Whitepaper

Application of Vibration Diagnosis for Early Detection of Damage in Research and Development

Application and benefits of vibration analysis for early detection of drive train damage in research and development in the automotive industry

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1 Introduction

Modern cars have to be economical and still be powerful to be successful in the marketplace. These demands place new challenges upon the research and development departments (R & D) of the automotive industry in 2011: The vehicles should get lighter, new drive concepts (hybrid) and designs should be quickly developed and in addition the space for the transmission should be kept as small as possible. At the same time, there are always more powerful engines. In the future, especially in the power train (engine-gearbox-axle and driven wheels) the use of new materials and manufacturing processes are being required. The resulting new designs are tested on test beds to ensure durability. Here, vibration diagnosis is used for early detection of damage to the engine, gearbox and final drive.

2 Vibration Diagnosis in research and development

Vibration analysis is used in R&D for the early detection of damage in the testing of transmissions and engines, among other things.

Transmissions and motors spend a large part of their trial on the test bed.

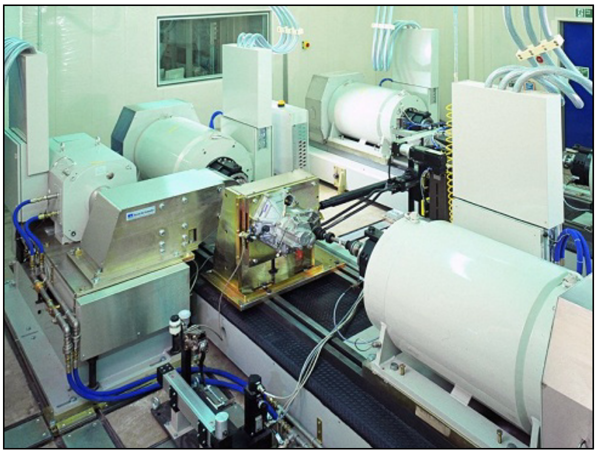

Figure 1: Power train test bed for testing of transmissions and axle drives.

Here, the device is tested under previously calculated load profiles which simulate the real load in a vehicle and / or performs these in a shortened trial period. Most automated test beds run in 24-hour operation.

When a defect occurs on a device under test, the test run is stopped as soon and as gently as possible and a diagnosis of the size and nature of the damage are carried out. These tasks are done with measuring systems for damage detection, for example, by the red-ant MIG16 SFE.

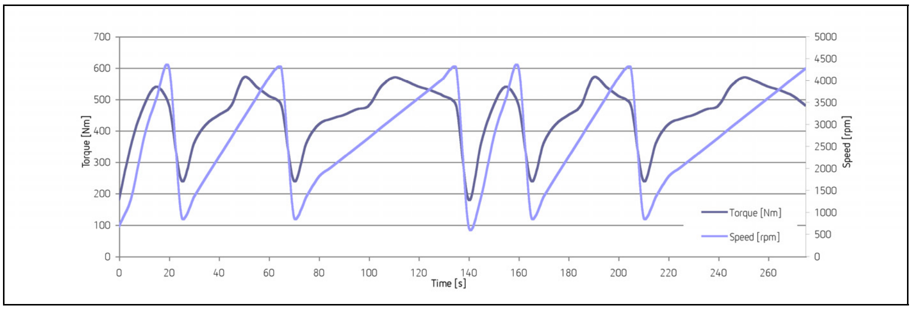

Figure 2: Rotational speed and torque of the WOT tests (Wide Open Throttle) of a diesel engine with automatic transmission

2.1 How does early detection of damage (SFE) work?

For early damage detection data from the device under test and operating data of the test run are recorded. Main input signals are:

- The vibrations at different points of the specimen (measured as vibration acceleration)
- Rotational speeds
- Torque
- Gear ratios
- Temperatures

The SFE-measurement system measures and digitizes the main input signals, calculates in real time the so-called NVH indicators and compares them with defined limits. If an indicator exceeds a threshold, then a pre-alarm is generated, which is immediately checked by a set of rules. In the case of a positive test, an alert is issued to switch off the test bed.

