DEDICATED MULTIPROCESSOR SYSTEM FOR AUTOMATIC RAIL FLAW DETECTION

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Abstract

An automatized ultrasonic rail flaw detection system has been developed for real-time rail flaw detection and evaluation. The whole system installed on a testing vehicle, working under rough environmental conditions must determine the internal irregularities of the rail, document them on the basis of a table containing the danger information, and immediately mark the rail in order to make easy the identification of the faulty segments for maintenance staff.

During the measurement, three pairs of ultrasonic transmitters and receivers, with different orientation, scan the rail providing indirect information about the vertical section. The rail flaw detection procedure itself is a twodimensional pattern recognition problem consisting of image reconstruction, spatial filtering with thresholding and classifying phases.

Preliminaries

One of the most competitive tasks for development engineers is to build reliable diagnostic equipment testing complex dynamic systems. Among them checking the country-wide railway track network can be considered a really challenging problem. The rails are naturally checked for defects by the manufacturer, but this control skips through defects of microscopical magnitude, e.g. oxide inclusions and small rolling errors.

The problem is that these defects tend to grow significantly under the enormous mechanical and thermal stresses, which the rails must stand, and result in flaws and cracks critical for traffic safety. Thus, the periodical testing of the rails, and recording the previously sensed, but still minute defects are of the greatest importance. The cracks in the rails when measured locally with hand-held equipment may be considered to be static, although, normally they evolve and grow slowly. Such tests are, of course, reproducible and give credible measuring results.

Testing the rails in the huge dimensions of the whole country raises many problems. The measurements are practically no more repeatable due to the long acquisition time, normal traffic conditions and urgent need for identifying the critical rail flaws as fast as possible. Thus, the track with its hidden and perceptible flaws must be considered as a dynamic object being identified in real-time as the measurement equipment passes by.

The most widely used rail testing technology is the ultrasonic checking. The ultrasonic heads of different geometry, typically perpendicular (rail surface-to-bottom) and tilted (rail surface-to-shoulder) ones, are slid in fixed configuration along the rail together with other possibly non-ultrasonic sensors.

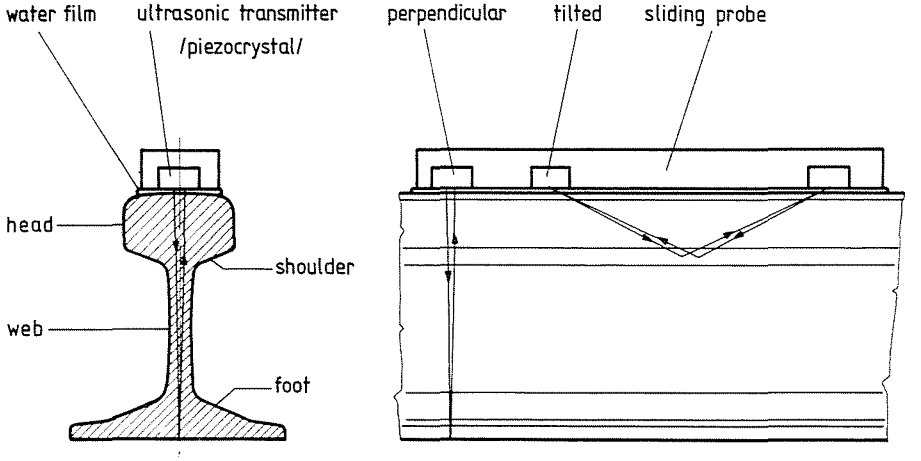

Fig. 1. Ultrasonic sensor assembly

The rail testing technology developed by the Hungarian State Railways, being still in use, is based on this sensing technique and comprises the whole sensing-identification-documentation-maintenance cycle.

The ultrasonic echo signals coming from a single perpendicular and two pairs of tilted heads, as well as the distance signal, are projected by means of suitable analogue hardware onto a rolling photopaper tape. The signals can also be traced on CRT screen for simple hardware diagnostic purposes. The whole hardware is mounted on the railway carriage moving continuously across the country.

The photopaper tapes containing echo signals from the day-long measurements (several hundred kilometers of the track) are sent to a special evaluating center to be scanned visually for flaws, where the types of flaws are identified by their location, size, density and danger level. On the basis of these data, the suitable maintenance activities are inferred and documented, then appropriate dispositions (rail replacement, etc.) are submitted to the maintenance stations all over the country.

