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The basics for acoustic aided vehicle function diagnosis using tractor production as an example

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In the development of tractors, individual requirements mean many variations of vehicles are produced. In this connection, many companies seek objective and reproducible quality control methods. ”Acoustic analyses” have great potential in testing vehicle components or entire vehicles. The aim of this study is therefore to validate whether application of acoustic measuring methods in the final inspection of tractor production is technically and economically possible, as well as practical. It is shown that vehicle components, e.g. gear wheels, can be successfully tested using the component's specific acoustic fingerprint through application of selected acoustic diagnosis methods applying order tracking analyses. Additionally, a self-compiled sound spectrum target is defined that enables application of objective and reproducible vehicle function diagnosis within the final quality inspection process. Also, measurement of overall sound levels proved practicable under hemi-anechoic characteristics.

Keywords:
Vehicle function diagnosis, tractor, acoustic process, order tracking analysis, final quality inspection

The development of new technologies, the increasing application of electronics or innovations in steering (GPS), lead to increasingly more unknown influences on the tractor. Small and medium sized companies (KMU), the type often to be found in agricultural engineering, first of all produce often without partly or fully automated assembly and, secondly, costs for restructuring in the areas of processing and quality cannot always be supported (Zäh and Lindemann 2013). Particularly because of this, qualitatively high-standard, but still cost-efficient, methods and systems are required for quality control in order to enable economically viable testing of products, ware, semi-finished articles and much more. In addition, particularly with small and medium sized companies in the vehicle production industry, there are many upstream suppliers of components such as engines, transmissions, etc., in the value-added chain. For this reason, it is important that quality can be easily and efficiently ensured. Above all for complex vehicles such as tractors, there are unknown influences that can only be checked for at the end of the process. While the use of well-trained personnel is indispensable in this respect, it is increasingly important to support their often subjective perceptions through reproducible measured values. Acoustic processes offer a suitable approach in this respect (Kirste 1989).

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Measurement equipment and methods

Vibro-acoustic screening of vehicles are nowadays mainly carried out only in research and development departments. Applying this process in the final quality control is still unusual in practice. Neither are such methods applied in tractor series production end-inspections because of the complexity and high number of model variants involved. However, new key technologies in easier-to-use hard and/or software mean there is a reasonable chance of their introduction in the end control process. Especially from an economics viewpoint, such analyses could help companies in the delivery of vehicles of more consistent quality, possibly leading to cost reductions in the medium and long term. Moreover, continuous diagnosis of vehicles and more precise documentation would enable a trend analysis for monitoring assembly processes. With such trend analyses accompanying assembly it is possible not only to monitor the quality of manufactured components over the long term, but also to tighten the quality criteria step-by-step. Hereby, not only fluctuations in quality from suppliers could be identified, but also unreliable processes or production machinery with too much variance in tolerances. In addition to current high legal requirements for exhaust emission protection, noise reduction legislation will become more important. Under EG directives 151 and 3112, permitted noise levels for wheeled tractors are already massively reduced (Renius 2013a). The companies applying themselves early to this trend towards noise minimising are in a position to secure long term business success.

In this study, standard procedures in vehicle final quality control are evaluated and, building on this, the basis for acoustic diagnosis methods is investigated. The first findings will then be gone into more intensively towards application with tractors. Differentiation is made hereby between hardware (microphones, amplifiers, etc.) and software. Subsequently, a concrete project is suggested to a company, with appropriate planning and support through preliminary tests on the tractor. Included is selection of an acoustic diagnosis method, with equipment plans and cost plans as well as assessment of economic efficiency and financial risk. Hereby the focus of the work lies on the possibility of realising the system without cost intensive roller dynamometer as well as offering simple operation for the user. The selected measurement system comprises the following relevant components (Figure 1):

- Sensors (microphone, rpm tachometer)
- Measurement frontend for signal processing
- Computer with software for analysis, presentation and documentation

