DSP-BASED DYNAMIC RAILWAY DIAGNOSTIC SYSTEM

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Abstract: The Dynamic Railway Diagnostic System (DRD) is a DSP-based measurement system that measures and stores the deformation signal of the rail caused by an in-motion train. The DRD is an intelligent sensor system, where the DSP-based sensor units pre-process and store the deformation signal, and a HOST PC collects the results and performs a second level of signal processing. This architecture makes the system capable to perform also other signal processing algorithms, e.g. faulty wheels can be detected. The DSP-based measurement method is a new approach in the field of in-motion weighing, with numerous advantages. Precise measurements can be performed on trains traveling up to 160 km/h. The visualization possibility of the deformation signals can be used to perform diagnostics on the wheels. In the paper, the DRD system and the DSP-based Measurement Units are presented. In addition to the theoretical considerations, measurement results of a built DRD system are presented, as well.

Keywords: railway diagnostics, dynamic weighing, digital signal processing, sensor network

1. Introduction: The DRD System

The in-motion weighing of railway carriages is a widely used and accepted method. The systems used today generally perform analog signal processing, basically they are enhanced static scales. The low cost of digital signal processors (DSPs) brings up the possibility to build DSP-based Measurement Units (MUs) that can be positioned near to the sensors to replace the analog electronic signal processing circuits. Due to the application of DSPs, the functionality of the system has some advantages versus the analog ones. The main advantage is that the digital signal processing methods (e.g. FIR filtering) can be realized efficiently and they provide higher precision than the analog methods. Besides that, the measured results are stored in RAM for further diagnostic purposes and the relatively high sample rate (24 kHz) ensures that the shape of the deformation signal is also available for visualization. Another advantage that the software implementation of the DSP methods has the possibility of easy upgrading.

The DRD system is a distributed measurement system that is built from intelligent DSP-based MUs and a HOST PC, where the measured data is collected and analyzed.

The paper is organized as follows: in section 2. a general description of the system is presented, in section 3. the digital signal processing methods are described in detail. In section 4., results of test measurements are presented.

2. System description

2.1. System architecture

The system consists of an industrial PC and a set of DSP-based Measurement Units. The MUs and the HOST are communicating via the standard RS-485 serial bus. The architecture is shown in Fig. 1. The MUs are represented by the black boxes attached to the rail.

The MUs measure the deformation of the rail by strain gages and pre-process this signal. Every MU stores a set of measurement results (weight, waveform, timing data) for each wheel that has passed at the measurement section.

As the train has passed, the HOST collects the measurement data from the MUs, and sets up a measurement database by sorting the results. The needed information can be obtained from this database, mainly by averaging the results of the different MUs. This is a fault-tolerant approach that provides high precision at the weight measurement.

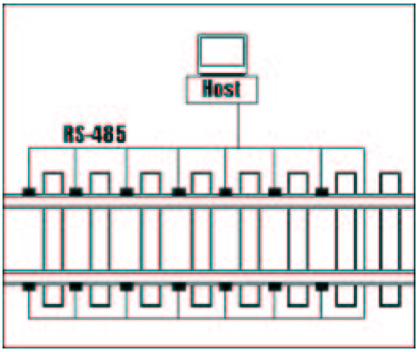

Fig. 1. System architecture

2.2. Measurement Units

The structure of the MU is illustrated on Fig. 2. The MU is based on the Analog Devices ADSP-21065L digital signal processor. The DSP samples the signal of a sensor bridge built from strain gages. The supply of the sensor bridge is also provided by the DSP via a DA converter. The AD and the DA is realized in a common Codec IC (AD73311). The digital potentiometers are used to balance the zero-offset of the sensor bridge. The values of the potentiometers are outputs of a control loop function (Autozero), that runs on the system when there is no load on the rail.

The used sensor bridge circuit is a solution suggested by Gerhard Jost in his dissertation [1]. This circuit measures the weight precisely by the strain gages excited by vertical shearing forces. The gages are placed at the spine of the track, switched in a bridge circuit that compensates horizontal shearing forces. The strain gages are KG-03 extensometers of Reznicek & Hlach AG. [2]

The output voltage of the bridge is proportional to the weight force on the rail. This signal is sampled by a sampling rate of 24 kHz. The MUs also have a temperature sensor, and the temperature data are stored for each deformation measurement.