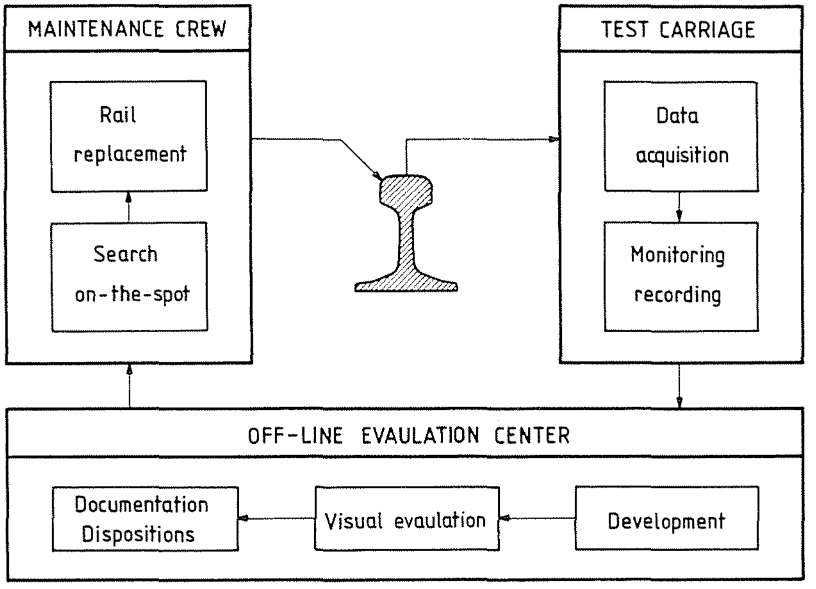

Fig. 2. Present rail testing technology

Due to the unreliability of the distance measurements, the documented positions of the flaws are only approximated. In order to carry out their dispositions, the maintenance crew must execute a local search with the aid of a hand-held equipment.

The testing technique, described above, suffers, of course, from considerable shortcomings, e.g.:

— there is simply no data reduction during recording, predominantly the faultless regions of the rails are recorded;

— data processing is significantly delayed (by days—tape development and interpretation) and probably biased due to the human inability for long-time concentration;

— due to the separate recording and data processing, the secondary (on-the-spot) localizing procedure is troublesome and cannot be overcome within the existing technology.

These and other shortcomings were quite natural in the time of system development in the early sixties. Confronting with powerful digital hardware now available the outlined technology is clearly obsolete.

Being aware of it, the Hungarian State Railways have sought ways for improving the efficiency of the testing. Since the recording equipment has already been used up, it was decided to initialize an entirely new, technologically up-to-date development project.

Objectives and Requirements

The main consideration of the development was to get rid of the above-mentioned shortages by entirely eliminating the photopaper carrier, incorporating the whole off-line evaluating center into the recording equipment, thus creating an intelligent, fully automated detecting and diagnostic system, with the minimum of human factors involved.

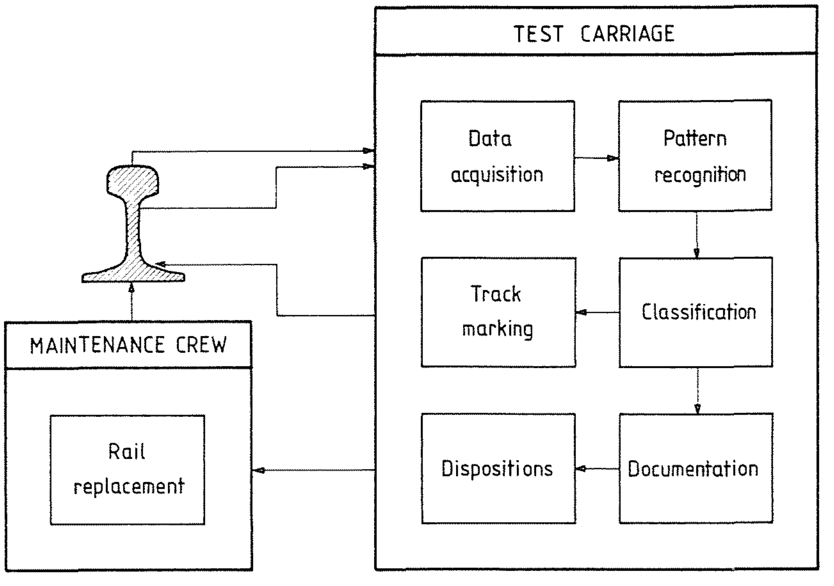

Fig. 3. Developed rail testing technology

The main objectives of the development were the following:

— to integrate on-line ultrasonic data acquisition with off-line postprocessing and documentation into one real-time activity;
— to develop the recording vehicle with on-board computer architecture able to cope with the tasks of:
  — data acquisition,
  — signal processing,
  — flaw data evaluation,
  — flaw data certification,

  simultaneously, keeping pace with the incoming data (with reasonable vehicle speed);
— to use additional data sources (sensors) for better flaw recognition;
— during the non-measurement intervals the equipment should be able to operate as a postprocessing computer center for statistical and other computations;

— the faulty places demanding the immediate attention of the maintenance crew (rail replacement) should be paint-marked as the recording vehicle passes by.

