3rd Congress of the Alps Adria Acoustics Association

27–28 September 2007, Graz – Austria

VIBRO-ACOUSTIC SYSTEM FOR AUTOMATIC DETERMINATION OF THE NUMBER OF AXLES OF PASSING VEHICLES

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Abstract: *In this project, the feasibility of a system for counting axles of passing vehicles by evaluation of carriageway vibrations was investigated for the first time. It was initially planned to use these just for registration of the number of axles by means of overhead bridges in electronic toll systems. Now the application of results in form of an own measuring service and the development of a mobile measuring system is planned as well, which would be able to be demonstrated in form of a pilot system.*

Contrary to the basic research study, in which measurements were performed exclusively on the same test stretch, the objective of the feasibility study was to enable the counting of axles of passing vehicles using vibro-acoustic methods under realistic conditions on various motorway sections. Special care was taken during the selection of measuring sites and the scheduling of measurements that different carriageway structures, weather conditions and traffic burdens were taken into account in the measurements in order to guarantee highest possible variability of the measured data.

The measurements were performed using two different recording systems and sensor types and the data obtained by algorithms of the digital signal processing were compared with each other. Thereby, it could be identified that both sensor types provide near to equal results and moreover, enable clear statements with regard to the number of axles of heavy lorries, so that the chosen path should be continued in any case. Moreover, the absolutely comparable results on asphalt and concrete carriageways indicate the technology's universal usability.

Key words: classification, feature extraction, segmentation, vibration

1. MOTIVATION

Since the 1st of January 2004, lorries have to pay road toll on all motorways and highways in Austria. Under the Road-Pricing Act, all vehicles with a maximum permissible total weight of 3.5 tons or more are subject to road pricing. Thereby, the base tariff per kilometre for vehicles with two axles as a performance-related toll was set by ordinance by the Federal Minister of Transport, Innovation and Technology in concert with the Federal Minister of Finance. The primary objective of the introduction of road pricing was to realise a toll system that was transparent and simple both for the user and for the operator. Therefore, it was decided that in the initial phase only the number of axles should be considered in the tariff calculation.

For controllability of the valid legislation, it is necessary to perform the classification of lorries based on the number of axles of the vehicle. Thereby, the benefit and need for an automated axle counting system is clear. Solutions using induction loops have the great disadvantage of having to be installed in the carriageway and requiring intensive maintenance. Therefore, laser scanners or other optical methods for determination of vehicle axles are currently being used.

In this project, the feasibility of a system for counting axles of passing vehicles by evaluation of carriageway vibrations was investigated for the first time. The basis for this feasibility concept [1] was developed in the previous basic research study [2].

Contrary to the basic research study, in which measurements were performed exclusively on the same test stretch, the objective of the feasibility study was to perform a count of axles of passing vehicles using vibro-acoustic methods under realistic conditions on various motorway sections. Special care was taken during the selection of measuring sites and scheduling of the measurements that different carriageway conditions, weather conditions and traffic burdens are taken into account in the measurements, in order to guarantee highest possible variability of the measured data.

2. MEASUREMENTS

Thus, the first measurement for investigation of carriageway vibrations was performed in December 2005 on a section of the A9 motorway level with the Übelbach exit. The carriageway surfacing of this measurement site consists of asphalt. Opposite thereto, a route section of the A2 motorway at the level of the exit Graz Airport, where the carriageway surface consists of concrete, was selected as the second measurement. The measurements were performed on 28 March 2006. Based on the selection of these two measurement sites and the time difference of the performed measurements, the oscillating characteristics of varying carriageway structures were able to be investigated under very differing weather conditions.

Fig.1. illustration of both measuring sites (upper: A9 at Übelbach, bottom: A2 at Graz Airport)

In addition to the sensor (laser vibrometer) that was used already in the basic research study for registration of carriageway vibrations, a second sensor type was introduced to the measuring environment by the project partner VCE. These are highly-sensitive acceleration detectors, which were positioned directly adjacent to the edge of the carriageway. Consequently, an option to compare the signals of the two different sensor types with each other was thus provided.

The development of a recording system was a significant point within the course of the project. As the individual sensors provide the best signal quality only in combination with specific peripheral devices, two segregated systems were specified within the course of the project. Thus, all contact-related structure-borne noise detectors were operated via the system of VCE, and the non-contact sensors – such as laser vibrometers, microphones and the video camera – via the system of Joanneum Research.

