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STRAIN-GAUGE MEASUREMENTS IN THE TRAIN LOAD DISTRIBUTION IDENTIFICATION PROCEDURE

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ABSTRACT

The paper deals with a particular problem of measuring rail web strain components due to train load. The measured strain time-histories constitute the base for the identification procedure of axle load distribution of a moving high-speed train. The problem has been solved within the frame of the feasibility study of active railway track supports for optimized dynamic response of a bridge structure to the passing train loads.

INTRODUCTION

The requirement to maintain a reasonable minimum speed across European network of high speed trains imposes demand of small deformability of railway tracks resting on bridge structures. Many existing bridges are characterized by unacceptable deflections and vibration under the high speed environment. Stiffening of such flexible bridges is not economically feasible due to the large number of structures involved. Under these circumstances, it is desirable to analyze alternative solutions.

An innovative approach to solve the problem is based on the concept of the active support of the railway track. Such a support system, mounted between the track and the bridge structure, should allow for adequate track vertical alignment to be maintained during the train passage. The active track support system involves controlled hydraulic actuator units (embedded in sleepers - therefore the used term "smart sleepers"), monitoring subsystem for measuring the oncoming train parameter data, and the central processing and controlling system for converting these data into control signals for actuators.

In most options of the "smart sleeper adaptive track shape control system", the particular problem of properly timed identification of the oncoming train is involved. The presented paper reviews the activities in solving the problem and describes some of the results achieved.

1. PROBLEM FORMULATION

The problem to be solved has been formulated as follows:

1. In order to control the smart sleeper system installed on the bridge, a defined set of data identifying the oncoming train has to be transferred in due time to the main computer system

for converting these data into signals suited for the actuator control subsystem. Followingly, the identification data acquisition at the "checkpoint" should proceed safely before the train enters the bridge.

2. With respect to the given problem, the identification of the oncoming train is related to the description of properties decisive for the bridge dynamic response. As a minimum, the identification data set (IDS) has to include the data defining the train speed, the train axles geometry, and the masses assigned to individual axles.

3. With respect to the bridge operational safety and reliability the monitoring of the activities on the adjacent railway track must be continuous. The correct function of the monitoring system should be ensured with a very high safety factor. Emergency cases must be taken into account. In the very improbable case of a total failure of the monitoring system, default values from the central computer system database will be used.

2. TESTS AND EXPERIMENTS

The base for the identification procedure of axle load distribution of a moving high-speed train constitute the measured rail web strain time-histories. In order to verify the designed identification procedure software, and with the aim to test the hardware assumed to be actually used in the realized monitoring system, appropriate tests were planned.

The tests of the primary data aquisition procedure have been carried out at the Railway Research and Testing Ground of Cerhenice. The large railway track circuit was used, permitting standard testing train speeds up to 160 km/hr.

The testing train (locomotive with one carriage) of defined axle mass distribution was used to load repeatedly the selected straight rail segment at successively increased speeds. The measured track segment involved on each rail five strain-gauge instrumented cross-sections located in successive sleeper pitch middle points. Two different independent measuring and recording systems were used. Three ways of triggering the measuring cycle were tested. Altogether twenty strain-gauge full-bridge systems were used to indicate deformations of both the left and right rail webs caused by the testing train load. Selectively, deformations due to shear, bending, and compression were measured. All measured strain time-histories were digitally recorded with stepwisely changed sampling rates.

Statistical analyses of records have led to conclusions applied in developing the unification procedure to get representative values of the axle loads (and axle positions) from sets of individual strain component measurement results. Spectral analysis of the records resulted in rules for selecting the cut-off frequencies of the applied analogous low-pass filters. Analysis of the strain time-histories related to the same wheel load and measured by identically located strain gauges in successive rail cross-sections has led to conclusions for measurement results corrections.

From the obtained relations empirical functions for correcting the measured strain extremes for axle wheel loads identification were derived. These functions improve the identification reliability by correcting the strain-axle load conversion coefficients with respect to the effects of the train speed, axle position and load level (in the first approach these coefficients are considered as constants). In practice however, these corrections must be based on numerical FEM-model analysis.

The measured data have been compared with the respective data predicted by the numerical FEM-model analysis. The conclusions drawn have been respected in refining the concept of the train identification.

