,
- highest possible MTBF was one of the most critical project factors,
- mounting structures of the laser probes should maintain the shape and dimensional stability.

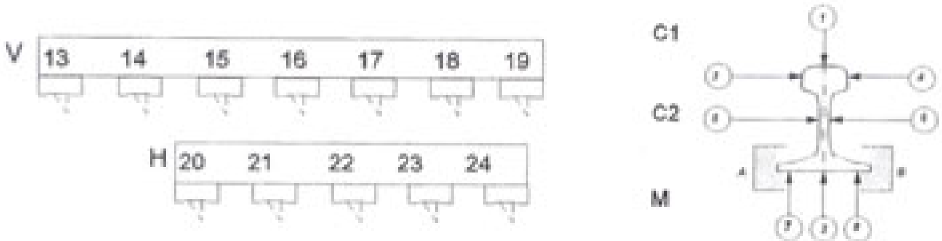

Figure 4: Measuring modules of the system: two beams for straightness measurement (H for horizontal plane, V for vertical plane) and a frame for measurement of the cross section of the rails with three sections - C1, C2 with laser probes and M with micrometers.

Operators directly supervise functioning of the system - although their direct involvement is not required, they select types and makes of rails to be measured, and introduce rails to the measurement system. As the rail enters the measurement zone it is pressed to the roller conveyor by the damping rollers which minimise rail vibrations and make the rail movement more stable. The system can operate on a three shift basis checking the rails' geometry, storing the measurement results and generating measurement reports - asserting the rails' conformity with specific customer's requirements - as the rails' quality certificates. The rails measured are identified by their numbers (ID symbols) taken from the list presented to the system, assembled according to the shift production plans. The measurement system was designed as consisting of two subsystems: the meter unit and the logger unit (Figure 5).

This design had been dictated by the need to distribute the specific tasks between the subsystems mentioned. Therefore, it was much easier to develop the bug-free software in separate, fully functional, and smaller modules, yet preserving the possibility of their relatively easy deployment and upgrading when the customer puts forth some new requirements. Trouble-free software maintenance features the basic design requirement when such long term projects are carried out.

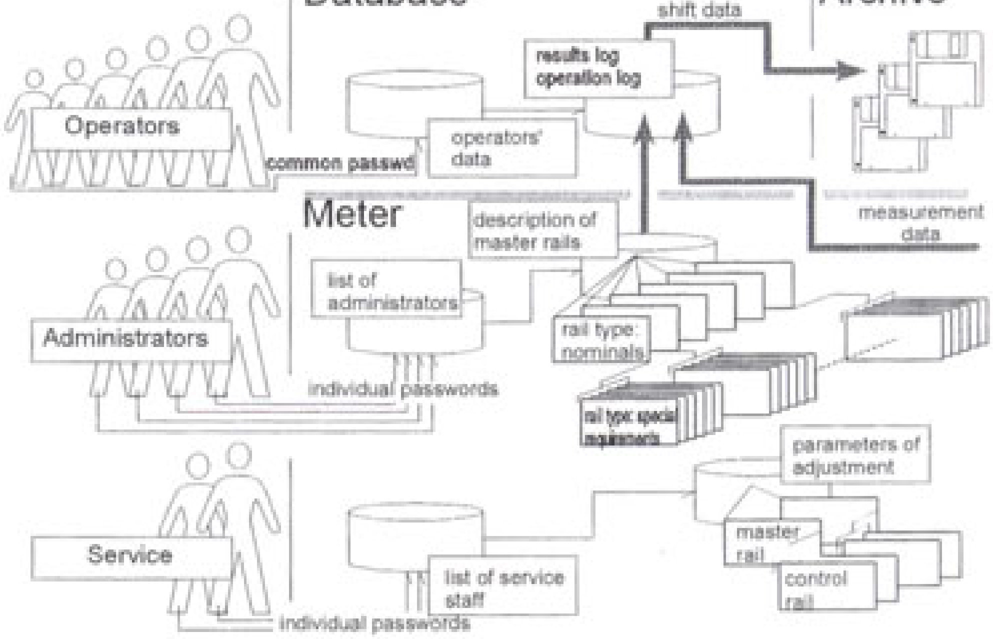

Figure 5: Units and functions of the computer supervisory module.

The meter unit carries out diagnostics of the system elements, controls the measurement cycle, reads and stores the intermediate measurement results (Figure 6), reproduces the true rail profiles, and maintains several database systems. On the other hand, the logger unit's main task is to provide storage and access to the measurement results. This unit's main task is generation of the measurement reports and printout of hardcopies of rail quality certificates including textual and graphical information. The logger unit produces general shift production reports listing: current customer's requirements, good rails numbers, and bad rails numbers segregated according to the fault detected.

To be able to carry out this principal task, this unit has to receive data transmissions from the meter unit and store it in a temporary database. Document generation tasks and data transmission are fully independent and are run concurrently. Moreover, some auxiliary fuctions of the logger include direct access to the measurement data stored in the temporary database containing about one month's production information, maintaining the measurement system operation log, and archiving the measurement data on diskettes. Archived measurement results may be written later on to the mass storage of an external database server.

The external database software supplied along with the measurement system provides for easy access to all relevant data describing the rails' geometry. This design principle ensures constant access to the measurement data stored for the time span required by the relevant railway regulations.

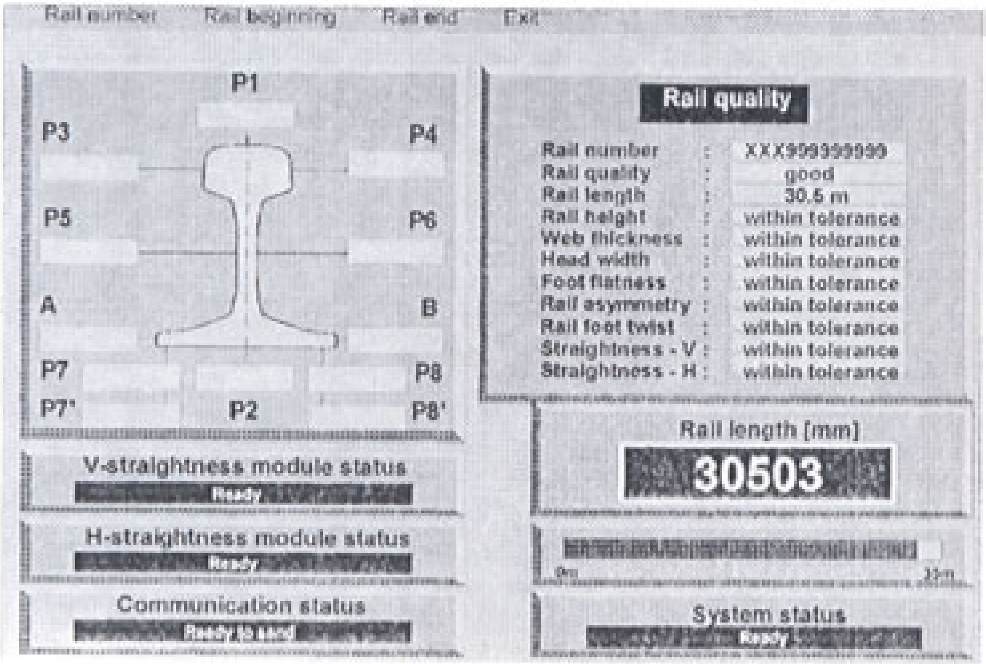

Figure 6: Meter screen mask during measurement.

Cross section measurement results do not require further processing as they have already been averaged "on the fly" as the rail was passing through the measurement zone. Figure 7 presents the exemplary rail profile in the vertical plane. The user may obtain similar plots for every geometrical parameter measured.

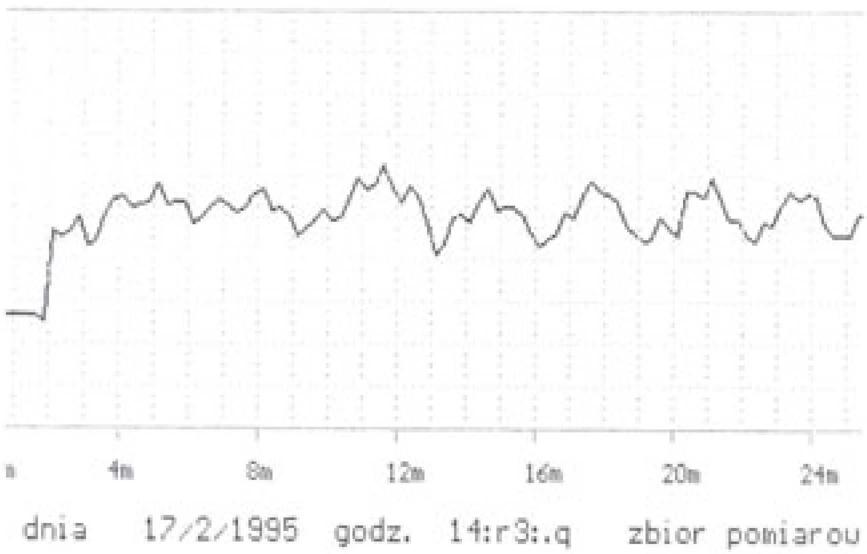

Figure 7: Exemplary rail profile in the vertical plane.

