

## DYNAMIC WEIGHING SYSTEM OF RAILWAY CARRIAGES

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**Abstract** – The Dynamic Railway Diagnostics system (DRD) is a DSP-based measurement system, that analyses and stores the deformation signal of the rail caused by a passing train. The weight of the carriage is calculated by signal processing methods, by digital signal processors. This architecture makes the system capable of performing also other signal processing algorithms on this signal, e.g. faulty wheels can be detected. The DSP-based measurement method is a new approach in the field of in-motion weighing. This method can weigh and perform the diagnostics on trains travelling up to 160 km/h.

**Keywords:** railway diagnostics, weighing, DSP

### 1. INTRODUCTION

Nowadays the in-motion weighing of railway carriages is a widely used and accepted method. Numerous companies propose different measuring systems that can perform this measurement. [1-3]

All of these systems perform analogue signal processing, mostly they are upgraded static scales. Nowadays the low cost of digital signal processors brings up the possibility to build a DSP-based system that performs pre-processing on the measured signals. This new approach has numerous advantages in contrast with the analogue measurement systems, such as higher precision, additional diagnostic features, easy upgrading.

This paper is about a DSP based measurement system, the DRD. In section 2., a general description of this system is presented, in section 3. the DSP-based Measurement Units and their functionality are described in detail. In section 4., results of test measurements are presented.

### 2. SYSTEM DESCRIPTION

#### 2.1. Two-level system

DRD is a standalone system that collects, analyses and serves online information about the conditions of the wheels of an in-motion train. The system consists of a powerful host industrial PC and a set of DSP-based measurement units (MU). The MUs and the HOST are communicating via the standard RS-485 protocol. The scheme of the system can be seen on Fig. 1.

The analysis is performed on two levels: the pre-processing is done by the MUs, then the HOST evaluates the pre-processed data. This is a powerful and useful method,

since the HOST handles all data collected and pre-processed by the MUs. With these data various kind of analysis can be performed, e.g. bad measurements can be recognized or faulty wheels can be identified.

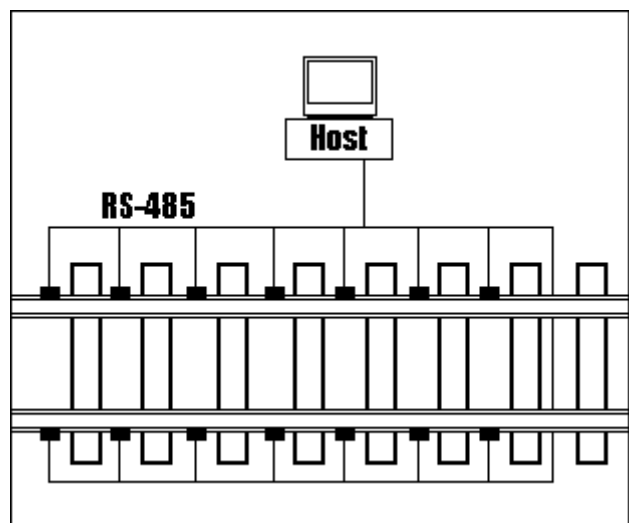


Fig. 1. The DRD system

There are 2x16 or 2x24 MUs in the DRD system, and every MU performs measurement and stores the results for each wheel. At the HOST, all these data are collected and processed. This structure is a fault-tolerant solution, as it ensures high precision at the weight measurement, and enables the isolation of bad measurements.

#### 2.2. Usual operation

The first MU of the DRD system automatically recognizes if a train is passing over the measuring section. This unit "wakes up" the other MUs via the serial line and the measurement process starts. The MUs sample and store the digital data of the deformation signals of the wheels. A typical deformation signal is shown at Fig. 2.

This process is performed on-line, so the calculated data are available just after a wheel has passed at an MU. The measurement process finishes when there is no activity on the rail for a relatively long time, meaning that the whole train has passed at the measuring section. For the end of the measurement process, every MU has a data table in its RAM containing the calculated information for each wheel. The HOST collects these data tables and builds up a large database containing every measured and calculated data.

This is a powerful solution, as on this data a second level of signal processing is performed, in order to calculate specific values or to obtain various types of statistics and diagnostics. The most important one is the weight calculation for each wheel, which is a specific average of the results measured by the MUs.