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

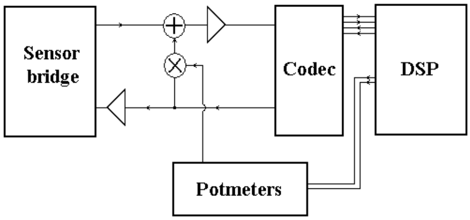

Fig. 2. The structure of the MU

3. Signal processing methods

3.1. The deformation signal

The typical deformation signal of an in-motion train is shown in Fig. 3. The weight of the wheel that caused the deformation is proportional to the average level of the flat top of the curve.

The shape of the waveform contains other valuable information about the wheel. E.g. if the wheel is slightly oval, or partially flat, the waveform will be distorted from the ideal waveform. The faulty wheels can be identified from the stored waveform data.

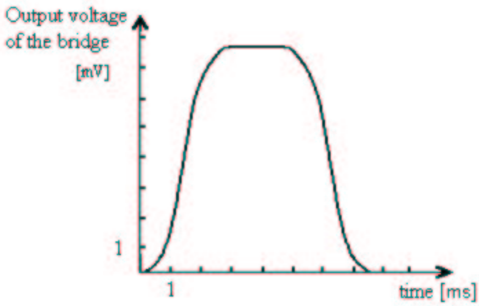

Fig. 3. The expected deformation signal

The measured deformation signal has considerable variance as the movement of the carriages have various kind of fluctuations. Due to vertical fluctuations, the deformation signal caused by one wheel can be different at the MUs. If the amplitude of the fluctuation is relatively high, it is possible that a wheel “flies” over a sensor. In this case the MU misses the measurement, the signal level does not rise above the trigger level.

The use of more MUs can avoid these effects, as every MU stores a deformation signal for each wheel. All of the measurements are collected at the HOST, and the measurement database is organized by the timestamps of each measurement. From this database, the missed measurements can be identified, and the fluctuations can be reduced by averaging.

3.2. Signal processing at the Measurement Units

The strain gage bridge receives an 5 kHz AC supply voltage from the DSP via the DA converter, so the output voltage of the bridge is an amplitude modulated 5 kHz AC signal. The deformation is proportional to the envelope of the modulated signal. The modulated signal is sampled by the AD, and the DSP calculates the envelope of the digital signal.

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

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

This envelope calculation is performed following the solution suggested in [2]. 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 ($f(t)$), and $H\{f(t)\}$ is the Hilbert transform of $f(t)$.

The on-line calculation flow can be seen on Fig. 4. 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. The further signal processing methods use this envelope signal as an input.

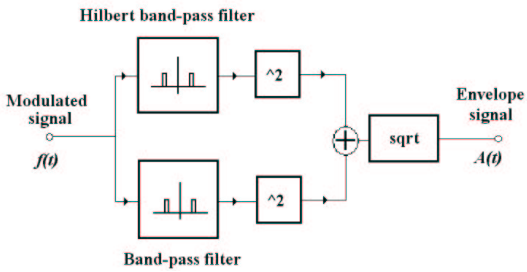

Fig. 4. Waveform calculation

When the value of the envelope signal rises above a trigger level (a wheel passes at the measurement section), the waveform storage starts at the MU, and the deformation signal is stored for each wheel. From the raw data, the MU evaluate the following values: peak value, deformation pulse duration, 32 samples of the deformation pulse, ordinal number of the wheel, time elapsed from the start of the measurement. Additionally, the temperature of the rail is stored for each measurement.

After the measurement period, when the entire train has passed, each MU has 38 numeric (16 bit floating point) value stored for each wheel. These data are collected by the HOST.

The 32 samples of the deformation signal are sent to the HOST in order to make the shape of the deformation signal available for visualization for the faulty wheel detection. To calculate these 32 values, decimation has to be done as the DSP stores much more sample points during the on-line storage process. The decimation results always in 32 points regardless of the velocity of the train (regardless the number of points recorded). The timing values are sent to the HOST in order to make it possible to build up the database of the measurements correctly.

3.3. Signal processing at the HOST

The HOST collects the measurement results from the MUs and builds up the measurement database. The faulty wheels and the missed measurements are located. The distorted deformation signals can be shown to human operators. The weight value of each wheel is calculated by averaging the measured weight values of different MUs.