2.2 Measurement of rail welds straightness in welding shops

Rails are supplied for track laying welded in welding shops into sections 120 m long or longer. Welding operation is crucial to further track quality as any excessive straightness errors in the weld areas require additional time consuming grinding of the rail running surface. Therefore, it is important that rails to be welded are carefully matched before welding and straightness of the welded section in the joint area is checked in case its straightening is needed. P.U.T. Graw developed the stationary measurement system for PKP, measuring rail straightness ±500 mm from the weld in the vertical and horizontal planes (Figure 8). The virtually maintenance-free mechanical module of the system features a compact unit with three laser probes travelling along the inspected welded rail.

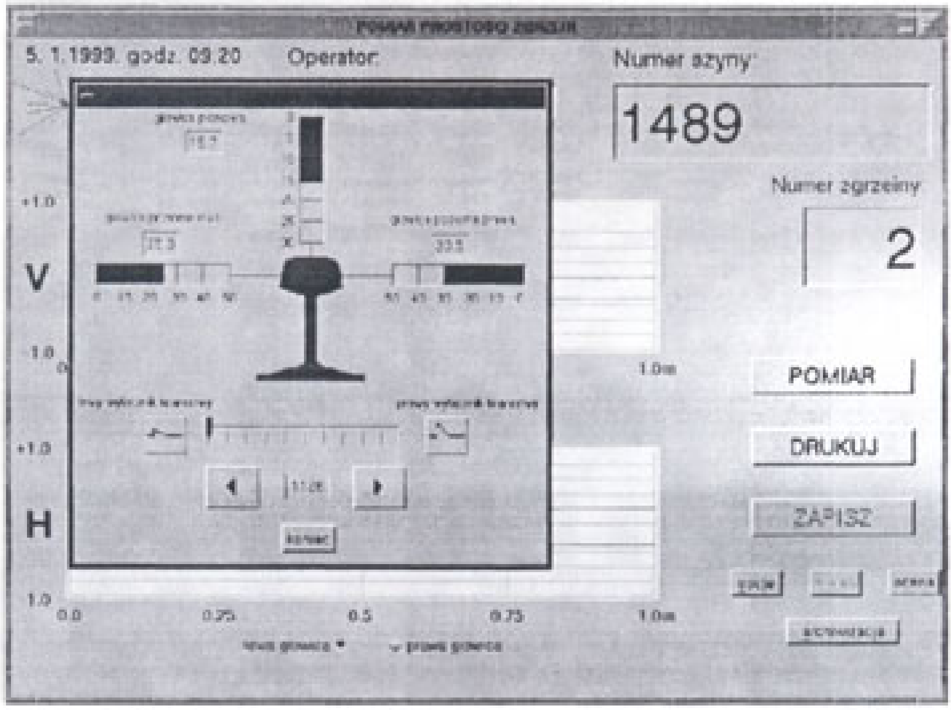

Figure 8: Screenshot of the rail weld straightness measurement system.

Straightness plots of the measured section of the welded rail are shown along with the selected geometrical parameters of the rail. Measured data may be stored for later use; moreover, welds of the same rail may be measured repeatedly which makes it possible to document welding quality and examine effectiveness of rail straightening (Figure 9). The required measurement accuracy of the rail welds is ±0.05 mm/1 m. This accuracy that is provided by the stationary measurement system described above is required also for measurements taken in the field conditions where welds are made - see section 3.2.

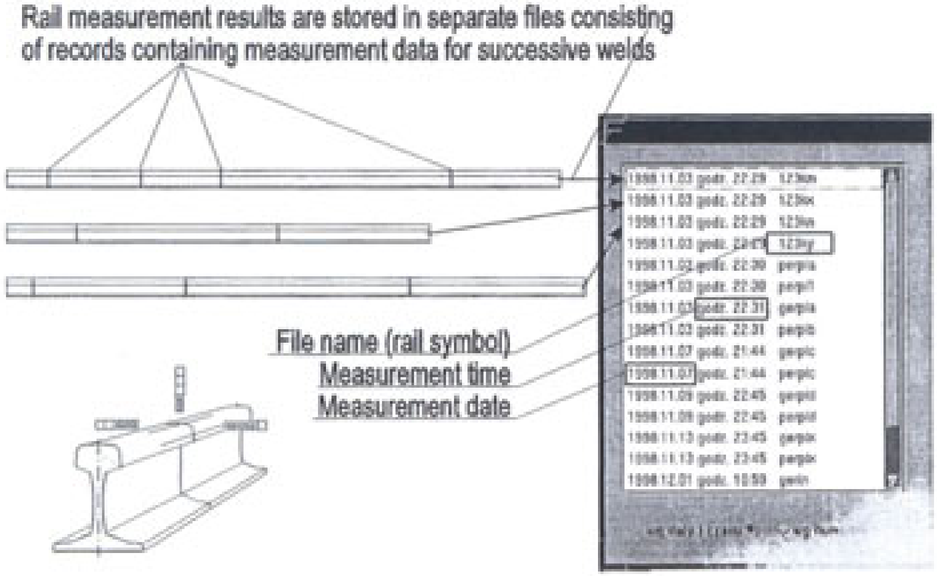

Figure 9: General layout of straightness measurement probes and structure of measurement results database.

3 Track measurements

Track measurements are connected mostly with maintenance. Regardless of the quality of rails obtained from the manufacturer many factors influence deterioration of the track, for example a: load carried over time, rail wear, etc. Therefore, regular checking of the track geometry is indispensable - and obligatory, according to railway regulations. Track geometry measurements may be made using geometry cars - mostly on the main lines, and using the track gauges on all remaining lines. The obvious requirement is that results obtained from these two sources should be consistent and compatible with the computer-aided maintenance tools. Moreover, transverse profiles of the track elements should be checked too. This information is essential while planning maintenance schedules and during commissioning of the work done by the service providers to ensure their proper quality.

3.1 Microprocessor based track gauge

Checking and forecasting of the track condition has been made easier by replacing the inefficient and arduous manual method of direct measurements with measurements taken by means of the microprocessor based TEB-1435 gauge rolled along the track (Zając and Jasiński[5]). The gauge features a supplement to the equipment dedicated for a system of methods of checking the track condition and is not intended to supersede measurements made with the geometry cars like EM-120 or WPA-50 (Burghardt *et al* [6]) (see section 3.6). Results of diagnostic measurements of the track structure are the basis for taking decisions regarding:

- operation in given conditions,
- forwarding a proposal for change of the track class,
- specifying the type, scope, location and date of repairs,
- limitation of speed or axle loads.

Along with automatically measuring and recording six parameters: the track gauge, and its gradient, level, twist, as well as the horizontal and vertical irregularities, the operator can store information gathered from visual inspection by inserting markers denoting:

- hectometer marker
- crossover
- sleeper fixing bolts missing
- sleeper replacement necessary
- flash
- burr
- side wear
- bridge, flyover, tunnel
- crossing
- broken rail
- fish bar bolts missing
- rail's flat
- skewed sleepers
- broken weld joint

All measurements are logged as a function of the instrument travel along the track and the measured parameters are displayed on the operator's panel from which the operator may also select the necessary service options when needed. It is possible to make measurements of as much as 5-6 km a day and the gauge's electronic memory can store the measurement data of up to 15 km of track.

The gauge may be easily transported to the location where measurements are scheduled. Its important features include the capability of continuing the interrupted measurement immediately after taking it temporarily off the track to give way to a passing train - even in holes and on embankments. The gauge to be used reliably in the field conditions should be also resistant to bad weather conditions. The gauge presented here (and deployed successfully in many districts by Polish State Railways), can complete the commenced measurements in rainfall, which is an essential requirement for most European railways.

Results are archived on the PC where the basic analyses and report generation features are available in the dedicated software supplied with the gauge. Measurement results may be also further used for specific analyses using other software, ranging from spreadsheets to domain specific expert systems developed for track maintenance (Bałuch[16]).

Exemplary measurement results are shown in Figure 10. The user can specify which parameters should be plotted on one report chart. The plots can be freely zoomed, panned, and overlayed with the tolerance limits imposed by the regulations or specified by the user.