Before going into details of the signal processing involved, it would be appropriate to summarize the fault phenomena and the maintenance required.

In Hungary, the rails of two different dimensions are in use. When track-laying rail segments of the same dimensions are connected with fish-plates and fish-bolts, segments of different dimensions are suitably cut and welded together.

The rail defects are situated usually in the rail head and are mainly of horizontal and skew geometry. The small oxide inclusions in the head grow into large shell-like defects which often surface and become sources of critical transversal cracks. In the rail web, horizontal cracks can usually be encountered, with skew faults originated in bolt holes. The fatigue process of the weldings is still another source of defects.

It can be stated as a rule that the most dangerous faults are cracks around the holes and in the web as well as the welding deficiencies between the segments. The faulty rails must be replaced by cutting out the weakened parts (at least 6 m apiece) and welding new faultless sections into them.

The main fault types—together with their dimensional specifications and maintenance activities prescribed—are standardized in suitable parameter/decision tables supplied by the Hungarian State Railways.

System Concept – Task Partition of Hardware and Software

Considering that the measurement data are not only recorded but should be properly analyzed and documented, and that the measurements are performed simultaneously on both rails, a natural system configuration emerges: two independent measuring subsystems must be connected to a PC-based system controller containing the necessary mass storage, hardcopy devices, etc.

The most responsible phase of development is the distribution of tasks among the hardware and software systems. Once accomplished, it determines the functional units and the system structure, which, on the other hand, accounts for system efficiency both in normal and critical operational conditions.

The complete substitution of the human evaluator with his visual pattern recognition ability calls for machine algorithm of considerable complexity, and the system must be supplied with distributed processing facilities, executing various concurrent tasks.

The current ultrasonic signals refer to the different places in the rail and come from the heads of different ray geometry. For proper comparison and interpretation these signals should be specially transformed and somehow buffered.

The buffered signals forming 2-dimensional images are blurred with noise of acoustic and electrical origin. The efficient noise and artifact suppressing technique is the spatial filtering which together with the subsequent elementary pattern selection gives the preprocessing part of the main algorithm.

The raw pattern data together with other sensor and control signals (eg. bolt hole sensor, welding sensor, engine driver's on/off line, etc.) must be classified for faults and these data enclosed in error records must be transmitted to the system controller.

The documentation of the faults should be prepared in two different ways. All the data ought to be, of course, recorded and stored in suitable format for further examinations, statistics and trend analysis etc. Nevertheless, the most critical data should be available immediately after the measurement as a sort of documentation abstract. These data together with the paint-marks left by special-purpose hardware activated by the system controller are considered sufficient for fast and reliable rail maintenance without any secondary fault search on-the-spot.

An additional requirement was to develop the system controller configuration to be used as a kind of fully supported data processing center during the standstill time between the consecutive measurement runs.

A purely hardware solution as well as a software one was automatically precluded due to both high density and rate of the data and to the relative complexity of the classifier algorithm. In the final phase of the classification process cca. 40 distinct kinds of flaws are to be classified. Therefore, instead of the complex and rigid hardware and the one-chip processor software implementations, a microprogrammable bit-slice classifier architecture was developed combining speed with considerable processing power. On the other hand, the relatively simple control structure of filtering and elementary feature extraction led to a pure hardware implementation of the initial part of the algorithm. The error record handling (storing, printing) and other control activities (alarms, marking), still real-time tasks but with less strict time constraints, do not demand special implementational considerations.

The hardware and software structure of the measuring system can be outlined as follows:

— transducer circuitry:

purely analogue, it controls ultrasonic test signal generation and sensing.

— A/D conversion:
interfaces the digital processing system; the 2-bit magnitude resolution, 4-bit in-depth resolution in the rail head (for tilted heads) and the same for the whole rail height (perpendicular heads) are considered sufficient with respect to the signal readability and the noise immunity as well.

