Clutch Pedal Vibration – Investigation and Counter Measures
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The hydraulic release system of vehicles represents a complex vibratory system which can lead to different noise and vibration phenomena. The release system is composed of a master cylinder, mounted at the firewall side, and a slave cylinder connected to a clutch release lever at the transmission. Both cylinders are interconnected with each other by hydraulic tubing. The excitation of this system is just as complex as its noise phenomena. Imbalances in the crank shaft of the vehicle or engine firing impulses are transmitted to the flywheel which undergoes a swashing movement. This movement in turn leads to vibrations of the diaphragm spring fingertip and these are transferred to the release bearing of the clutch. Furthermore these vibrations are transmitted to the hydraulic fluid in the slave cylinder, through the hydraulic fluid in the conduit and then through the master cylinder push rod to the clutch pedal. Here the transmitted oscillations can cause vibrations of the clutch pedal. Thus the appearance of a pedal growl is possible, which is audible to the driver, as well as clutch squealing may also occur. Because of today’s high demands on convenience and quality the customer will no longer accept this condition. With focus set on pedal vibration, solutions for solving this problem will be shown and its effects will be presented in different measurements from test benches and vehicle tests.

1 Introduction
The customers’ subjective perception of noise and vibration plays a significant role for the design of modern automobiles. Therefore the NVH behaviour becomes more and more important in today’s vehicle development process. The main source for the most part of the NVH phenomena in the interior is the combustion engine. Here the hydraulic release system represents one of the possible transmission paths. One of the major NVH phenomena in this system is the pedal vibration and its affiliated sound phenomena.

A method for investigating these phenomena is to perform vehicle and test bench tests as well as computer simulations. This paper gives an overview, how these investigations on pedal vibration are done by LuK and counter measures for solving this problem will be presented.

2 The Hydraulic Release System

2.1 Design
The hydraulic release system consists of the following parts: The pedal connected with the master cylinder mounted at the firewall. The hydraulic tubing, which interconnects the master with the slave cylinder, and finally the release bearing for actuating the clutch. Figure 1 represents a scheme of a common hydraulic release system with a modern Concentric Slave Cylinder (CSC). The CSC combines the slave cylinder with the release bearing. When the clutch pedal is activated, the driver senses the system’s response. To satisfy requirements on the clutch pedal, clutch system components must be tuned in terms of friction, stiffness and mechanical advantage of the release system.

2.2 Mode of Operation
Depressing the clutch pedal pushes a plunger into the bore of the master cylinder. A valve at the end of the master cylinder bore closes the port to the fluid reservoir and the movement of the plunger forces the fluid from the master cylinder through the tubing to the slave cylinder. Since the fluid is under pressure, it causes the piston of the slave cylinder to move the release bearing, thus disengaging the clutch. When the clutch pedal is released, the diaphragm spring pushes the slave cylinder back, which forces the hydraulic fluid back into the master cylinder. Most NVH phenomena of the release system occur when engaging or disengaging the clutch or holding the clutch pedal pushed down.
3 Clutch Pedal Vibration

3.1 NVH Phenomena of the Release System

With focus set on the release system, different NVH phenomena are investigated by LuK. An inherent part of these phenomena are pedal vibrations itself as well as the combination with noise. Figure 2 gives an overview of the most occurring phenomena.

Figure 2: NVH Phenomena in the Release System

“Eek-Noise” is a phenomenon which occurs when the clutch is slowly engaged. The frequency of the noise is affected by the eigenfrequency of the pressure plate and vibrations are also transmitted by the release system to the clutch pedal. [1]

The onomatopoeic term “Whoop” refers a noise occurring by engaging and disengaging the clutch. The incitation either comes from axial movement of the flywheel combined with torsional vibration from the engine, or from vibrations of the pressure plate. In both cases a clutch pedal vibration occurs. [2]

“Chatter” is a vibration in the longitudinal direction of the vehicle and is transferred via the release system and the driver’s seat. The chatter itself is a very complex phenomenon which can either be self-induced or pressure induced. Its connection with a noise phenomenon is also possible. [3]

The “Run Down Clatter” is a noise accompanied by a vibration in the clutch pedal when the pedal is depressed and the engine speed is running down. It is assumed, that the coincidence from the eigenfrequencies of the hydraulic column and the firewall is responsible for this phenomenon.