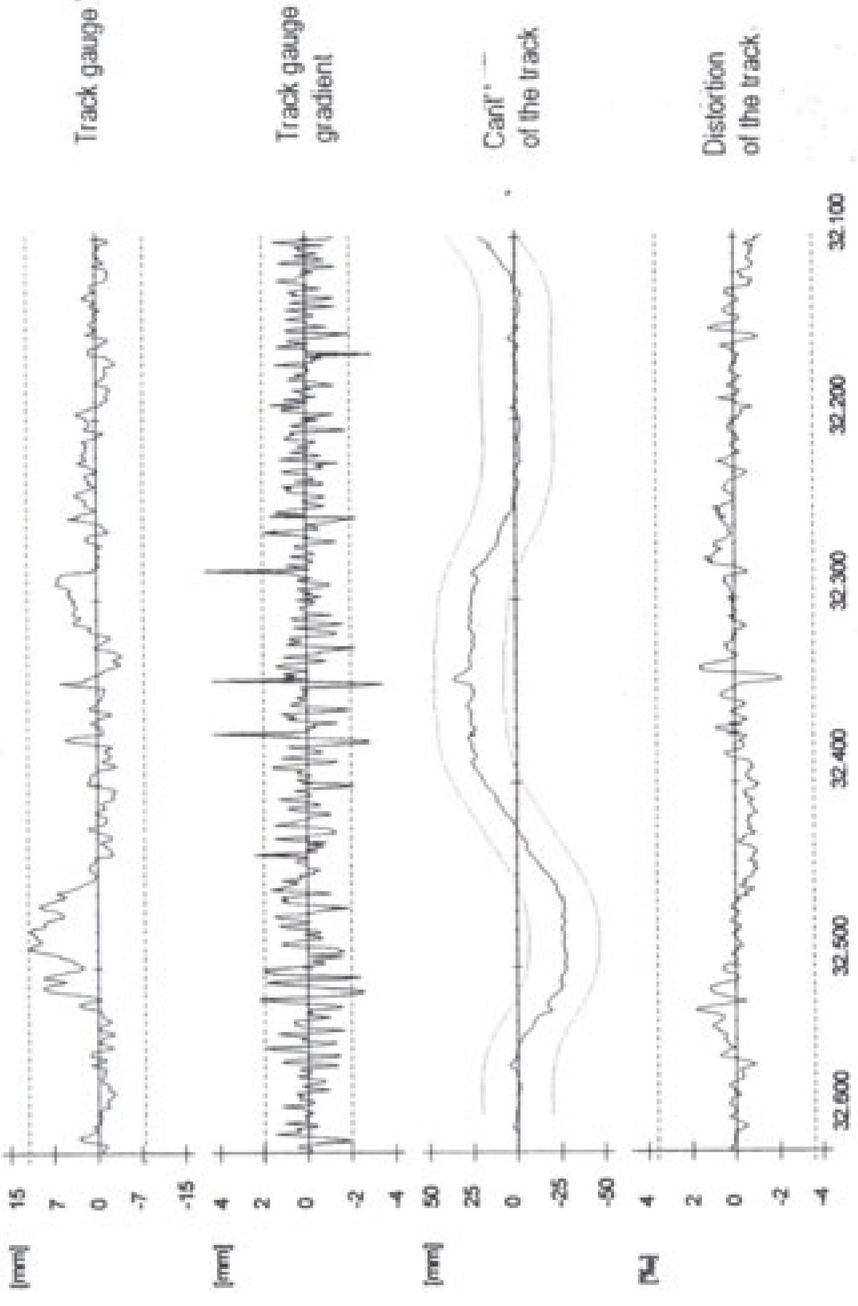

Figure 10: Plots of the geometrical parameters of the inspected track.

3.2 StraightEdge - portable rail straightness gauge

Quality control of rail welds done in the track called for development of a portable straightness measurement gauge. *StraightEdge* is an example of a gauge which makes it possible to carry out measurements on site in one or two planes - the measurement may be carried out in the vertical plane or on the side rail head surface. (Figure 11). The gauge makes it possible to measure weld straightness on the measurement length of 1 m. The device is equipped with the handheld PSION computer for measurement data processing and for visualization of the measured rail profile plot on the small LCD display along with the allowed values of deviation, that makes it possible to carry out evaluation of the weld straightness directly in the track. The computer memory can store several hundred measurement results and makes the subsequent processing on a PC computer possible.

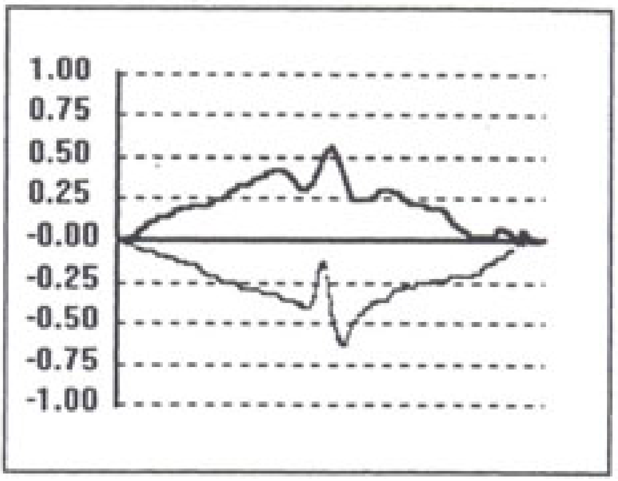

Figure 11: Exemplary plots of welded rail straightness in two planes.

The microprocessor based control system of the device is supplemented by the auxiliary PC software for visualisation and reporting of the measurement data with database capabilities built in.

3.3 Rail short waves measurement

Short waves - of about 100-200 mm length - on the running surface of the rail, are responsible for many undesirable effects, such as noise, etc. Waviness is one of the main factors determining the need for grinding of the track which is a very costly operation. Therefore, it is essential that this decision is made with full knowledge of the state of the track. A portable gauge has been developed by P.U.T. Graw that makes it possible to measure the rails with the following accuracy: ±0.03 mm/1.5 m and ±0.01/200 mm. Figure 12 presents the exemplary plot revealing the significant waviness of the rail on the measurement length of 1500 mm.

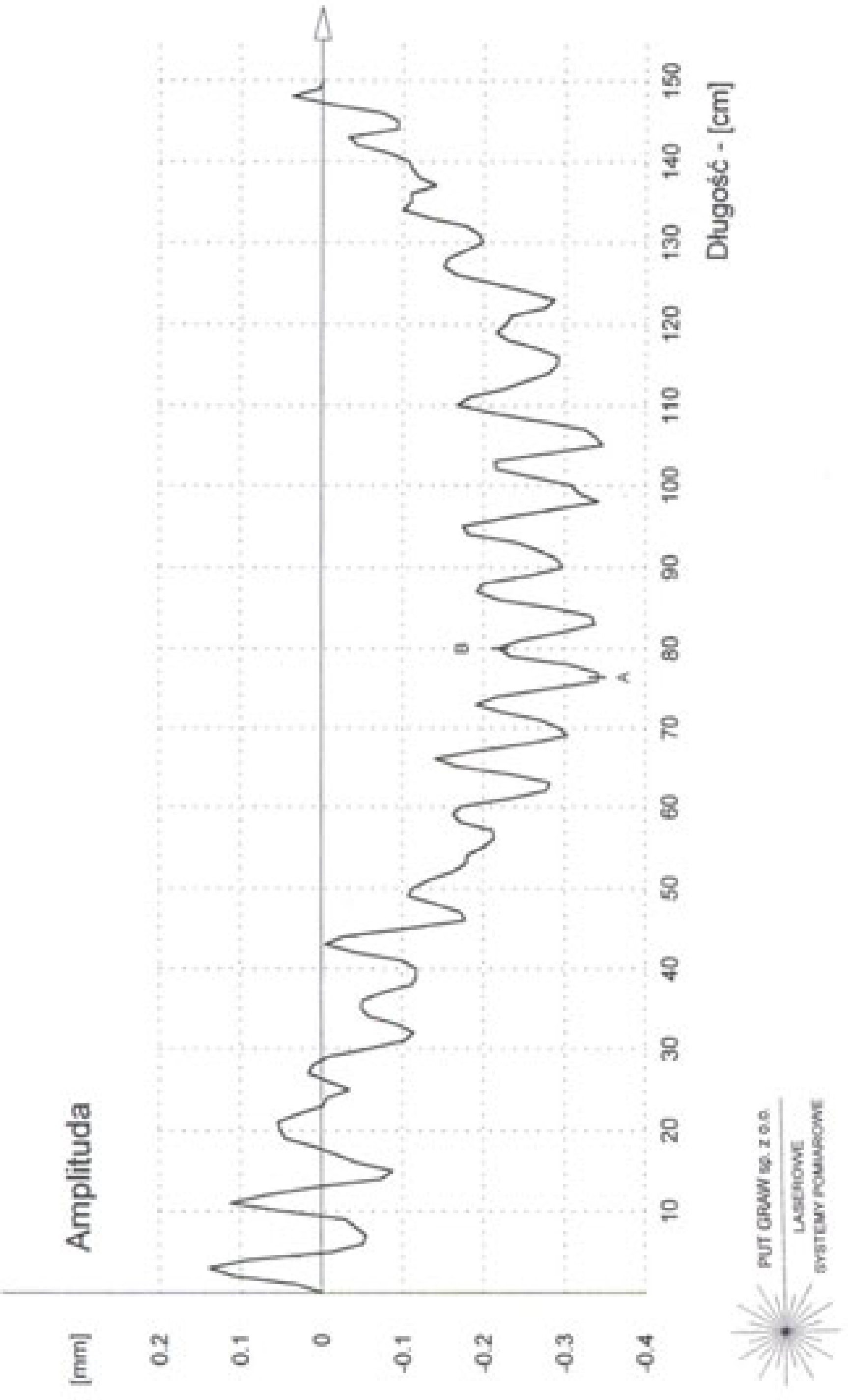

Figure 12: Measured values: wavelength 76 mm, amplitude 0.145 mm, depth of surface irregularity 0.25 mm/1200 mm. (Note: plot points denoted A and B will be discussed in section 3.4, compare Figure 16.)