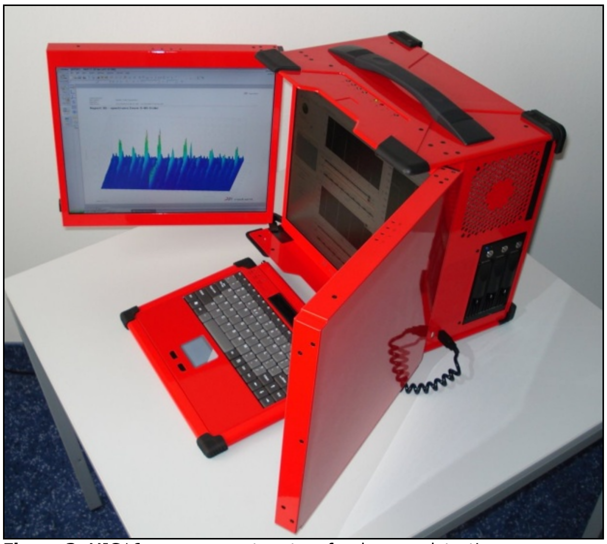

Figure 3: MIG16 measurement system for damage detection

The following figure shows a possible scheme to detect such signals on a test bed for a power train (engine, gearbox, and final drive).

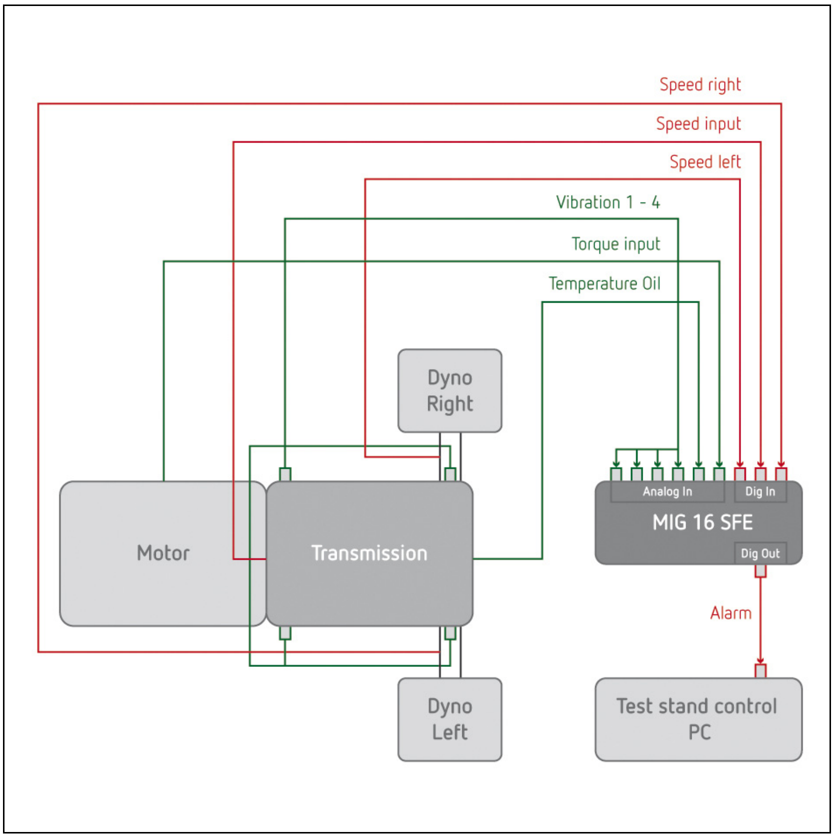

Figure 4: Signals to connect a SFE measurement system to a power train test bed.