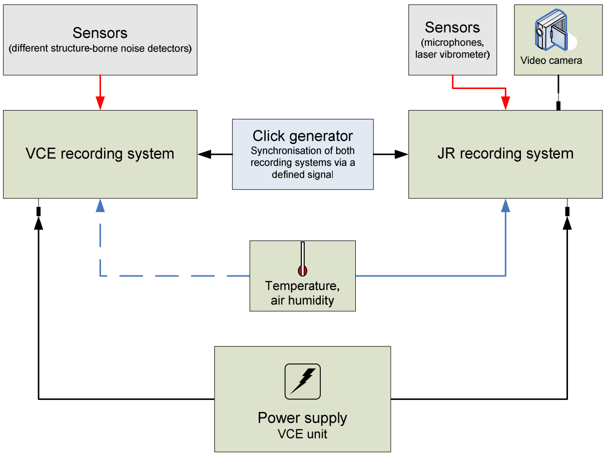

Fig.2. block diagram of the developed recording system

Aside from the recording of pure sensor data, the possibility to distribute environmental data such as temperature and air humidity to both recording systems was created in addition. Furthermore, for subsequent evaluation of the sensor data, a special synchronisation signal was distributed to both systems via a control line in order to guarantee the synchronism of these.

Then the obtained recording data was annotated. For this purpose, the individual passes were provided with markers and designated in accordance with a suitable pattern. This way, it was taken into account in the designation of the markers whether the pass related to an articulated lorry, a lorry with or without a trailer, or to a small pickup truck. The number of axles was taken into account for each type of vehicle in the designation of markers. In this way, it was possible to feed the various vibration signals into the evaluation algorithms automatically in the later course of the project.

3. DATA EVALUATION

The evaluation algorithms developed by Joanneum Research in the basic research study were used and optimised for evaluation of the recorded vibration data of the laser vibrometer. A comparison of the results from the feasibility study with the results of the basic research study indicated that a count of axles by vibro-acoustic methods is also possible under normal traffic conditions and works excellently.

The evaluation of vibration data of the acceleration detectors was performed by the project partner VCE. As these sensors vary significantly from the laser vibrometer in the way they work, the evaluation algorithms developed in the basic research study could not be used for examination of the vibration data of the acceleration detectors. Suitable evaluation algorithms were thus newly developed by the project partner VCE within the course of the project, which were able to be used for examination of the vibration data of this new type of sensor. Even more pleasing is the fact that a comparison of the results of the two different types of sensors indicates very high conformity.

Figure 3 shows the passing pattern of a triple-axle lorry with a triple-axle trailer as an example. The six axles of the entire vehicle are clearly visible thereby within the signal sequence as distinct peaks.

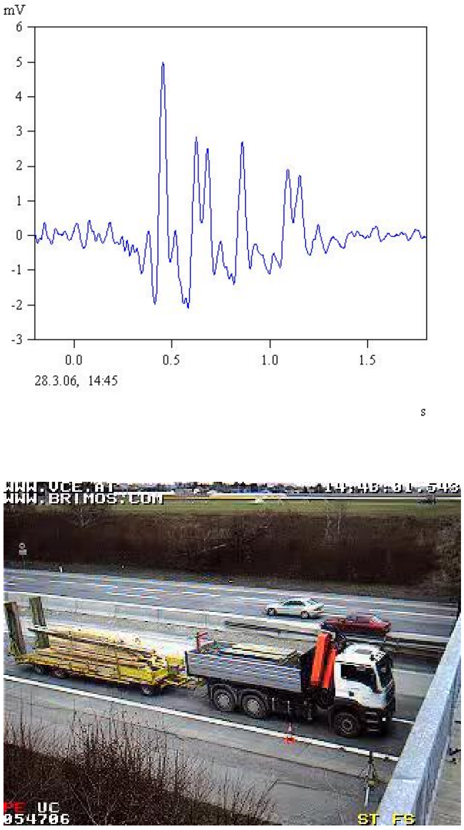

Fig.3 passing pattern of a triple axle lorry with a triple-axle trailer

However, even those passes in which the results of the varying sensor types did not provide such a good conformity were able to be identified within the course of the investigations. This is evident from the evaluation of the measurement on an asphalt carriageway (Übelbach), where the laser vibrometer was mounted on the bridge head of the motorway overpass located at the measuring site. Contrary to the acceleration detectors used, which measure carriageway vibrations directly by being placed along the breakdown lane, not only the usable signal, thus the movement of the carriageway surface during the pass of a vehicle, but also any possible movements of the bridge are detected due to the way the laser vibrometer is mounted.

Even minute excursions of the bridge structure are enough to be detected as an interfering signal in the recording due to the very high sensitivity of the sensor. Oscillations of the bridge structure occur when vehicles pass the measuring point with a speed that is sufficiently high. When a vehicle passes below a bridge, a negative pressure is created due to the volumes of air in motion, which leads to a vertical excursion of bridges in the direction of the carriageway. The higher the speed of the passing vehicle is, the greater also is the negative pressure that is created, and thus also the maximum excursion of the bridge.

This effect can be observed particularly well when cars pass by. Figure 4 illustrates the passing pattern of three consecutive cars. The interferences can be identified clearly thereby based on the signal peaks. The areas of the cars’ passes are marked in the illustration by ellipses. It is clearly to be seen that there is an indentation of the carriageway surface at first (equivalent to a valley within the sequence of the signal). Immediately after that, however, a strong overswing into the opposite direction occurs. This overswinging and the subsequent dying out of the sensor signal are to be allocated exclusively to the movement of the bridge while the car passes by.