The described noise and vibration phenomena are complex in their constitution and incitation, but they have the pedal vibration phenomenon in common. Thus the pedal vibration will be exemplified in the following.

3.2 Pedal Vibration

The excitation of the pedal vibration is a complex process as displayed in Figure 3. The imbalances in the crank shaft of the vehicle or engine firing impulses are transmitted to the flywheel which undergoes a swashing movement. This movement in turn leads to vibrations of the diaphragm spring fingertip and these are transferred to the release bearing of the clutch. Furthermore these vibrations are transmitted to the hydraulic fluid in the slave cylinder, through the hydraulic fluid in the conduit and then through the master cylinder push rod to the clutch pedal. The fluid as well as the tubing can act as transformers for vibrations, which are sensible at the clutch pedal by the driver.

Figure 3: Excitation Scheme for Pedal Vibrations

Due to the different modes of operation, the occurring pedal vibrations might appear in different frequency ranges or pedal positions. Therefore a classification of the pedal vibration phenomena as shown in Figure 4 makes sense.

Figure 4: Differentiation of Pedal Vibrations
3.3 Methods of Investigation

Useful tools to investigate the pedal vibration phenomenon are vehicle measurements, test bench researches and computer simulations. For test bench researches or specific investigations on components in the car, LuK developed a “Hydro-Shaker” for exciting the system or the components.

The “Hydro Shaker”, displayed in Figure 5 above, consists of the following parts: A piezo stack as excitation source, a hydraulic cylinder connected to the piezo stack for transmitting the excitation to the hydraulic path and a prestress cylinder to put a preload on the system. The “Hydro Shaker” allows applying static or dynamic forces by 12kN in a frequency range up to 1000Hz. The shaker can be integrated in the complete release system without affecting the dynamical behaviour significantly.

3.3.1 Vehicle Test

Vehicle tests are commonly performed in the operating point where the pedal vibration occurs. This can be in idle speed while engaging or disengaging the clutch or in an engine speed-up. The following parameters are measured: Engine speed, pedal acceleration, pedal travel, temperature in the engine compartment, pressure behind slave cylinder and before master cylinder, flywheel travel. The advantage of vehicle tests is the authenticity of the vibration phenomenon and the possibility of subjective evaluation.

3.3.2 Test bench

For elementary investigations vehicle tests are basically used, but to gain a better knowledge of the pedal vibration and its affecting parameters, vehicle tests are not suitable due to the multitude of different excitation sources and transfer paths. On a test bench it is possible to investigate the NVH phenomena in more detail. Therefore special test benches were constructed to carry the hydraulic release system. The excitation was realised by using the Hydro Shaker as the source. Figure 6 shows the test assembly in principle.

The test bench provides the opportunity to identify the natural frequency of the hydraulic path, including the hydraulic tube and the fluid. Also counter measures for solving a vibration problem can be proven.

3.3.3 Computer Simulation

To obtain a better understanding of the entire vibrational system and to define a layout concept of the release system, LuK has developed its own simulation software called “EFAS”. The software allows the calculation of eigenfrequencies of the complete release system. Effects of modifications of components, like the tubing, can be detected in an early stage of the product development. In the following case, the model in Figure 7 provides information that is representative of many NVH phenomena of the release system.

With the mass and the stiffness of the components it is possible to simulate the frequency characteristics of the system. The results of the simulation, based on the model above, are shown in Figure 8.

In this case, the natural frequency analysis of the vibration model results in a correspondence of the cover natural frequency and the frequency of a standing wave in the fluid column, which leads to an increased noise and vibration transmission in the release system.
Natural form cover f=1100 Hz
Natural form hydraulic path f=1100 Hz

Figure 8: Results of a Natural Frequency Analysis of the Release System

Detuning the two frequencies can solve the problem, thus by changing the cover stiffness or the length of the hydraulic tube, which is the simplest solution. If a wider frequency shift is not possible with elongating the hydraulic tube, other counter measures can be considered.