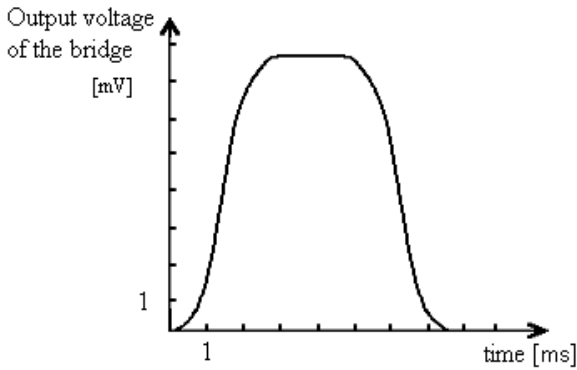


Fig. 2. A typical deformation signal

At the HOST these data are accessible via the standard graphical user interface, so the usual possibilities are available; plotting graphs of the measurements, printing, archiving on hard disk.

Remote system management is also possible as standard PC architecture allows easy interface for wide variety of communication protocol.

The communication line is the standard RS-485 line, where predefined command words are sent between the HOST and the MUs.

### 3. MEASUREMENT UNITS

#### 3.1. Structure

The structure of the MU is illustrated on Fig. 3. The heart of the MU is the Analog Devices ADSP-21065L digital signal processor. This powerful 32-bit floating-point processor enables the MU to perform complex pre-processing of the deformation signal.

The MUs measure the deformation of the rail by strain gages. The DRD system uses a bridge circuit solution suggested by Gerhard Jost in his dissertation [4]. With this solution the weight is precisely measured by strain gages deformed by shearing forces. The gages are placed at the spine of the track, switched in a bridge circuit that compensates horizontal shearing forces.

This solution enables the DRD system to be mounted on any normal section of rail, no prefabricated pieces of rail are used. Therefore there is no need for any serious rebuilding of the measuring section to mount the system.

The strain gages are KG-03 extensimeters of Reznicek & Hlach AG. [5]

The output voltage of the bridge is proportional to the weight force on the rail. This signal is sampled by an AD converter, and digital data are processed by the DSP. Every MU has an Analog Devices audio AD73311 codec IC,

which contains a 16 bit AD and a DA converter. The sampling rate is set to 24 kHz.

The MUs also have a temperature sensor, and the temperature data are stored for each deformation measurement. However, the DSP does not process this value, it only sends it to the host for the global calculations.

In detail, the MU comprises three printed circuit boards: analog front-end, analog electronics and digital electronics card. The analog front-end card is responsible for the supply of the sensor bridges and signal conditioning. The temperature sensor is also placed on this card, because physically this is the nearest to the rail. Power supply circuitry is placed on the analog card. The DSP and an audio codec are placed on the digital card. This part is responsible for signal processing and data storage.

The programming and configuring of the MUs are performed via the HOST computer and the serial (RS-485) line. Each MU can also be monitored and tested.

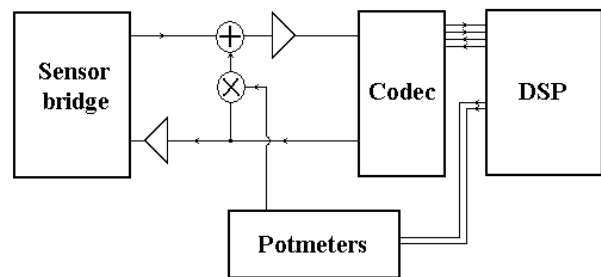


Fig. 3. The functional diagram of the MU

#### 3.2. Functional description

The MUs have three operating modes; Standby, Measurement, and the Autozero mode. In most of the time, the MU is in Standby mode, when the only activity of the system is that it constantly compares the output voltage of the strain gage bridge and a preset trigger level. If this trigger level is reached for the first time, the MU sends a "Measurement Start" command to the HOST, which sets the MUs to Measurement operating mode. When the level of the output voltage is below the trigger level for a relatively long time, the MU signals this to the HOST, which switches back the MUs to Standby operation mode.

During Measurement operation mode, the samples of the deformation signal of each wheel are stored in RAM. From this waveform, an important parameter, the average peak level value is calculated by the DSP. This value is proportional to the weight of the load on the wheel. From these data the mass of the load in the carriage can be obtained.