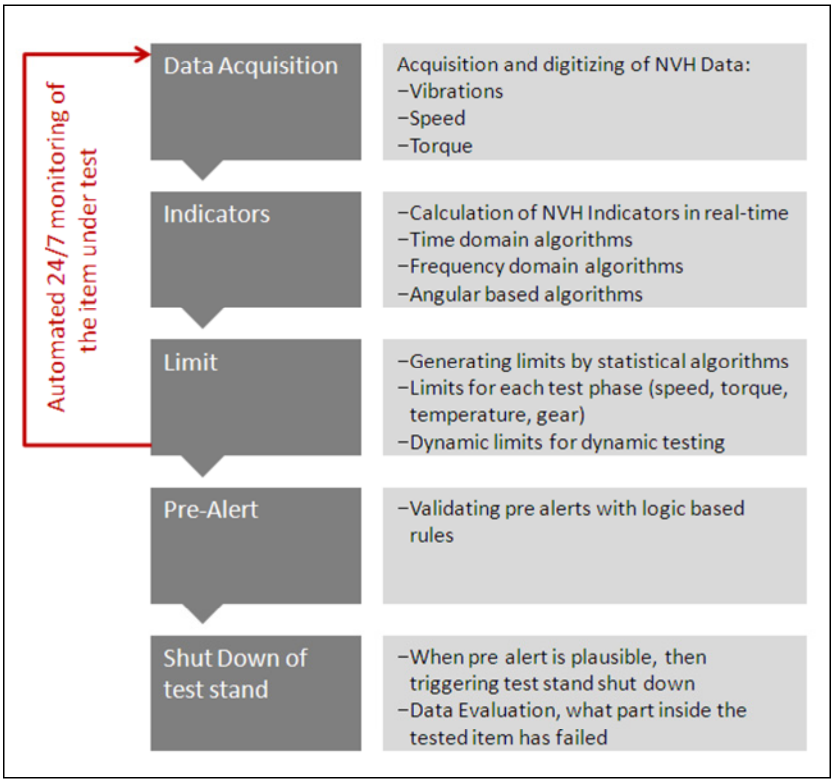

Figure 5: Process of SFE from data acquisition through to shutdown of the test bed.

An important point is the setting of limits for the indicators. The system usually learns the limits for different operating points (torque, speed) automatically. In this case, depending on the check profile, different statistical methods such as standard deviation, medium, minimum and maximum value generation are used.

An example of the automated limit generation of the SFE MIG16 measuring system is shown in the following picture:

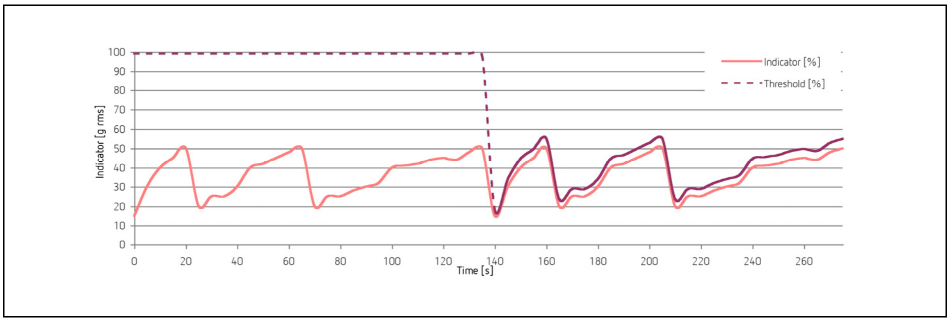

Figure 6: Learning process of the SFE system: The SFE system establishes indicators and limits for the vibration acceleration from the WOT test shown in Figure 2. Bright red: NVH indicator of vibration acceleration; dark red dashed line: Limit has not yet been learned; constant on dark red: Limit active.

2.2 What does SFE deliver? (Results and examples)

The SFE-measuring system can provide the following important four points in an endurance test:

- Consolidated findings about the damage
- Origin of the damage and its propagation speed
- Reduction of the test time and thus increase the test bed utilization
- Cost savings through a more intensive use of prototypes

Consolidated findings about the damage

The indicators of the SFE-measurement system give precise information about the course of damage within the trial period. The following figures show the course of the SFE indicator during the test period and a photograph of the damage at the end of the trial.

An accurate determination of the damage location is possible through indicators such as the order spectrum before appraisal by disassembly.

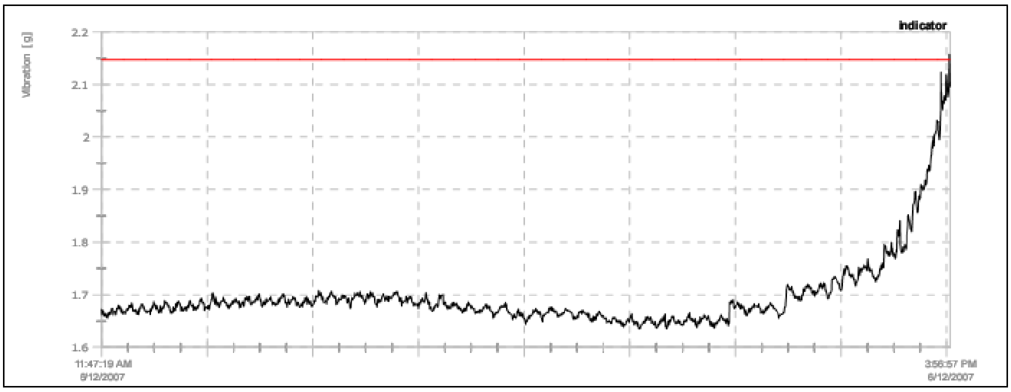

Figure 7: Progress of the SFE indicator during an axle transmission test, about four hours before the shutdown. Black line: SFE indicator; red line: Limit. A very slow progressing damage can be seen within an hour. Shutdown was carried out by SFE-measuring system. Appraisal by disassembly showed damage of the pinion head bearing (Fig. 8).

Figure 8: Damage to the inner ring of the pinion head bearing of an axle transmission. Pitting size about 25 mm² and 5mm².