The data are accessible via the standard graphical user interface, so the usual possibilities are available; visualization 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.

4. Test results

The test measurements were performed on a prototype DRD system, which consists of 4 MUs and a HOST PC. The prototype system is set up on a straight section of a regular railway line with significant railway traffic. In Fig.5. a series of deformation signals is plotted. In Fig. 6. the deformation signal of a wheel of a locomotive is shown in detail. This signal is captured by an MU, the figure shows the content of the internal RAM after the envelope calculations. In Fig. 7. the 32 points of the deformation signal is shown in the same way as it is visualized at the HOST.

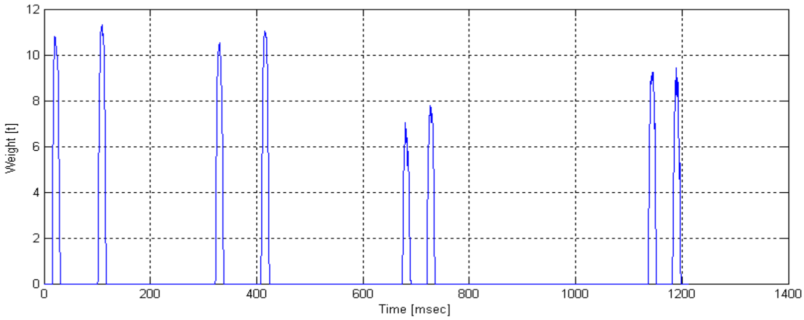

Fig.5. Reproduction of a series of deformation signals of one MU at the HOST

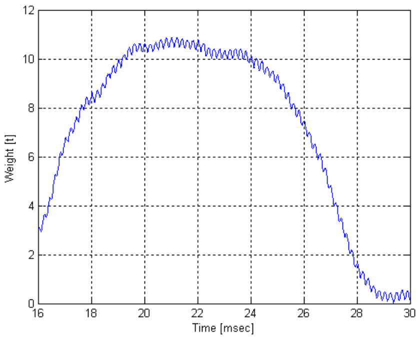

Fig. 6. Detailed deformation signal

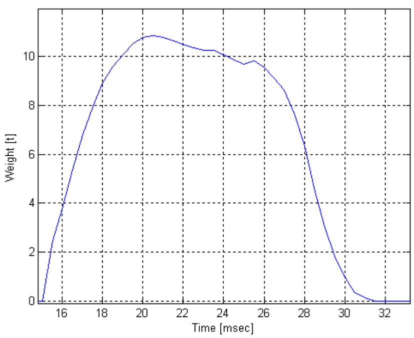

Fig. 7. Deformation signal after decimation

The measured deformation signals prove our previous assumptions, the proposed signal processing algorithms can be used to evaluate the required data efficiently. The Autozero algorithm compensates the zero-offset with a remaining zero error (due to the resolution of the digital potentiometers) around 1,5% of the peak load output level. The width of the signal is about 14 ms that corresponds to the deformation signal of a train passing around 80 km/h.

These prototype measurements show that the deformation signal is not distorted even if the velocity of the train is high. The maximum allowed velocity is 160 km/h, since above this value there are not enough samples to perform the calculations. This maximum velocity is an important advantage of the DRD system, as the commercial in-motion scales have a much lower velocity limit.

5. Conclusions

The Dynamic Railway Diagnostics system is an intelligent sensor system, that diagnoses in-motion railway carriages. Primarily it measures the weight of the carriages, secondarily it performs fault-detection on the wheels of the carriage. The system is based on intelligent sensor units, the Measurement Units and a HOST PC. The DSP-based MUs measure the deformation signal of the rail by strain gages, and the signals are pre-processed by online digital signal processing methods. The HOST collects the pre-processed data, and builds up a measurement database, with the averaged weight values and visual representation of the measured signals.

Since digital signal processing is a new approach in the in-motion measurement field, the DRD system provides better performance than the commercial systems. The DRD system can perform diagnostic functions and measures weight properly in a wide range of velocity, with a maximum velocity of 160 km/h. Additionally, the visualization of the deformation signals can be used to diagnose the wheels of the train.

At the present more test measurements are being performed with the DRD, and in the near future, the authentication of the weight measurement will be performed.

References

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