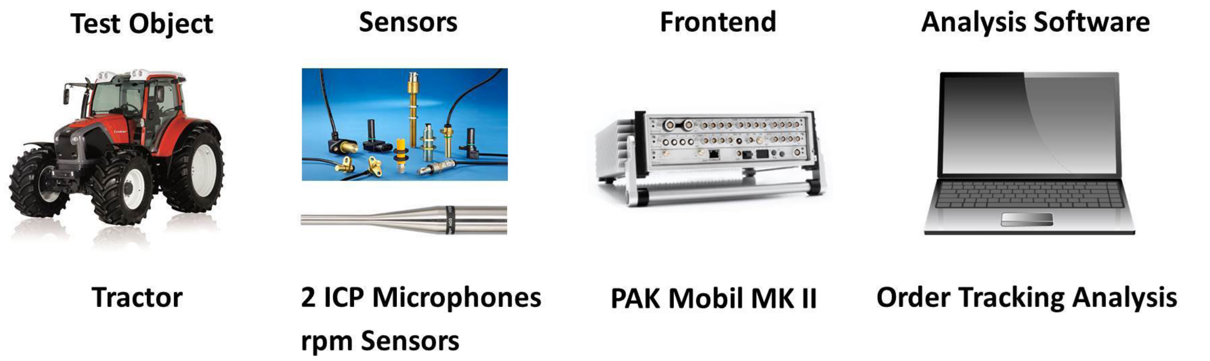

Figure 1: Measurement chain

Towards implementing an efficient and cost effective acoustic quality control in the final inspection of a medium sized enterprise, trials were conducted on tractors taking account of the criteria for selection of appropriate analytical methods as presented by Tschöke and Henze (2003). In addition to the necessary key capabilities, a process suitable for end control should be able to present the relevant area of a vehicle – in this case a tractor – in a depictive way. Therefore, alongside the selection of measuring method, the correct analytical process has to be identified. Because a large proportion of components in a vehicle rotate, e.g. in the transmission or engine, processes with affinity for rotation analysis are very suitable. For a vehicle function diagnosis, whereby especially the engine function, the transmission function and the functional capabilities of pump drives are essential, applicable procedures are order tracking analysis, torsional vibration analysis or degree of crankshaft angle analysis. On the other hand, use of the somewhat simpler designed frequency analysis was also tested. Also considered hereto is the method successfully conducted at the Technical University of Munich for noise reduction on a small commercial truck using frequency analysis (Renius 2013b). The advantage of this approach is that the simultaneous recording of rpm for analysis can be omitted. However, there occur in part during measurements on the entire tractor system high fluctuations in noise level because, without a chassis dynamometer, precise representative excitation conditions cannot be created. This is why, even with similarly conducted start-ups, it proved very difficult to gather required information. On the other hand, the order tracking analyses which were carried out online in a measurement computer fitted in the tractor, convinced with very good and clearly presented measurement results, allowing expectation of a practicable vehicle end control implementation. The difference between an order tracking analysis and a frequency analysis is demonstrated in Figure 2. In contrast to frequency analysis, the energy content of the noise in order tracking analysis is not applied over the frequency but instead over the order (Hübner 2005, Klein 2003). Thus, through gear ratio influence (standardisation on a datum shaft) relevant noise level values are assigned to precise orders. Thereby the order is a high multiple of the rpm.