3.4 Rail head measurement gauge

Railways, as the user of rails, may use this gauge for control of wear of rail heads in the track, control of accuracy of the rail head profile on welds, and for commissioning of the rail head profile after grinding. Railways treat correctness of the rail head profile as an ancillary criterion, next to their straightness, when deciding the necessity of their corrective grinding. This fault may be rectified by profile grinding, requiring sometimes as many as 6-7 passes of the grinding train, whereas on the average 4-6 passes are enough to repair minor track faults. To prove the necessity of scrupulous rail profile control, certain major faults - in extreme cases - required in some locations 10-12 grinding passes. The same holds true for the rail welds: the joints profile often differs from the theoretical profile thus deteriorating the overall track quality. The typical faults of the rail head profile occurring in the track are:

- local deformations of the running surface of the rail, due most often to manufacturing errors,
- traces of the wheel spin, causing local quenching of the rail head that results in further chipping of the rail material and appearance of minute cracks,
- spalling of the running rail surface, as large as several millimetres sometimes, occurring most often in the heat treated rails,
- at high train speeds, crushed grains of the breakstone that got under the wheels cause micro-cracks of the rail head running surface.

It is well known that just the slightest unevenness of the rail head crown surface causes a serious increase of contact (Hertzian) stresses resulting in rail head wear, micro-crack propagation, and sometimes even structural changes of the rail head surface layer. The rail head geometry may be measured precisely and efficiently using dedicated equipment only. These measurements may be carried out manually, using special curve gauges, devices with a measuring arm driven by hand along the rail surface, or fully automatic ones, where readings are not affected by an individual's skill and accuracy (Figure 13).

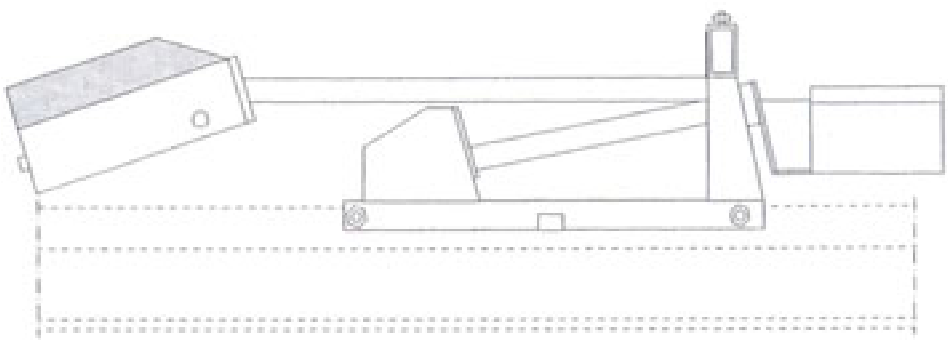

Figure 13: Rail head measurement gauge.

Another taxonomy of rail head measurement methods is based on the way in which the rail surface shape is detected. There are two methods: contact and non-contact (Figure 14). The non-contact method makes it possible to avoid the inevitable shape errors of the measuring tip or roller affecting the contact methods.

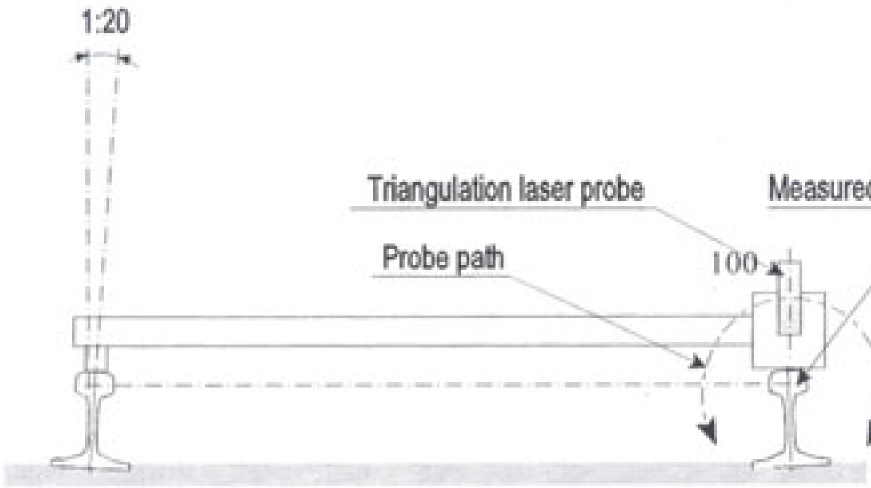

Figure 14: Principle of the non-contact measurement of the rail head profile.

Any measurement equipment intermediate elements touching the rail head deteriorate accuracy of discerning details of its surface. The larger the stylus radius or roller diameter of the device, the less detailed the resulting measured profile is. Due to this inevitable disadvantage, all contact gauges are acceptable for rough measurements of the rail profile only, as they are not capable of reading the true rail head profile with the minute details necessary for its more sophisticated analysis.

Therefore, it is preferable to employ the non-contact method which is capable of revealing even the most minute surface details. Moreover, it is obvious that it is desirable to employ measurement equipment that may be used to check the rail quality both in the manufacturer's premises and on the track.

Rail manufacturers have to follow the recommended rail quality assurance procedures that include automatic inspection of rail dimensional tolerances which turn out to be more precise and reliable than manual measurements. The same holds true for the railways that have to carry out track maintenance as safety measures call for inspection of the railway tracks at carefully determined service time increments.

It is essential from the economic and safety of operation points of view that the decision to grind the track is made based on sound technological assessment of the track condition after analysis of the results of measurements of rails' straightness and deterioration of the rail head shape.

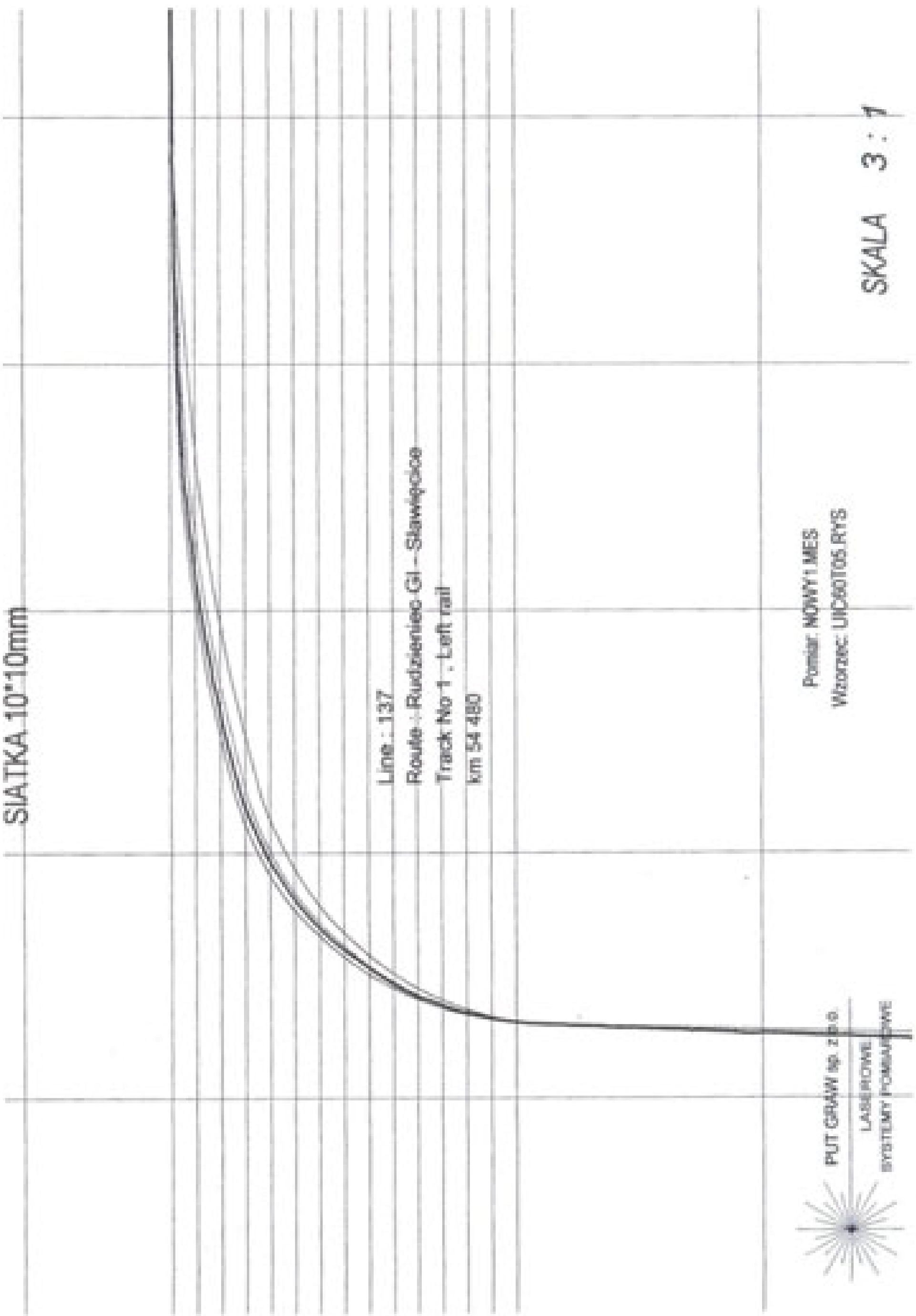

Figure 15: Example of a correct rail head shape.