— pipe-line structured processor:
Z80 processors with special memory architecture are responsible for
a) proper reshaping of tilted head signals to match physically those coming from the perpendicular heads,
b) buffering both kinds of signals,
c) filtering out artifacts and noise by means of a 3×3 moving window filter. The implemented filter algorithm is suitably tailored to the application and performed by read-out operation from a table.
d) discovering easy-to-recognize elementary patterns, eg. horizontal vs. vertical, upper vs. lower part of the head, near bolt hole or not etc.

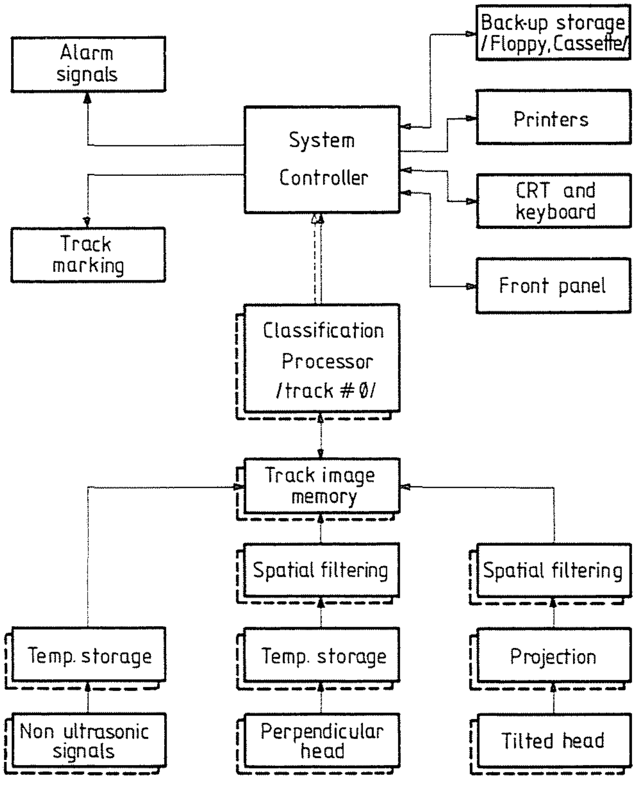

Fig. 4. Detailed system structure

e) buffering the preprocessed data together with other sensor signals in a multi-port memory which is the interface between the pipe-line processor and the subsequent processing unit.

The software involved is minimal and is limited to control tasks maintaining constant data stream through the unit.

— sequential processor-classifier:

Am2900 family based bit-slice processor with considerable data and program memory performing tasks of:

a) further feature abstraction on the buffered data (see point e., above),
b) classifying the discovered flaws according to the decision tables supplied,
c) compiling records with all the relevant facts (fault class, position, dimensions, dispositions, etc.),
d) maintaining the record stream towards the controller.

All operations derived from the concrete measuring tasks are solved by proper programming. The code is loaded from the controller making it possible to switch between different operating modes—classifier (for measurement) or all-pass (test and demonstration).

It is estimated that the classifying process involves app. 100 micro instructions/flaw, each instruction 128 bit-wide.

— system controller:

Z80 based microcomputer (MOD-81) with standard (CRT, KB, LP, mass storage) and special (front panel, paint-marking device) peripherials responsible for:

a) setting-up the measurement when departing,
b) testing the whole system configuration and managing a functionable configuration,
c) loading proper code into the classifier,
d) managing constant record stream during the measurement,
e) distributing the error records among the storage devices and printers,
f) intervening on critical events, e.g. paint-marking of the rails when fatal faults occur, suspending the measurement in the case of operational trouble, alerting the operator when system is running short of resources, etc,
g) realizing an easy-to-use graphical and textual man-machine interface,
h) yielding a customary post-processing workstation for the rail engineering computations with disk-loadable system and application program.

The programs for the system controller were written in high-level language containing real-time programming tools. The software development technology (Real Pascal-S) was supplied together with the controller hardware and basic OS.

Conclusions

Integrating different hardware and software technologies, an efficient measuring system has been developed relatively well tailored to the complex and demanding task of the real-time rail testing on the track.

The move of the previous off-line processing center into the carriage itself, and the substitution of the human work by fast machine algorithms made it possible to

— cut the test cycle from days to hours,
— simplify the circulation of documentation,
— relieve the maintenance crew from some of the former tasks, and simplify the data transmission between measurement and post-processing.

Comparing to the 30 km/h maximal test carriage velocity in the traditional technology the developed system supports testing velocity of 50 km/h which corresponds to an expected 10% flaw density in the rails. The used back-up storage accomodates measurement results from 400–500 km of the track without disk change. Finally the data buffer interfacing the pipe-line and sequential processor covers about 20 m of the rail length.

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