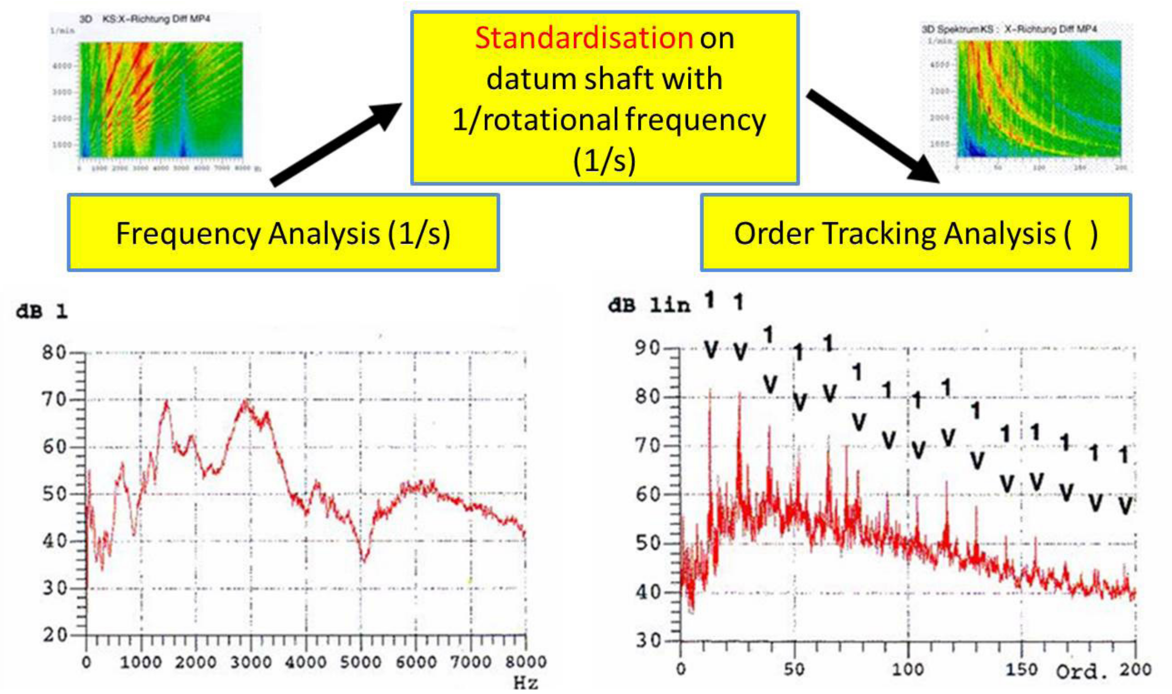

Figure 2: From the frequency to the order tracking analysis (Wagner 2005)

The central parameter for a qualitative high value order tracking analysis is a precisely measured revolution count (rpm). The first attempt with an optical sensor did not lead to an optimum result. Consequently, rpm count was directly measured at the transmission control unit. The data connection (fitted measurement computer) is thus shorter, and the complicated attachment of an optical or magnetic sensor is not required. Attention should be paid that in future three rpm figures are required for an order tracking analysis on a power-split transmission: the drive rpm, the output rpm and – for the hydrostatic part – the variable rpm.

From trials and evaluation of different methods it was deduced that, for functional diagnosis, sound pressure level should be measured with two microphones. This is because use of acceleration sensors in the final quality control proved too complicated. For application on the vehicle, linear microphones with A-rating (Figure 3) have been applied (Zeller 2012). Additionally, the installed microphones corresponded to the ICP® principle.

Figure 3: Microphone position (airborne sound microphone driver, airborne sound microphone near field transmission rear) on the Lintrac 90 (Photo: Lindner Traktorenwerk GmbH)

For noise measurement, frontend and/or evaluation electronics are additionally required to process signals for the measurement computer. Alongside large measurement frontends which also tend to be heavy and feature many channels, more compact systems were tested within the context of this work. Among the equipment tested were the measurement frontend Pak Mobil MKII (Müller BBM VibroAkustik Systeme GmbH) and the SQuadriga system (Head acoustics GmbH). The general operation is through the respective system software in the vehicle-fitted computer. The commercially available evaluation electronics are mainly modularly fitted and are available with capacities per requirement. For application with two microphones, a version with two slots or modules was sufficient. With both systems, the construction proved very robust and not liable to breakdowns. A great advantage of the applied frontends from the company Müller BBM VibroAkustik Systeme GmbH was the high precision of the tachometer input with a 50 MHz counter and associated capacity for order tracking analyses (Müller BBM VAS GmbH 2014).