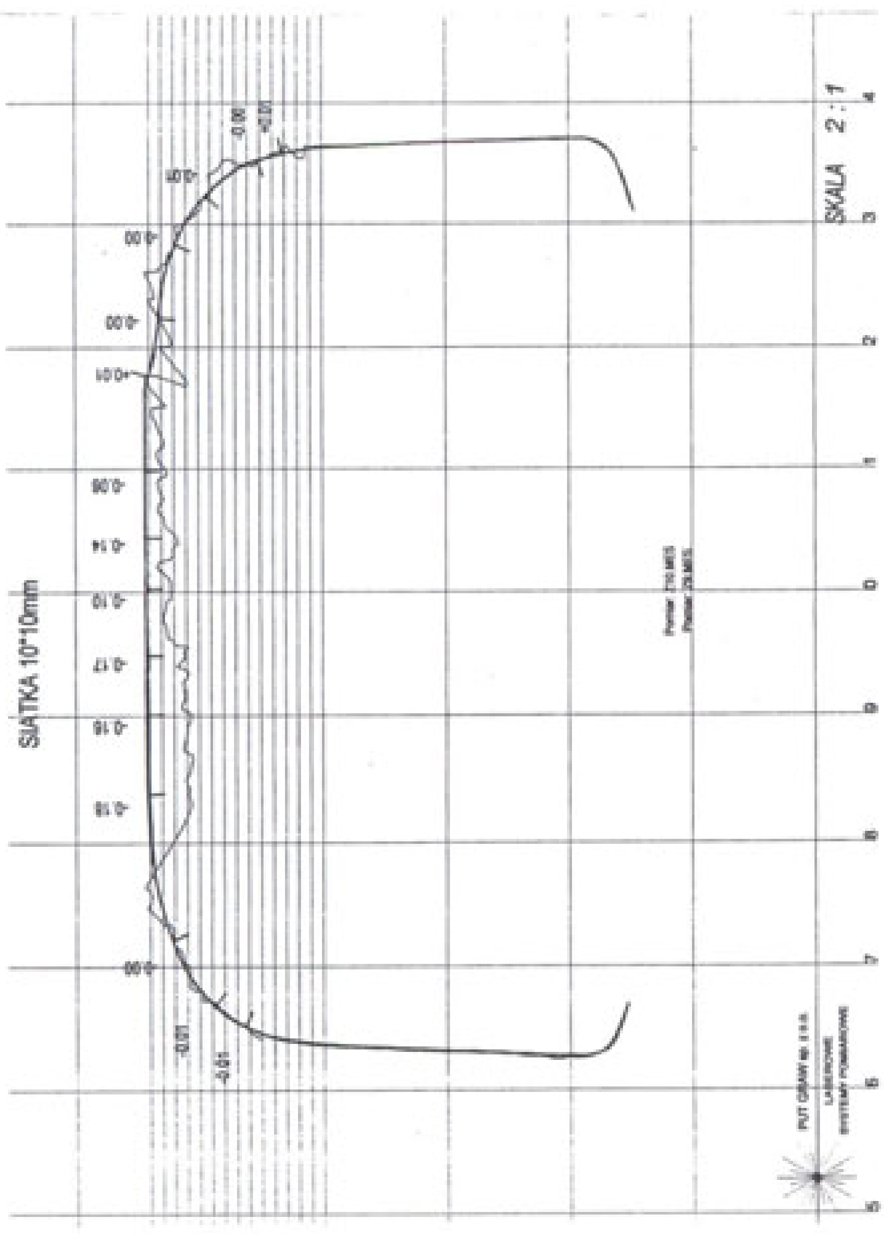

Figure 16: Error plot of differences between two rail head profiles (A and B points on the rail waviness plot in Figure 12).

It is possible to overlay a number of measured profiles to visualise any changes of geometry, e.g. after mechanical adjustments of the rolling pass or after modifications of any other process parameters, or else with some other measurement results - Figures 15 and 16.

Please refer to Figure 12 to recall the rail's running surface short waves revealed. Figure 16 presents the two measured profiles and the plot of differences between these two profiles, at points: A at the bottom of the wave and B at the top of it. This information is very important from the maintenance point of view, so these two devices should be used together, thus yielding the most essential data which cannot be collected in any other way.

The track condition and results of the maintenance work have to be checked very carefully regardless of who carried it out. It may be done by the railways' internal services or else by third party service providers, e.g. using leased grinding trains.

3.5 Measurements of the geometry of railway switches

Switches feature an important - and difficult to measure - element of the track. Its geometry deterioration over time requires regular inspections and repairs. To this end a novel instrument has been developed by P.U.T. Graw - the device features a portable measuring X-Y machine developed for measurements of the railway track elements in field conditions. Practical measurement accuracy required and offered by this gauge is 0.1 mm.

Having fixed the gauge at a desired location, the operator guides the spherical measuring tip along the measured profile, taking care that this tip does not lose contact with the controlled surface. The measurement system of the gauge transforms the tip trajectory into a set of points with the known X-Y coordinates and stores them in the electronic memory of the device. When the measurement session is over, the measurement results are transmitted over the RS-232 link to the PC computer mass memory, where the dedicated software makes possible fast evaluation of the results collected - Figures17 and 18. The dedicated software makes it possible to compare the measurement results with any templates the user may wish to design and overlay on the measurement plot. This boils down to the possibility of superimposing several plots of results obtained in different locations on the same switch or to comparing the measurement results with the theoretical profiles. All standard zooming, annotating, and dimensioning capabilities are available - similar to those developed for the rail head measurement gauge. The device may be used for planning the maintenance scope of switches, it is possible to work out their detailed documentation and graphical representation of wear for each switch. Results of measurements carried out with the gauge may be used for commissioning the scope and quality of repairs done by the service providers. Moreover, a possibility of presenting many profiles measured in the same transverse section of the switch during its operation makes it possible to follow its wear developing in time.