The shape of the waveform contains other valuable information about the wheel. For example, if the wheel is slightly oval, or partially flat, the waveform will be distorted from the ideal waveform of the circle wheel. In case the wheel is partially flat, the deformation signal would be similar to the one shown in Fig. 4.

With specific signal conditioning algorithms these faulty wheels can be detected. The efficiency of this fault detection is increased as 16 (or 24) MU stores the waveform of each wheel.

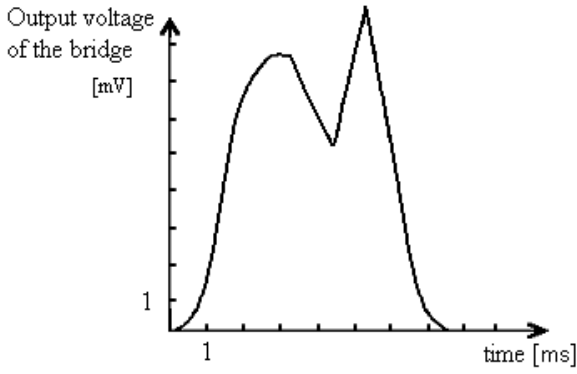


Fig. 4. The deformation signal of a faulty wheel

The DSP calculates and stores the following data for each wheel:

- Peak value
- Deformation pulse duration
- Temperature of the rail
- 32 samples of the deformation pulse
- Ordinal number of the wheel
- Time elapsed from the start of the measurement

The last two values are stored for monitoring purposes. The HOST needs these values in order to build up the measurement database correctly. E.g. it can be identified if an MU has missed a measurement.

The peak value is the average of the samples of the flat top level. This value is proportional to the mass of the railway carriage. The pulse duration is reciprocally proportional to the velocity of the train. The temperature is used in correction calculations at the HOST.

In order to perform the more complex diagnostics on the wheels, or perform further signal processing methods, 32 samples of the deformation signal are also stored and sent to the HOST. This solution also enables a useful possibility, that a human operator at the HOST can check the shapes of the recorded signals.

### 3.3. Calculating the waveform

The strain gage bridge receives an 5 kHz AC supply voltage. Thus the output voltage of the bridge is an amplitude modulated 5 kHz AC signal. The deformation signal is the envelope of this modulated signal. This modulated output signal is sampled by the AD, and the DSP calculates the envelope of the digital signal.

This envelope calculation is performed following the solution suggested in [5]. The main point in this solution is that the envelope function,  $A(t)$  equals to the absolute value of the analytic signal of the incoming AM signal,  $f(t)$ .

$$A(t) = \sqrt{f^2(t) + H^2\{f(t)\}} \quad (1)$$

where

$$f(t) = A(t)\sin(\omega t) \quad (2)$$

and  $H\{f(t)\}$  is the Hilbert transform of  $f(t)$ .

The on-line calculation flow can be seen on Fig. 5. This includes an additional filtering step, in order to reduce noise. The band-pass filter is a FIR filter, with a narrow pass-band around the modulator frequency (5 kHz).

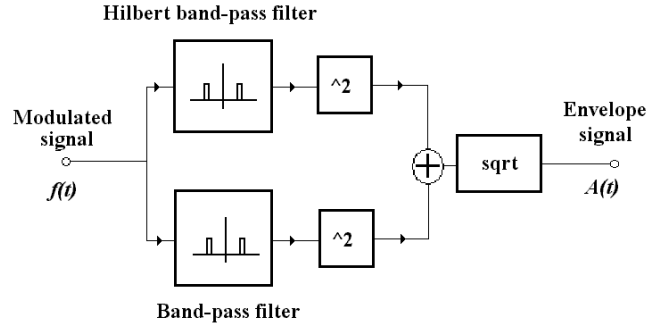


Fig. 5. The envelope calculation flow

This envelope calculation of the incoming data is constantly performed by the DSP, during all three operating modes. The further signal processing methods use this envelope signal as an input.

### 3.4. Autozero

There is a built-in Autozero function in the MUs. When the HOST sends the "Autozero" command to the MU, a control process is performed in order to calibrate the zero level of the strain gage bridge. Obviously, this command is expected when there is no load on the measuring section.

The Autozero process sets two digital potentiometers in order to compensate the occasional asymmetries of the bridge. One of these potentiometers sets an in-phase, the other a quadrature sine wave in order to compensate the output signal of the unbalanced bridge. This solution can be seen on Fig. 3.