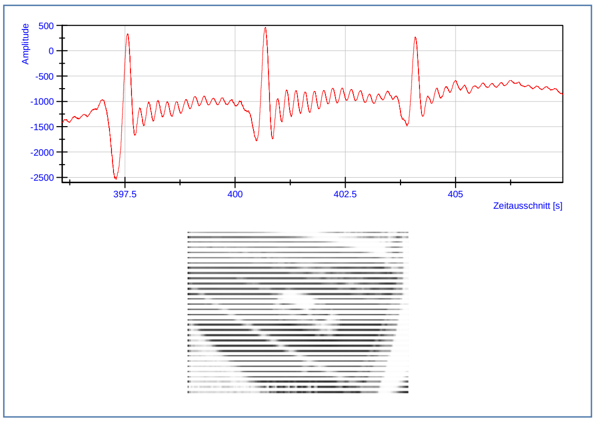

Fig. 4 passing pattern of three consecutive cars

Within the course of the evaluation of the measuring results of this feasibility study, during which two completely different types of sensors were used for the recording of carriageway vibrations, it could be identified that both sensor types provide nearly equal results. The conformity of the signal sequence of both sensor types is particularly high in the case of assembly of the laser vibrometer at the side of the carriageway, which must be led back to the fact that the interfering influences caused by the suction force of passing vehicles at the measuring point are significantly smaller than in the case of assembly of the laser vibrometer on an overhead bridge.

Moreover, experiences were gathered both on an asphalt carriageway, as with the first measurement at Übelbach (A9), as well as also on a concrete carriageway at Graz/Feldkirchen (A2). The results are comparable, so that the feasibility of a system for the vibro-acoustic count of axles on both types of subgrade can be taken for granted.

Aside from the quantitative determination of the number of axles of a passing vehicle, the vehicle’s distribution of axle load can be concluded as well. Thus, Figure 5 illustrates that the rear axle of the tractor vehicle has to bear the largest share of the total load, which is reflected by a distinct maximum in the passing pattern.

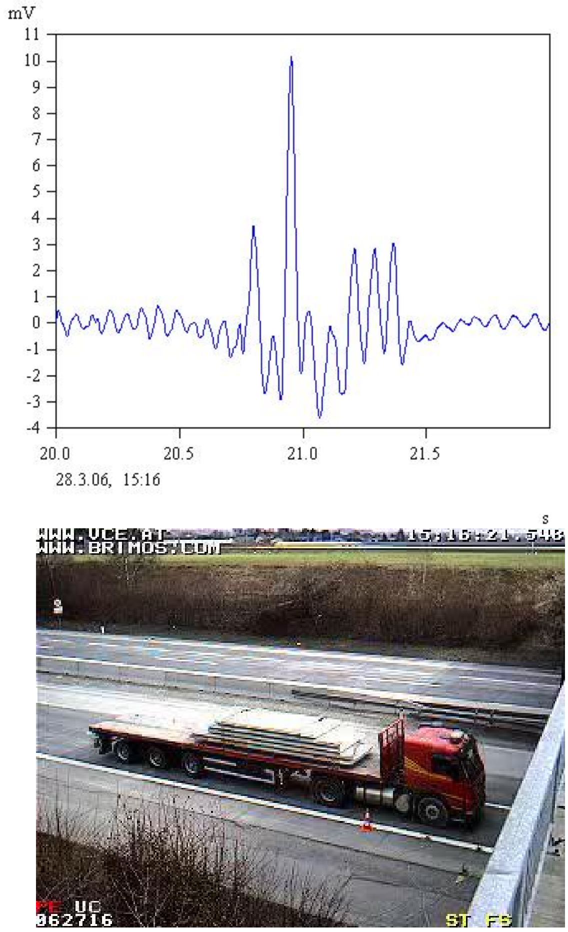

Fig. 5 passing pattern of an articulated lorry indicating the distribution of axle load

The additional wealth of experience gained in relation to the varying characteristics of individual axle constellations can be used as well in future for the desirable but still pending development of an automatic detection of axles and thus represents a decisive pre-requisite for the realisation of this project.

3. CONCLUSION

The measurements were performed using two different recording systems and sensor types and the data obtained by algorithms of the digital signal processing were compared with each other. Thereby, it could be identified that both sensor types provide near to equal results and moreover, enable clear statements with regard to the number of axles of heavy lorries, so that the chosen path should be continued in any case. Moreover, the absolutely comparable results on asphalt and concrete carriageways indicate the technology’s universal usability.

Among the particular advantages of the methods used are certainly the flexibility and mobility in relation to the site of use. Above and beyond that, the measurements can be performed without any significant restrictions to normal traffic as well as at a low cost before, during and after the measurements, which represents a significant advantage in comparison with other methods.

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