Results

It was demonstrated on 6 vehicles specially adjusted for the purpose that the selected measurement equipment enabled analyses that could be evaluated and were reproducible. An example of such measurements is presented in Figure 4, 5 and 6. Investigated thereby was a Geotrac (Lindner Traktorenwerk GmbH) with mechanical transmission. During the trial, the all-wheel drive engaged repeatedly for undefined reasons, especially during cornering. The reason for the all-wheel drive engaging could have been pressure reductions in the respective system. Noticeable after the subsequent order tracking analysis was a very high noise level when all-wheel drive was engaged from both all-wheel drive wheel pairs M and N (M = Z33/Z28 and N = Z32/Z58). Also, the bevel gear set K with the order 18.41 produced an increased noise level after start-up was carried out. Testing of the contact pattern and adjustment of the gear wheel pairs thus identified confirmed the analysis results. Because the gear wheel noise level was unacceptable compared to the previously recorded vehicles in the series, this necessitated a rebuild of the all-wheel drive wheel pairs and bevel wheel set. The identified components (marked with orange) in the tested Geotrac transmission diagram show the unacceptable gearwheel pairs M, N and K transposed from the order spectrum. Additionally, the wheel pairs in the diagram are marked in alphabetical order for easier understanding (Figure 4).

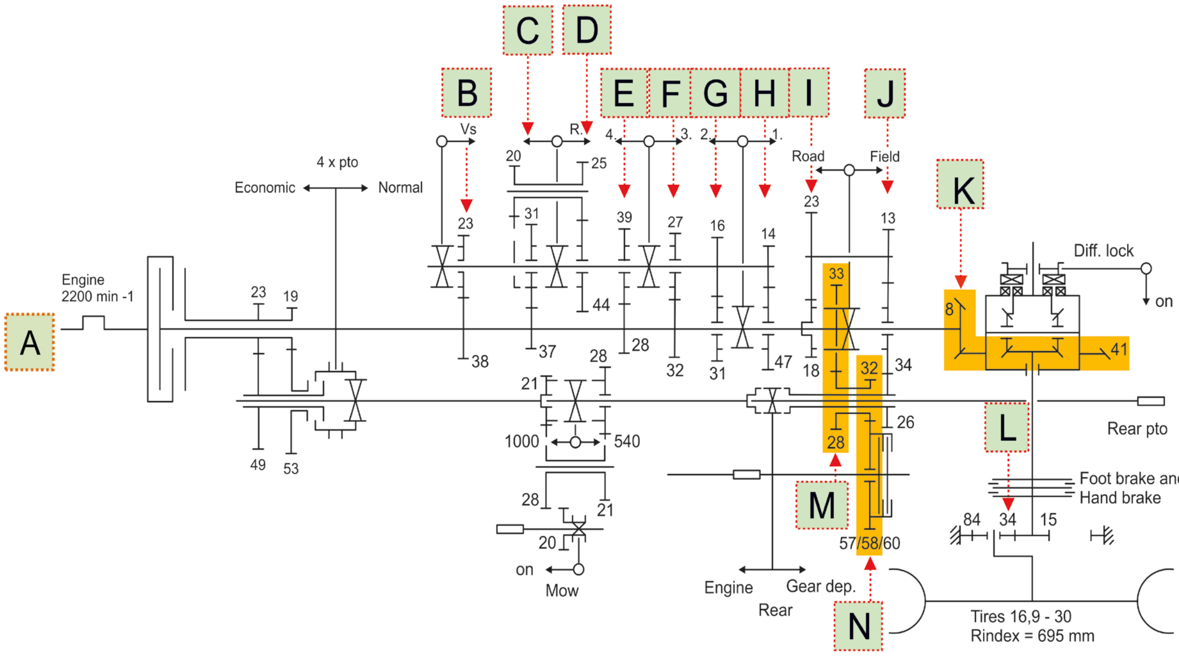

Figure 4: Transmission diagram

A Campbell Diagram was produced using the recorded data. This showed the relationship between a spectrum and the engine rpm and can thereby represent well the spectral procedure of a start-up. The diagram therefore demonstrates noise level depending on rpm and the order. Using the example of the tractor in the trial, the Campbell Diagram shows through the red vertical lines (high noise levels) clearly which orders and therefore which gearwheels, are involved (Figure 5). Alongside the visible red lines of the bevel wheel sets and the all-wheel drive wheel pairs, resonances are also recognisable as hyperbolas.