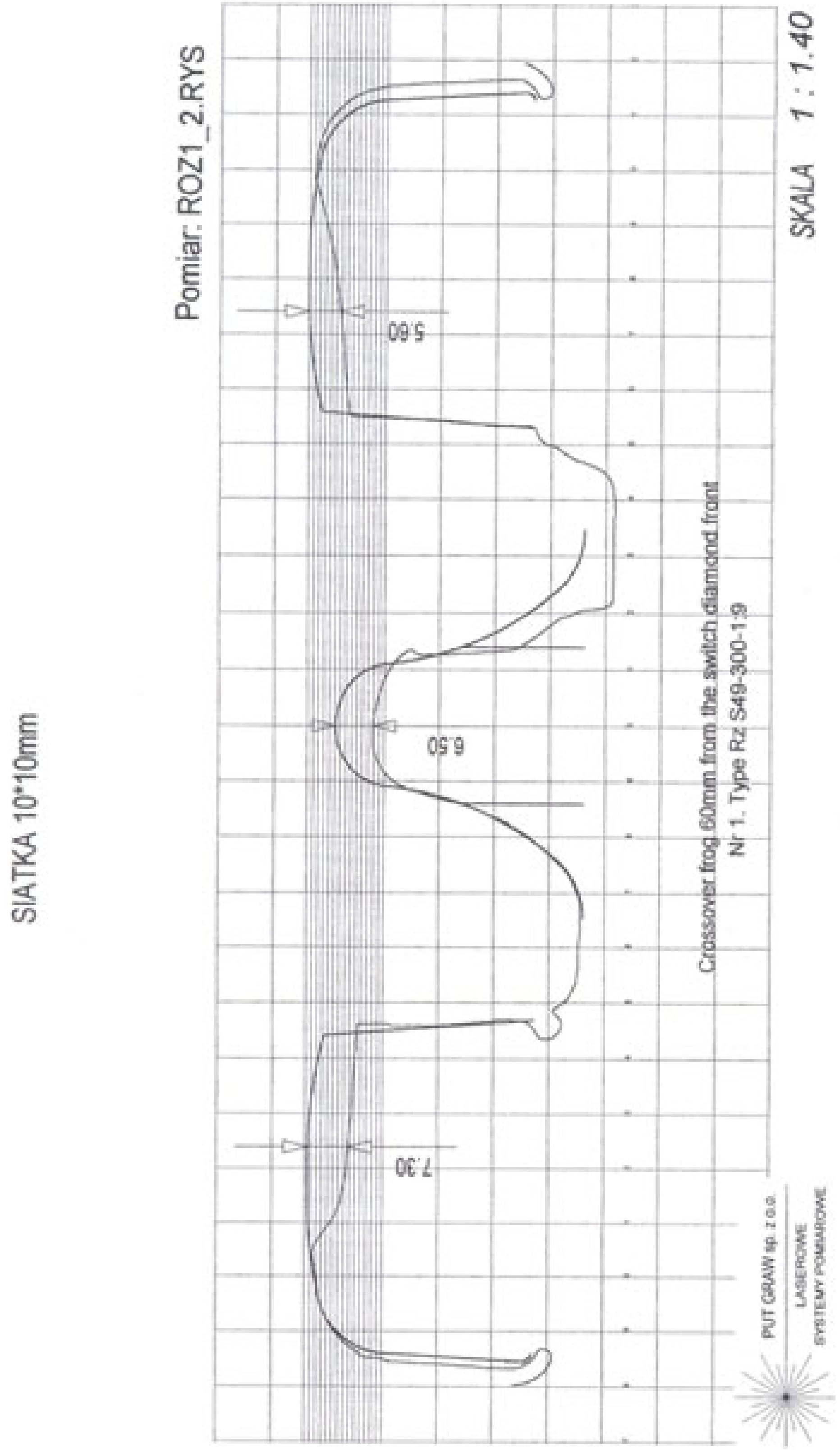

Figure 17: Measurement results of the crossover frog 60 mm from the switch diamond front.

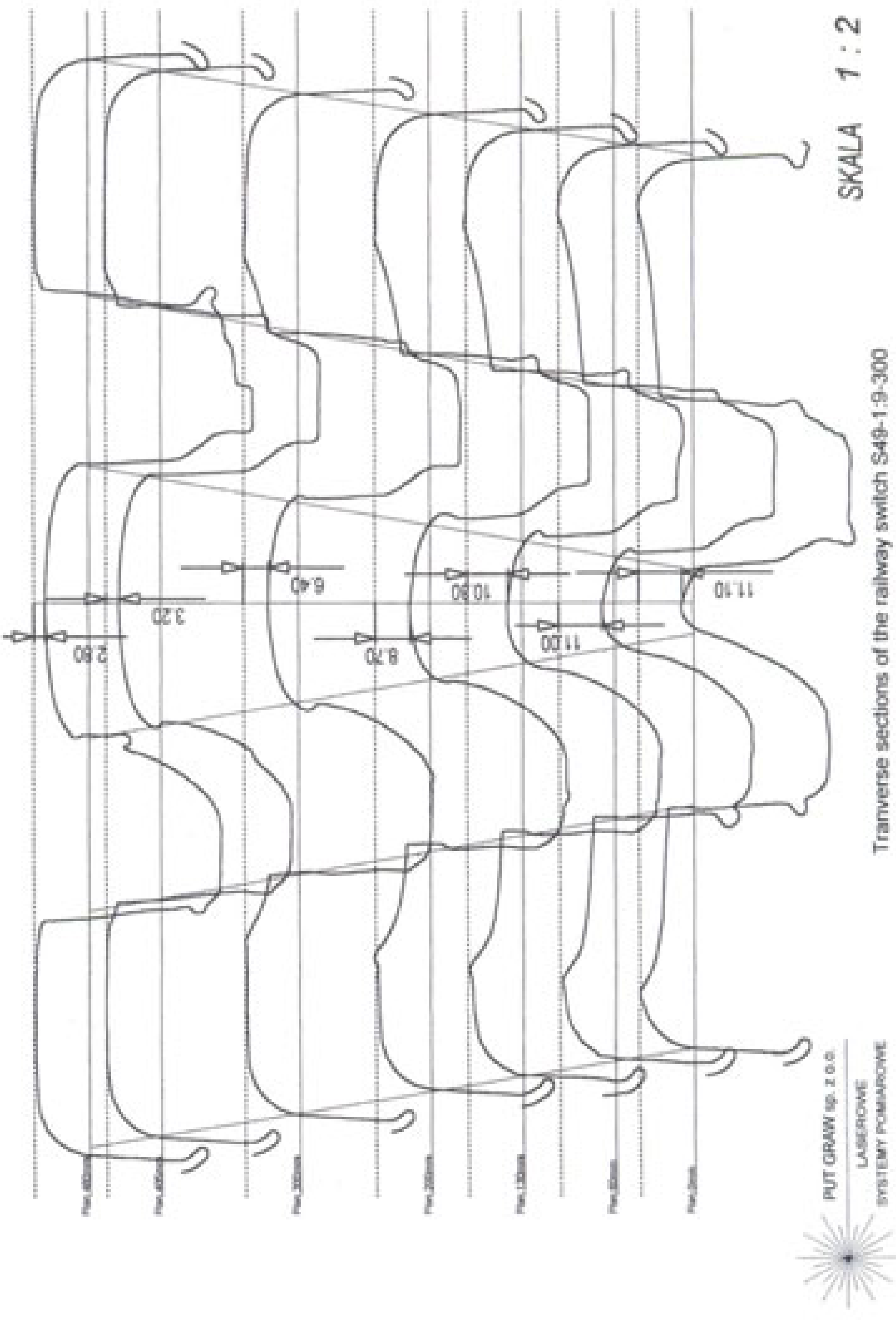

Figure 18: Multiple transverse sections of the railway switch at different locations along its length.

3.6 Track geometry cars

Safety measures call for inspection of the railway tracks at carefully determined service time increments. The inspection task requires evaluation of the selected track geometry parameters: this has to be done reliably and in real-time which is being done using test vehicles. The family of these vehicles includes entirely Polish designs: WPA-50 (Burghardt *et al.*[5]) and EM-80 (Madejski *et al.*[4]), and also fully refurbished by P.U.T. Graw the Plasser & Theurer EM-120 one. A general data acquisition, storage and analysis system is shown in Figure 19:

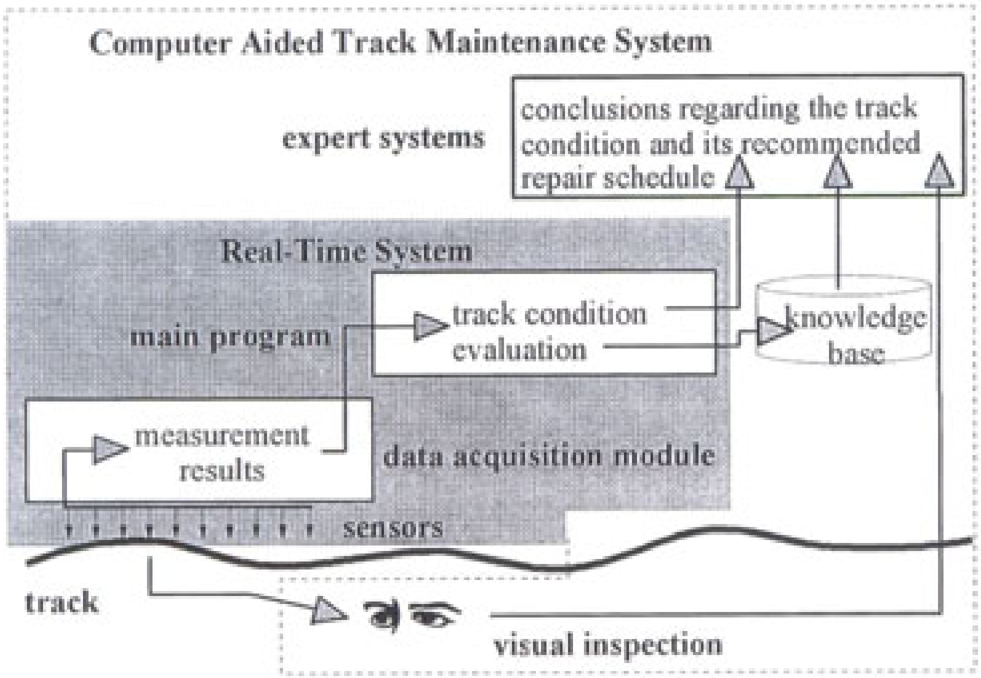

Figure 19: General outline of the track maintenance system.

All real-time data acquisition and further signal processing must recognise the elementary distance increments as small as 0.25 m with parameters' accuracy of about 0.1 mm. The WPA-50 self-propelled measuring car was designed for low-speed operation at 50 km/h. However, its slightly modified real-time data acquisition and processing system has been tested at speeds exceeding 120 km/h already and implemented in a refurbished EM-120 car. Geometrical track parameters determined include among others:

- left and right rail profiles
- cross level
- horizontal curvature of both rails
- track twist,
- track gauge

The system was designed to work in the on-line (real-time) mode when driving along the track and in the off-line mode during calibration, simulation and replay of stored results from previous measurement sessions (Figure 20).