4 Counter Measures

4.1 Anti Vibration Unit (AVU)

One result of development is the so-called “Anti Vibration Unit”, which can be used especially to dampen low-frequency vibrations without additional loss of travel, thus eliminating unpleasant pedal vibrations. The “AVU” stops the vibration transmission when the pedal is not in actuation. Its functionality is based on the principles of a valve. Different pre-loads on the gasket allow a tuning of the opening pressure and thus the amplitude of the filtered pressure fluctuation can be adjusted for the specific application. A section view of the “AVU” is represented in Figure 9.

Figure 9: Section View of Gasket Vibration Damper

4.2 Dual Stage Damper

The “Dual Diaphragm Damper” represents the latest level of development. With its two diaphragms, each with different properties, this damper enables the implementation of a dual stage characteristic. Thus the tuning of the release system can be done more accurately.

Figure 10: Section View of Two Stage Damper

4.3 Measurements with the AVU

The effectiveness and the advantage of the represented Counter Measures will be shown in the following, taking the “AVU” as an example. The presented measurements are results from vehicle tests. In the first step the excitation of the release system is taken into account. In the Figures 11 and 14 the engine speed is diagrammed over crankshaft rotations. These Diagrams are used to compare the excitation and to proof, that the excitation hasn’t changed between the tests.

Figure 11: Engine speed over Crankshaft Rotations before installing the AVU

In Figure 12 the pressure progression in the hydraulic hose at two measuring points is shown, one at each end of the hose. The pressure peaks, which occur with every ignition, are clearly identifiable. These peaks are transmitted through the whole release system and are also measurable as vibrations in the clutch pedal, as shown in Figure 13.

Figure 12: Pressure Progression in the Hydraulic Hose without AVU

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After installing the AVU, the same measurements were performed again. As Figure 14 shows, the excitation is in the same range as in the test before.

In Figure 15 the effect of the AVU is visible very well. All the pressure peaks are heavily damped after leaving the AVU.

The Measurements in the clutch pedal also show the effect of the AVU. The pedal vibrations are reduced to the minimum.

LuK developed a new cover design, which integrates the release bearing in the clutch cover. Thus the force flow and the axial relative movement between the release bearing and the gearbox are interrupted as well as the axial movement of the clutch cover is no longer transferred to the release system. Pedal Vibrations excited by axial movement of the crankshaft or axial eigenmodes of the flywheel or the clutch cover can be anticipated by installing a “Cover Fixed Release System” as shown in Figure 18.
Vibrations excited from components inside the clutch, like the pressure plate or the diaphragm spring, are still transferred to the release system because a relative movement still exists between these parts and the release bearing. Therefore an AVU unit can be implemented in the connection or integrated in the CSC. The “Cover Fixed Release System” is most effective for pure axial vibrations.

In the following vehicle measurements, the effect of a Cover Fixed Release System is shown. First the test vehicle was measured with the regular Release Bearing mounted in the gearbox. In the test, the engine speed was held at $2000 \text{ min}^{-1}$ in low gear and the clutch was engaged. By disengaging the clutch, a pressure pulsation in the release system and a pedal vibration occurred. The diagrams in Figure 19 show the interesting parameters, like engine- and transmission speed, flywheel stroke, pressure in the hydraulic tube and pedal vibration. The pulsations in the pressure and the high amplitudes in the pedal acceleration are clearly visible.

In the next step the regular release system was replaced by the “Cover Fixed Release System”. This system has been tested under the same conditions as the release system in the test before. According to this test the measurement set is shown in Figure 20.

With the installation of the “Cover Fixed Release System”, the pressure pulsation and the pedal vibration were highly reduced. A reduction of Peak-to-Peak Value by 76% was achieved.

5 Summary

This paper explained the approach to investigate the pedal vibration phenomenon. Due to the complexity of this phenomenon, different possibilities to investigate the pedal vibration had to be taken into account, like vehicle tests, test bench researches and computer simulations. The effectiveness of counter measures, like the “Anti Vibration Unit” (AVU) and the “Cover Fixed Release System”, was shown in vehicle tests.

References