### 3.5. Measurement

In case the MU is in Measurement operating mode, and the output level of the gage bridge reaches the trigger level (approx. 5% of peak load level), the storage of the deformation signal starts. All the samples are stored in RAM as far as the level of the signal is above the trigger level.

The stored deformation signal is oversampled, as a few hundred samples are stored in RAM for each wheel. The exact number of samples recorded depends on the velocity of the passing train. For example, if the train is slower, the deformation signal is wider in time, therefore more samples are taken.

As stated in 3.2., every MU calculates and stores different values for each wheel. Some of these calculations are performed on-line, but some of them can only be calculated when the whole deformation signal is available in RAM.

The most interesting process is the calculation of the 32 samples, which are sent to the HOST for further processing. Decimation has to be done as the DSP stores a lot more sample points than 32 during the on-line recording procedure. The decimation is always done for 32 points

regardless of the velocity of the train (regardless the number of points recorded).

For this decimation process an  $n$  parameter is calculated, where

$$n = \left\lfloor \frac{\text{number of samples recorded}}{32} \right\rfloor \quad (3)$$

After the evaluation of this parameter, the  $n$ -decimation can be done on the recorded signal.

## 4. TEST RESULTS

### 4.1. Test circuit

In order to test a prototype MU at laboratory conditions, a test circuit is built, which substitutes the strain gage bridge during the test measurements. This is also a bridge circuit with the same properties as the strain gage bridge. By changing the resistance of the elements, an output signal is generated, so the deformation signal can be simulated. The exact values of resistances and voltages of the simulation are based on the information documented in the Reznicek & Hlach KG-03 extensimeter datasheet. [6]

In the test bridge circuit, there is a Reed-relay in parallel with one of the resistances. An impulse generator switches this relay with rectangular impulses. This has the same effect as if the resistance of the strain gage would have been changed due to deformation.

The variation of the deformation signal as a function of time can be simulated changing the width of the rectangular pulse of the generator.

The test circuit is suitable to test the MU's standalone operation.

The next step of the testing is to perform measurements on a real railway line.

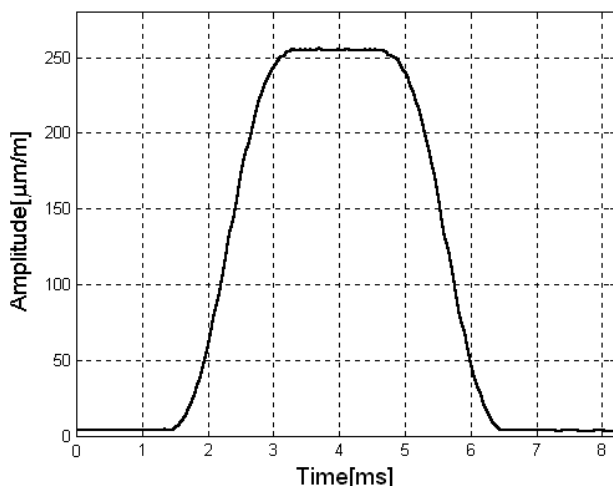


Fig. 6. The digital deformation signal (peak level corresponds to 10 t of mass)

### 4.2. Test results

After performing a series of test measurements, the following results are obtained:

The Autozero function successfully compensates the unloaded sensor bridge if it is not balanced. The remaining zero error due to the resolution of the digital potentiometers is around 1,5% of the peak load (10 t) output level.

The prototype is calculating the envelope function as stated in 3.3., and stores the deformation signal in on-chip RAM. An example can be seen on Fig. 6. This signal is captured by the MU, the figure is the plot of the content of the internal memory. The width of the signal is about 2 ms, that corresponds to the deformation signal of a train passing around 160 km/h.

## 5. CONCLUSIONS

The Dynamic Railway Diagnostics system (DRD) is a DSP-based measuring system, which diagnoses in-motion railway carriages. Primarily it measures the weight of the carriages, secondarily it performs fault-detection on the wheels of the carriage. There is also a possibility for future extensions and upgrade of the system, as the DSP software can be enhanced without modification of hardware.

Since the digital signal processing is a new approach in the in-motion measurement field, the DRD system is expected to provide better performance, than the systems used today. The DRD system can perform new diagnostic functions and measure weight properly in a wide range of velocity, with a maximum velocity of 160 km/h.

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