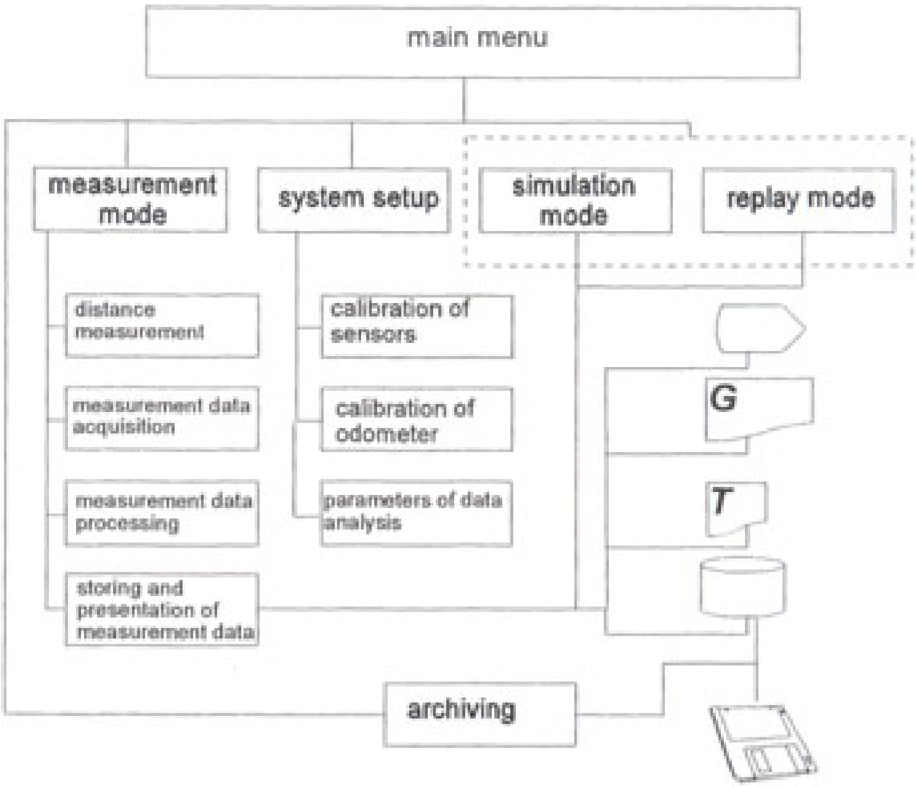

Figure 20: General structure of the geometry car system software.

Graphical output of seven values is produced in real time by the system. Track faults detected may be automatically chained to be treated as a single defect provided that several successive parameter values exceeding the boundary value are found within a given distance from each other. Multiple analysis parameters supplied to the system by the operator include the standard reference length (usually 1000 m) used for evaluation of track condition, data used for automatic track curve detection, etc. Output files produced by the system are stored in an external archive; they are also used as data for expert systems supervising the track life history and determining service time increments. All information collected by the geometry cars are stored in a dedicated stationary central database system. The database makes it possible to retrieve historic data on demand when any analyses have to be carried out, in case of accidents, etc. (Figure 21). Moreover, the data collected features the main source of information for track maintenance planning. It should be stressed that information collected by geometry cars cannot be measured by track gauges as the car weight reveals additional details of the track quality.

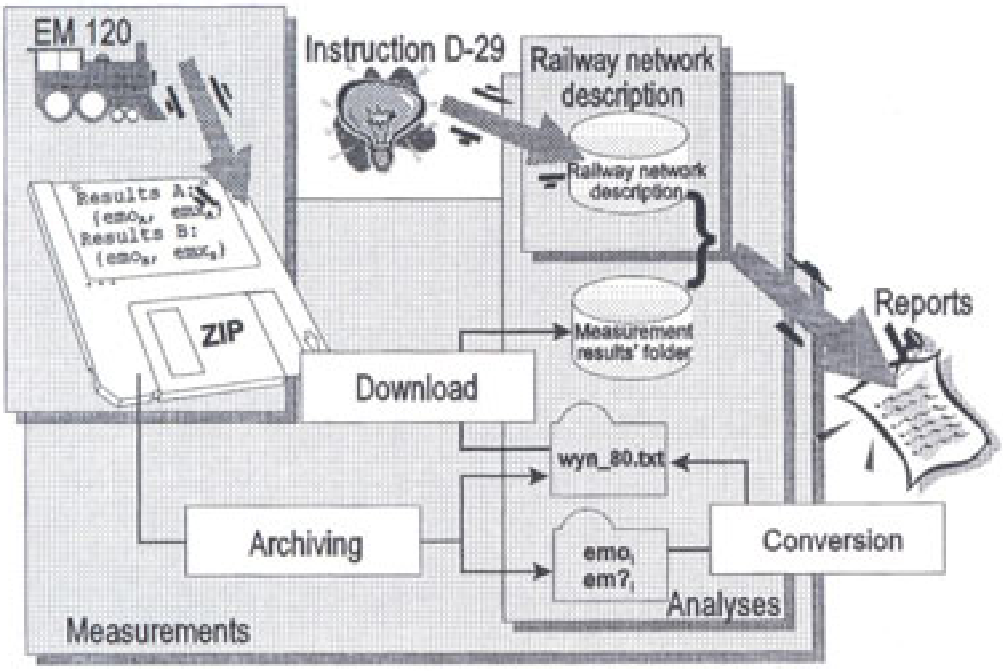

Figure 21: General structure of the stationary data storage and analysis system.

The system shown above is a necessary add-on to the geometry cars, as without them it would be impossible to manage the vast amount of continuously collected measurement data.

4 Measurement of the rolling stock wheels and wheel sets

4.1 Wheel profile geometry measurement

Checking of the wheel profile is required in maintenance procedures of the rolling stock. However, depending on the particular task to be carried out, either entire wheel profile is needed or only its basic geometrical parameters, as defined in the respective regulations. Entire wheel profile is necessary in the manufacturing process of wheels, for quality control, and also in repair work when the cutting offset is to be determined before machining.

Another application is analysis of the reasons for the premature wearout of wheels that may happen when they are used on track with an improper rail head shape - due to manufacturing or further maintenance grinding faults. In all other cases information about basic wheel profile geometry parameters is needed. To this end another gauge has been developed that makes it possible to measure in a fast and convenient way only the O_w, O_g, and q_R parameters.

4.1.1 Continuous wheel profile measurement

The device developed makes it possible to read the entire profile of the wheel surface both of the wheels on the lathe during the manufacturing process as well as of the wheels mounted on the rolling stock - cars and locomotives. Measurement is carried out by manually guiding the contact tip along the checked surface. All readings are logged in the electronic memory of the gauge which may store as much as 40 profiles. All measurement data is downloaded to the PC computer for processing of measurement data. Dedicated proprietary software is used for visualisation of results, analyses, annotating, and comparing the measured profiles with any reference profiles that might be selected by the user. These include, for instance, standard wheel shapes or previous measurement results, making it possible to follow wearing out of the working surfaces of the wheels. Once the profile is measured it may be freely zoomed, panned, and rotated, and measurements may be made in angular and Cartesian coordinate systems (Figure 22). It is possible to determine any dimensions of the profiles, including their O_w, O_g, and q_R parameters.

A unique application of this software is juxtaposition of the measured rail head profiles and wheel profiles. This makes it possible to carry out detailed analyses regarding the mechanism of wearing out of the particular surfaces of the mating elements. Measurements may be made of particular profiles, their fragments or superimposed profiles.

4.1.2 O_w, O_g, q_R measurement

Many applications call for determining O_w, O_g, and q_R parameters only, disregarding the true wheel profile. This is so in most maintenance applications. Dedicated $O_wO_gq_R$ gauge is a specialised electronic vernier making it possible to measure these geometrical parameters of the wheel on site and - eventually - store them for further use. The dedicated database system was developed to make it possible to retrieve previous measurement data, compare them, and to output hard-copy reports on a PC, e.g.:

```
        Measurement Report, done: 20.01.1998r at 13:38

   Repair shop: Xxxx    Measured by: Aaa Bbb     Staff ID: 999
            Train #: 21435                    Car  #:   149
            Bogie A  32145                    Bogie B  87609
      Wheelset 1       Wheelset 2       Wheelset 3       Wheelset 4
      123455432        234554321        345543211        455432112
        Wheel            Wheel            Wheel            Wheel
      Right  Left      Right  Left      Right  Left      Right  Left
Ow    26.9   26.9      26.9   26.9      26.9   26.7      26.5   26.3
Og    24.3   24.6      24.8   24.9      25.6   24.3      24.3   24.3
qr     8.6    8.8       9.0    9.2       9.9    8.6       8.6    8.6
```