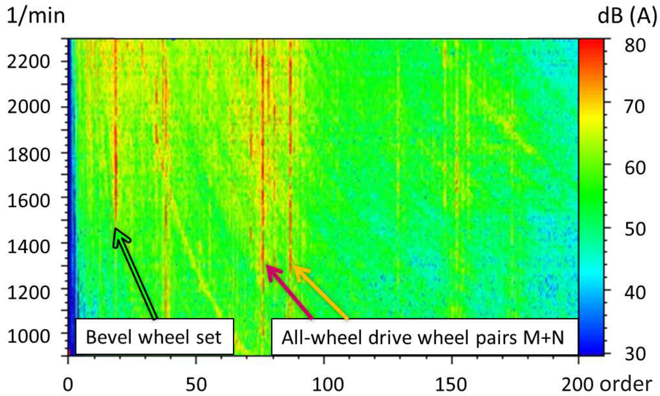

Figure 5: Geotrac recordings, Campbell Diagram of the order analysis (airborne sound in near field transmission rear)

The situation appears even more marked in Figure 6 where the peaks of the 3rd, 5th and 6th orders clearly stand out. Thereby, the gear wheel pairs reach maximum values of over 80 dB(A).

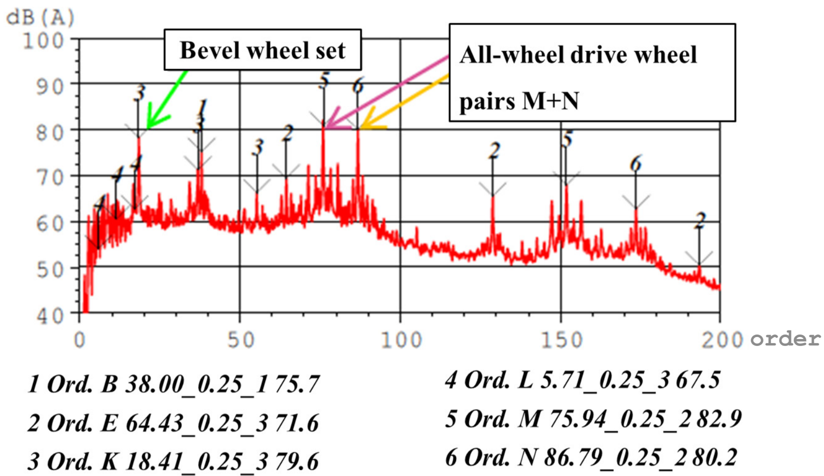

Figure 6: Geotrac recording, order tracking analysis of airborne noise in near field transmission rear

The example recording took place under the following conditions: Scanning rate in Hz, a resolution of 0.125 and a window evaluation after Hanning. Hereby, the microphone was attached centrally at the rear of the vehicle in the transmission near field (Figure 3). The recording results are based on a drive in 4th gear – forwards – transmission group high – gear group road and with activated all-wheel drive. The measured rpm range was from 950 to 2300 1/min.

The results of the analyses nearly always led to identification of the problem cause. Additionally investigated was the extent to which it is possible to define a target order curve for a tractor – despite the high number of tractor model variants. Hereto, a recording series was carried out on 10 tractors with the same mechanical transmission type. It was shown that the recorded noise levels of the individual wheel pairs were very close to each other, with a certain amount of scatter. It was therefore possible to create target order curves.

