Vibration reduction on automotive shafts using piezoceramics

Holger Kunze, Mathias Riedel (*Fraunhofer-Institute for Machine Tools and Forming Technology, Dresden/Germany*)
Knut Schmidt (*Volkswagen AG, Group Research, Wolfsburg/Germany*)
Emanuele Bianchini (*Vibration-X, Winchester, MA, USA*)

Introduction

The demand in the automobile sector for higher comfort in the vehicle is of a great importance alongside the requirements of lighter weight and low fuel consumption. These requirements are typically in conflict with each other. Measurements presently employed to reduce the noise levels by using additional damping material are associated with a higher structural weight. Alternatives for the future are therefore being searched for. One solution is the use of intelligent materials instead of viscoelastic materials and proof mass absorbers. Viscoelastic materials are quite heavy especially at low frequencies. Whereas intelligent materials persuade with their multifunctional properties. They are characterized by their ability to be used in shape with the structure as an actuator as well as a sensor.

Besides other intelligent materials the piezoelectric ceramics seems to be the most promisingly ones for the use in automobile structures. Piezoelectric devices and active vibration reduction are advantageous in this application field due to their low mass to performance ratio. Our research study explores the use of such piezoelectric devices for an axle of an AUDI A2.

Figure 1: AUDI A2

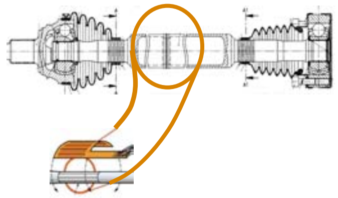

Figure 2: Applied piezoceramics on a test automotive shaft

Experimental Detail

The goal of this experimental study was the reduction of the first natural bending mode at 212Hz of the figured axle (Fig. 2) with the use of piezoceramic elements. At first a feasibility assessment of the piezo active control of the shaft was done by ACX Inc. Also a custom QuickPack design was developed that can be simply applied to the selected driveshaft.

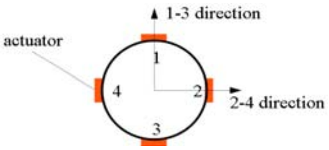

Figure 3: Cross section of the shaft

The experimental setup consists of two independent channels of actuators. Each having two multilayer piezos diametrically opposed on the shaft and are placed nearly centered along the length of the shaft. The opposed actuators will be wired together, out of phase, such that a single voltage induces bending in that axis. It also contains 4 independent piezo strain sensors. It is positioned to the right of the actuator, yet close enough that physical collocation with the actuators is maintained.

Figure 3 shows the cross section of the shaft and illustrates the relatively small amout of piezos required for active control of the shaft.

The laboratory tests simulated the condition present in the road. Figure 4 shows the test setup used for the static (non-rotating) and dynamic (rotating) tests on the driveshaft. A simulated harmonic disturbance was input in the attachement points of the shaft. The ends were mounted as shown to simulate repeatable boundary conditions.

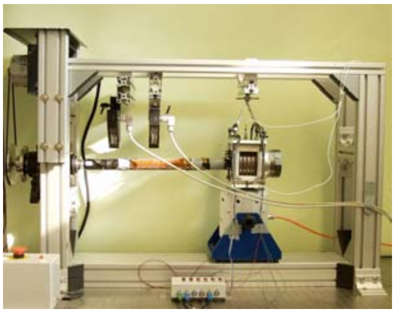

Figure 4: Stationary test setup

The power consumption of each actuator pair was less than 20Watts. To transfer the information from the shaft and the required energy to the shaft, we used a slip ring solution.

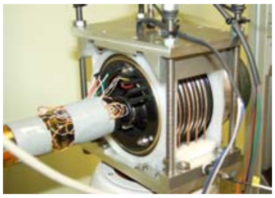

Figure 5: Slip ring solution

Shaft Parameters

Shaft:	Driveshaft AUDI A2
Shaft Modulus:	210 Gpa
Shaft Density:	7800 kg/m³
Shaft Outer Radius:	19 mm
Shaft Inner Radius:	15.5 mm
Shaft Total Length:	680.2 mm
Shaft weight:	5231 g
Max. Deflection:	0.045 mm (at 212 Hz)
Max. Rotations:	1440 RPM

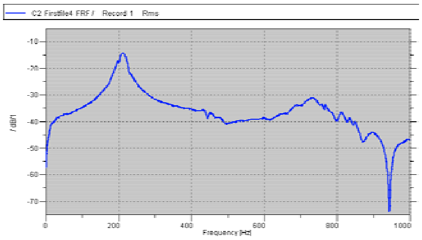

Figure 6: Open loop transfer function

Figure 6 shows the open loop transfer function from the disturbance (hammer impuls) to the displacement (piezo strain sensor). It illustrates, that our driveshaft has a distinct first bending eigenfrequency of 212 Hz. In the real car we have a harmonic disturbance that comes from the engine and the disturbance frequency changes with the engine RPM. That´s why the first bending eigenfrequency will be stimulated more or less depending on engines RPM. What we tried to do is to reduce the worst case disturbance frequency at 212 Hz.

Control

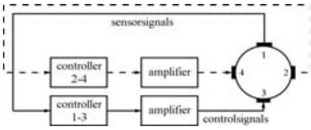

Figure 7: Control approch for an active shaft

The investigation of the shaft showed that the influence of the actuators on the Signals of the 90 degrees rotated Sensors is at a low level. Because of this we decided to establish 2 independent control loops, one for each of both actuators as shown in figure 7. Both controlloops are using the same type of controller transfer function. Because of the equality of the plants of both controlloops, the parameters of the two controller transfer functions are chosen to be equal.

In order to get fast results an easy to tune colocated feedback controller proposed in [1] was chosen to damp the first natural bending mode of the shaft. The structure of these controllers is simple and they can be implemented very easily using passive circuit elements and two op-amps. For testing a rapid-control-prototyping-system has been used to implement the controller transfer function digitaly with a 10KHz sampling frequency. After tuning the controllers to the first bending mode several experiments were performed with non-rotating and rotating shaft. Figure 8 shows the steady state response of the rotating shaft to a 212 Hz excitation in open and closed loop operating mode. As can be seen a significant drop of the sensor voltage amplitude was achieved in closed loop operating mode.

[1] H. R. Pota, Resonant controllers for smart-structures, Smart Mater. Struct. 11 (2002)

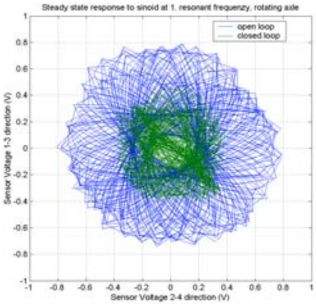

Figure 8: Experimental sinusoidal response for first mode (rotating shaft)

Results

The work described here details the test setup, the control strategy as well as the test results obtained. Beyond these tests we performed the hardware implementation in the car. Finally we conducted experiments with the stationary car with rotating shaft as well as experiments driving the car on the road. The achieved results in reducing vibrations measured by accelerometers at the gearbox, the shock absorber and near the tire were impressive.

As final test we performed measurements with microphones near the drivers and co-drivers ear. The obtained results show a reduction of interior sound pressure level of 12dB at the eigenfrequency of the shaft at 212 Hz.

Further work

Further research work focuses on the miniaturization of the control- and power electronics. Furthermore a non-contact power transfer solution for rotating structures has to be found, studied and adapt to our problem.

With piezoelectric devices applied to automotive shafts it should be possible to build lightweight shafts with excellent acoustic behavior.

Fraunhofer
Institut
Werkzeugmaschinen
und Umformtechnik