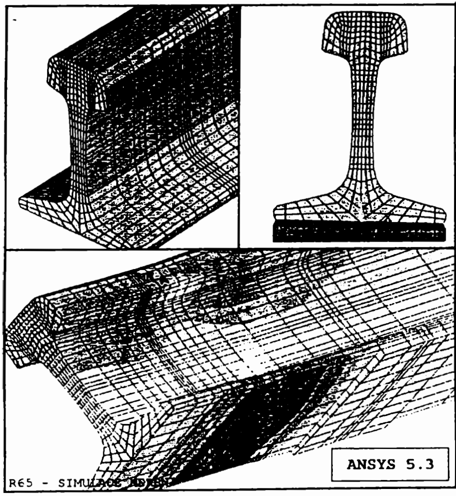
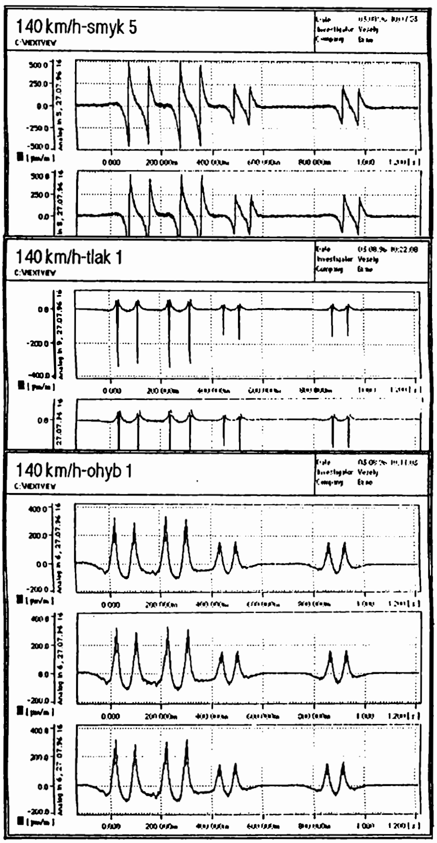


FIG.1 RAIL FEM-MODEL



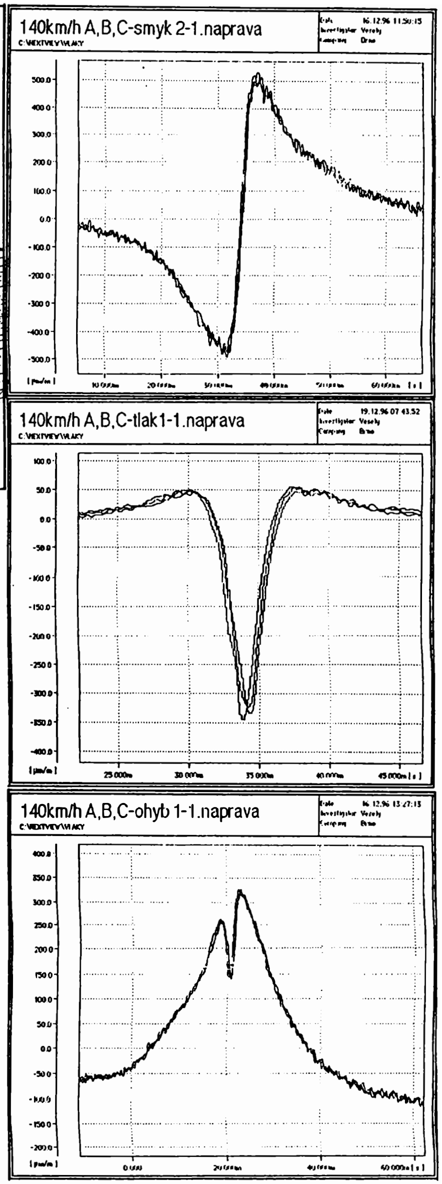


FIG.2
STRAIN TIME-HISTORIES

A - ALL AXLES RECORDED
B - EXTREMES ZOOMED

3. COMPUTER FINITE ELEMENT MODEL ANALYSES

In the course of the test preparations, computer FEM-analyses of railway track responses to experimentally defined moving loads have been performed. From representative displacement fields in the railway track structural system parts the importance of individual elements of that system (e.g. fixing elements, resilient pads, sleeper) with respect to the identification measurements have been assessed. Further, the influence of some factors on the quality of the measurements have been assessed (e.g. number of substantially participating sleepers for various stiffnesses of the railway track). Simulation analyses have been performed to clarify particular problems related to the measurements (e.g. train axle base or speed influences). In order to select proper locations of strain gauges, the strain field in the rail due to expected train wheel loading has been analyzed. The measured strain time-histories have been analysed to verify partially the developed identification procedure.

Detailed analyses of the experimental results revealed some new problems requiring optimization of the strain gauge positioning. Therefore a more elaborated program of the loaded rail FEM-analysis has been prepared. Based on the test results a new computational model has been developed (14747 elements, 17532 nodes with 51376 degrees of freedom, ANSYS 5.3 program). Illustrative graphics showing selected zone of stress field of the loaded rail web are appended. The rail load has been moved in order to simulate the measured time changes of the strain fields and a series of field patterns has been obtained by repeated computations. The strain gauges used in the experiment have been exactly modeled and the computed strains have been compared with the measured ones. Boundary conditions approximating the test conditions have been defined. It can be concluded, that computer FEM analyses represent the main means in any further refinement of the identification procedure.