Through the trials conducted on the vehicles, it could be shown that measurement of total sound levels under hemi-anechoic conditions is practicable. Thus a test stand is not necessary for the reproducible monitoring of vehicle end controls, this being achievable with an appropriate driving cycle under the required conditions that themselves are available for the user beforehand. The recording thereby takes place in a start-up suitable for the order tracking analysis, without load and over a fixed track distance of 600 metres. The test track was asphalted with no sound reflecting objects in the vicinity (> 100m), thus avoiding possible influences on the recording results. Hereby, the tachometer range 950–2300 1/min was driven through. All gears were measured with and without all-wheel drive and with and without use of the field gear group. Also differentiated were results from groups high and low and forward and reverse drives. Noises such as wind or tyre-roll were found to have no influence on the results. The relevant noise levels were given exact orders through the transmission ratios (standardisation on a datum shaft) and were thus able to be identified and evaluated precisely. Elements that had too high a sound pressure level (e.g. gear wheels) could be successfully identified. Identified as dominant sound sources, in addition to the expected gear wheels within the transmission, were pumps and pump drives. These tended to stand out as peaks in the spectrum. Moreover, engine combustion stroke and disrupting torsional vibration of the engine were recordable. Additionally defined was a target sound spectrum necessary for the acoustic diagnosis procedure. Thereby, it is possible to control self-applied threshold values for tractor variants according to the respective series. The order curves measured during the function diagnosis of a tractor were deposited with the analysis program, with the result presented graphically online.

Conclusions

Application of the measuring system presented here is recommended for a medium sized enterprise. The measurements evaluated in the final work confirm successful implementation of the accompanying acoustic measurements for diagnosis. The measured values of a function diagnosis should be documented and serve the company concerned as legal basis. Alongside the testing of vehicles, conclusions as to quality in production can be deduced. Trend analyses can also contribute to stabilisation of production processes, or of those used by suppliers. Such an approach could enable introduction of new production methods and support continued progress in efforts towards improving quality. For example, gear wheel efficiency can be observed in this way over the longer term with new manufacturing processes able to be qualitatively evaluated. However, a challenge represented by the introduction of acoustic measuring procedures in final control remains for the moment, this being coping with the many variations of vehicles in tractor production. Because of the limited number of trials with tractors in the study reported here, the influence of the variants on the efficiency of the function diagnosis could not be completely investigated. Hereby, it is recommended for companies that measurement results be controlled according to series, with iterative adaption of the target value process applied.

References

Hübner, C. (2005): Messung der Güte von Kleinelektromotoren am Prüfstand unter Berücksichtigung der Lastkennlinie. Bachelor-Thesis, FH Düsseldorf

Kirste, T. (1989): Entwicklung eines 30-kW-Forschungstraktors als Studie für lärmarme Gesamtkonzepte. Fortschritt-Berichte VDI, Reihe 14, Nr. 43, Düsseldorf, VDI-Verlag

Klein, U. (2003): Schwingungsdiagnostische Beurteilung von Maschinen und Anlagen. Düsseldorf, Stahleisen, 3. Auflage

Müller BBM VAS GmbH. (2014): Müller BBM Vibroakustik Systeme-Frontends. http://www.muellerbbm-vas.de/produkte/datenerfassung/frontends, accessed on 11 April 2016

Renius, K. Th. (2013a): Vorlesung: Traktoren und Erdbaumaschinen. TU München, Lehrstuhl für Fahrzeugtechnik, Blatt T 6.4-1

Renius, K. Th. (2013b): Vorlesung: Traktoren und Erdbaumaschinen. TU München, Lehrstuhl für Fahrzeugtechnik, Blatt T 6.4-2.

Tschöke, H., Henze, W. (Hg.) (2003): Motor- und Aggregate-Akustik. Renningen, Expert Verlag

Wagner, W. (2005): Grundlagen der Akustik. Passau, ZF Friedrichshafen AG

Zäh, M.; Lindemann, U. (2013): Vorlesung: Qualitätsmanagement – Qualität im Produktlebenszyklus. TU München, Lehrstuhl für Werkzeugmaschinen und Fertigungstechnik/Lehrstuhl für Produktentwicklung.

Zeller, P. (2012): Handbuch Fahrzeugakustik. Wiesbaden, Vieweg+Teubner, 2. Auflage

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