The following figure shows the resulting order spectrum of the above trial with the pinion head bearing damage:

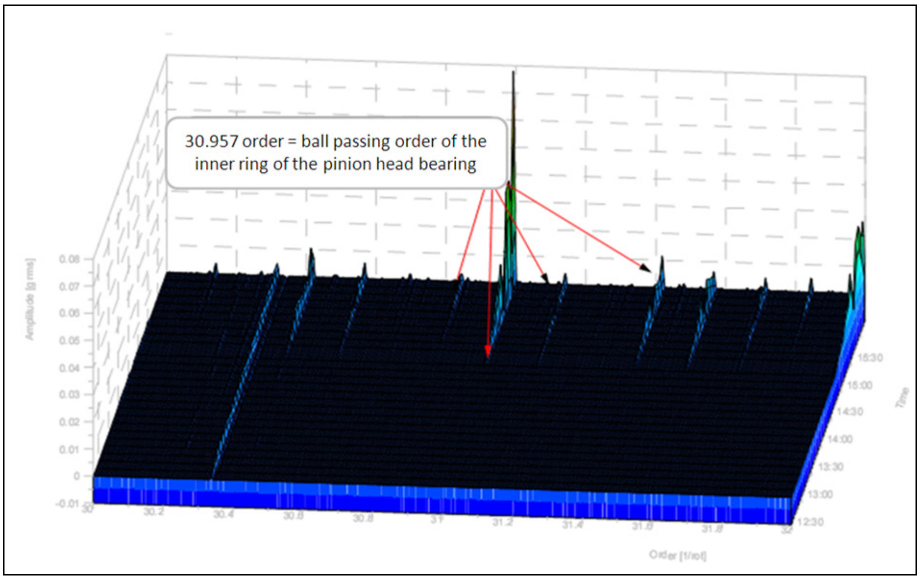

Figure 9: Order spectrum of the damage on the inner ring of the pinion head bearing of an axle transmission. Excerpt shows the third harmonic of bearing outer ring roll over order and the last three hours before the shutdown. X-axis is the axis of order, based on the input shaft (= first order). Y-axis shows the amplitude in g (rms). Z-axis is the test time. The growth of the 30.957 Order represents the damage on the inner ring of the pinion head bearing.

The high-resolution order spectrum (1/1000 order resolution) allows damage in bearings and gears to be precisely identified. It may even be able to distinguish between inner and outer bearing ring, and between pinion and sprocket teeth.

Origin of the damage and propagation speed

Since all data are recorded, an arbitrarily long period can be analyzed before shutdown. Thus, damage will be recorded and understood from its formation through to the shutdown (see also Figure 9).

Optimizing the test time

Normally, the device under test will be put under load for a given testing period before the test bed stops. Subsequently the device under test is disassembled for appraisal and a report is made.

If the device under test fails before the test time expires, usually great damage has occurred, such as tooth or piston rod breakage. The test may no longer be pursued in this case.

The time between damage onset and the shutdown due to a broken component can take several hours in a case like tooth pitting. An SFE-measuring system allows for targeting a test run shutdown at a certain damage level. Since the indicator and its associated limit are shown in real time on a SFE-measuring system, the test bed operator can estimate the time of the shutdown. If the indicator is increasing and approaching the limit, the operator can already start to prepare the next device for testing. In this way the utilization of existing test bed facilities is increased.

Using this procedure with the MIG16 SFE measurement system, utilization of test beds at a red-ant customer could be increased from 65 to 90 percent.

Cost savings through a more intensive use of prototypes

A prototype test object consists of many different components such as bearings, gears, shafts and housings. Their procurement is usually time-consuming and expensive. The use of a SFE measurement system prevents damage to the prototype and to a large extent consequential damage to other components.

A transmission, for example, can be tested, gear for gear. If a gear tooth is damaged, the test is stopped, the gear is removed from the test program and the trial run continues. Thus, a transmission can continue to be tested even when the first component has already been damaged. By using a SFE measurement system the life of several independent components can be tested with only one prototype.

Due to the timely recognition of damage, consequential damage to other components is avoided. Thus, the undamaged components such as housing and shafts can be re-used for further test attempts.

3 Summary

The use of measuring systems for early detection of damage in the research and development sector creates optimal conditions in terms of efficiency and cost. The report illustrates which benefits for R&D departments are achieved through the use of SFE-measuring systems.

The economic analysis shows the relatively low cost in relation to other related expenditures.

The reconstructed application example of an innovative on-board solution represents only one of many possible options, offered by the use of SFE-measuring systems.