4. THE TRAIN LOAD DISTRIBUTION IDENTIFICATION PROCEDURE

4.1. Train identification data acquisition

The developed identification procedure assumes, that the train identification data set (IDS) required for the computerized control of the bridge-track-train interaction shall be acquired at the identification station located on the railway track at a minimized distance from the bridge. At present state the "checkpoint" distance of about 2000 m is assumed (excluding the operational time of the track supports). At the checkpoint, the monitoring and identification system (MI-system) with the appropriate transducer system (M0 - M4) is installed. The MI-system is designed as an automatically working self-contained measuring and computing system. All measured data are processed automatically to define the train IDS which is automatically transferred to the central computer system using RS 485 bus. The train IDS includes following data:

- speed of the train entering the checkpoint ("initial speed VI"),
- speed of the train leaving the checkpoint ("end speed VE"),
- total number of train axles,
- distances of successive train axles from the leading train axle,
- loads assigned to successive train axles.

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Direction of the >>> ------+--------------+-------------+---------------- >>>
train passage              M0     L     M1    L     M2, M3, M4
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The speed of the train is determined by measuring the time that the train needs to pass a defined distance (measuring base). Rail strain components at the selected cross-section are continuously measured and the measured strain time-histories are digitized and stored. From this primary data base the local extreme values are extracted and converted to the values of corresponding rail loading forces. These forces are finally assigned to individual axles as representative axle loads. The measuring cycle is started by the signal pulse of the measuring base leading pickup used in the train speed measurement, and closed by the last signal of the measuring base closing pickup.

The parameters required for MI-system function (basically determined by computations) should be adjusted in the course of putting the system in operation. Periodical tests involving re-adjustment of scaling coefficients are assumed.

4.2. Speed of the train

The speed of the train is determined by measuring the time interval that a selected wheel needs to pass a precisely defined measuring base length L. The strain-gauge measuring systems (M0, M1, M4) indicating strain components in the rail web due to wheel compressive load are used. The generated signals have the form of very narrow triangular pulses and are best suited for precise time interval measurement.

The initial speed VE is determined using impulses generated by the leading wheel of the train when passing over M0 and then over M1. The end speed VE is determined using impulses generated by the last validated axle wheel of the train when passing over Ml and then over M4. The instantaneous train speed needed for precise determination of the axle distances (positions) is computed using VI and VE values.

4.3. Train axle loads and spacing

Three independent strain-gauge measuring systems are used to follow time-histories of strain components at precisely selected rail web surface locations under the wheel-rail contact point of the reference cross-section located at a selected sleeper pitch middle point:

M2 - strain components due to shear loading (signal type S),
M3 - axial strain components due to bending of the rail (signal type O),
M4 - vertical strain components due to rail compression (signal type T).

Precise measuring amplifiers are used for signal conditioning. Their signals are processed in digitized form in the measurement controlling computer provided with A/D convertors. The sampling rate selection depends primarily on the measured train speed.

As follows from measurements as well as from FEM-based analysis results, any measured strain component value can be converted to the actual loading force value by a sophisticated individual distance- and time-dependent scaling procedure. Purposely, only conversion of measured strain extremes to the axle load is of interest, thus the scaling factor should be determined selectively for this particular case. In the first approach the scaling factors can be assumed as constants determined by computation, depending on the type of the rail type and railway track structure. However, in the case of moving load certain functional corrections depending essentially on train speed, axle base, and axle load have to be introduced.

Even in the case of constant scaling, the signal conversion process is rather complicated. First of all, disturbing (false) signals have to be eliminated. High frequency signal components are eliminated using low-pass filters in the measuring amplifier output, impuls-like signals are disregarded by setting up a proper signal sensitivity level (lower than the expected minimum axle load).

Secondly, probable distorsions of the typical signal pattern in the zone of local etremes are taken into account. In the case of shear, the appearance of consecutive pairs of signal local minima and maxima is analyzed using a properly selected sensitivity levels. In the case of bending strain signals, secondary local minima are disregarded. Two properly selected sensitivity levels (lower and upper) are used to solve the problem. Identification of the compression strain extreme is performed relatively simply using properly selected lower and upper signal levels.

The properly scaled local maximum values of the three strain component time-histories, i.e. presumable maximum values of loads corresponding to a specified train axle wheel are generally non-coincident in magnitude as well as in time (axle position). Therefore a simple averaging is impossible. To unify the local extremes, i.e. to assign the extremes to the same specified train axle, a procedure using the criterion of "sensitivity level to extremes along the train" is applied. The data are processed in a special manner to get the single representative axle load (and the representative axle position, too). The unification procedure compensates the dropout of any of the three evaluated signals as well as the consequent shift in numbering of the axles.

5. COMPUTER PROGRAM FOR IDENTIFICATION OF THE TRAIN LOAD DISTRIBUTION

The computer program "TRAIN" for identification of the train load distribution is based on the identification procedure described above. The program has been thoroughly tested using the data recorded during CERHENICE measurements. In order to test all probable extraordinary operating situations, the data have been modified to simulate all possible irregularities, disturbances, signal dropouts, etc. Finally, complete measuring cycles including data transfer to a computer-listener have been simulated using measuring tape recorder. The program enables the operator to carry out all presumed changes in setup files during servicing.

CONCLUSION

The procedure for identification of the train load distribution has been developed and succesfully tested. The performed series of tests proved the operational reliability of the respective computer program.

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