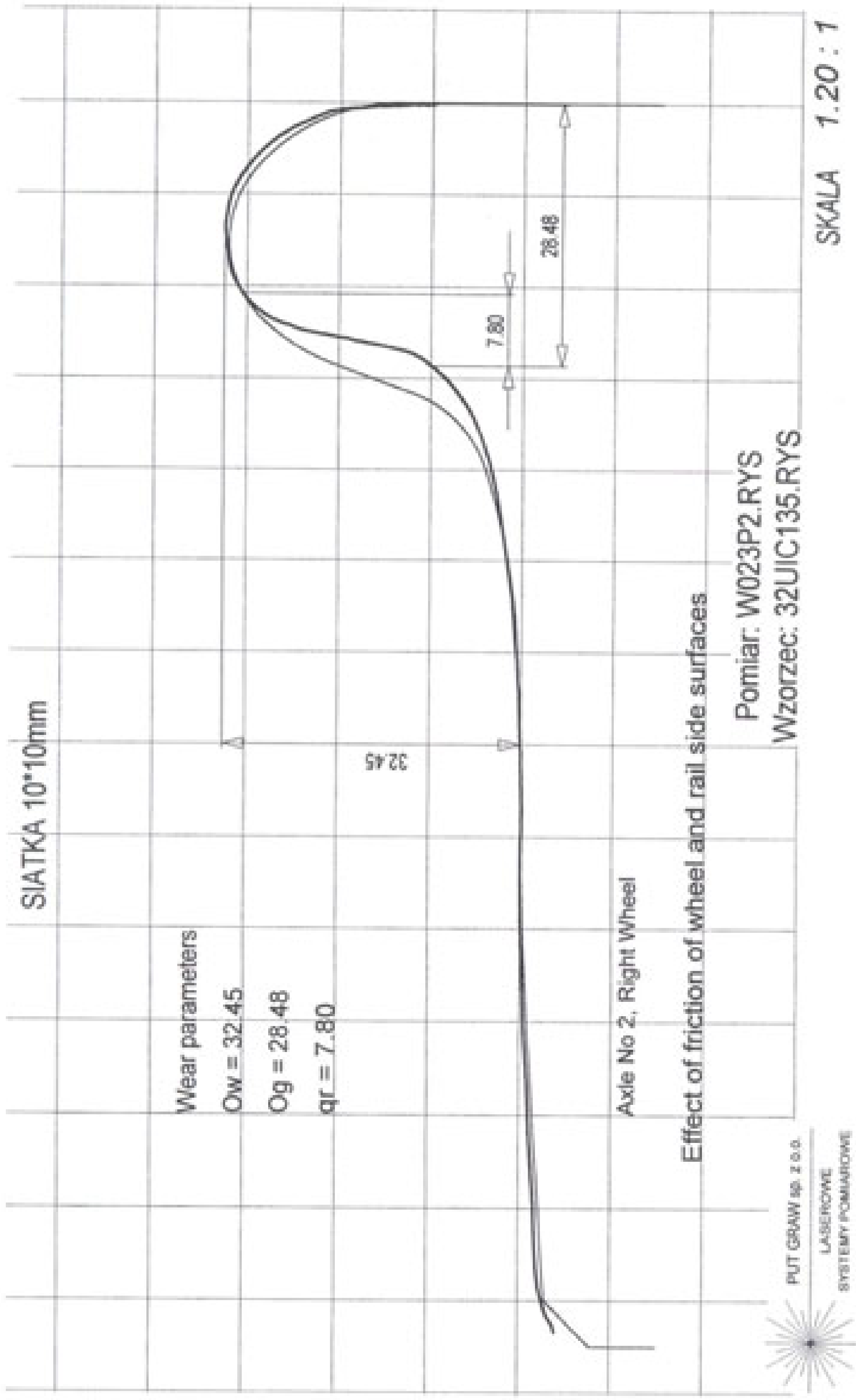

Figure 22: Worn out wheel running surface profile; dimensions were added in user selected locations.

4.2 Automatic geometry control of wheel sets of the rolling stock

All efforts in geometry measurements in railways are aimed at ensuring safety of the traffic. Therefore, it is necessary to control regularly the basic geometrical parameters of wheelsets of the rolling stock. The special measurement system was developed by P.U.T. Graw (Grabczyk *et al*[8]) for the Railway Research Institute (CNTK) of the Polish State Railways. Its task has been to make it possible to measure wheel profile parameters and wheel diameter during train shunting. As things are, the required profile measurement accuracy was achieved (Figure 23), and also distance between wheels in a wheel set, whereas the system's diameter measurement module is still under development (Figure 24).

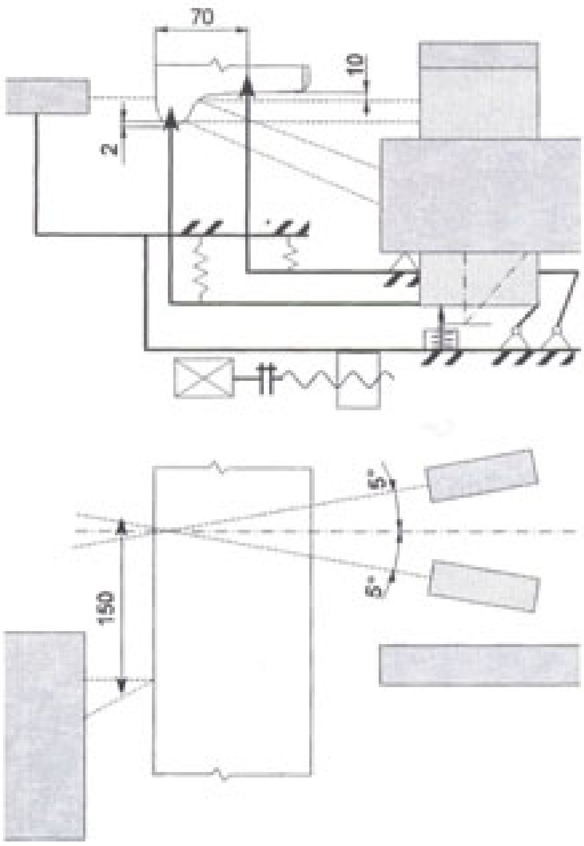

Figure 23: Measurement system for the wheel rim.

This system is quite independent from the maintenance staff and does not require any operator's involvement in the measurement process. The measurement system is a stand consisting of two independent modules for the wheels' diameter measurement, and two additional ones for the measurement of the wheels' profiles.

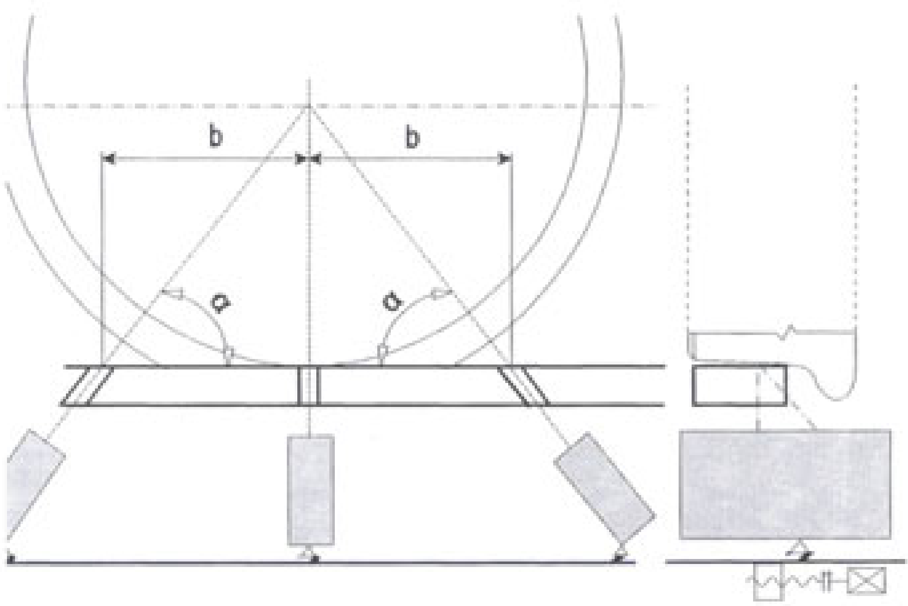

Figure 24: Non-contact wheel diameter measurement module - under development.

One of each type of module is mounted respectively on the right and left sides of the track. The results of the experiments revealed that there is a good repeatability of measurements of all parameters and the differences between the manual, contact measurement methods, and the new, non-contact methods were of about 0.5 - 0.7mm for the wheel profile, and ±0.5 mm for its diameter.

5 Recapitulation

Safety targeted measurement gauges and systems were presented - all of them developed, tested, and deployed. They ranged from stationary systems for rail manufacturers, checking wheel sets of rolling stock for railway maintenance services, through the geometry cars, to the portable and easy to use measurement gauges.

All of them make it possible to store and archive the results. This information - properly used and interpreted by dedicated software analysis including dedicated expert systems - helps to bring track and rolling stock quality and resulting operation safety, to a new, significantly higher level. The scope for users of this hardware and software is very broad - ranging from the manufacturers to the railway maintenance staff and up to the geometry cars' and wheel set control system operators. Further, implementation of the EDI systems, making use of the RF and telephonecommunication channels, will make access to the track and rolling stock condition data and analysis results possible on line.

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