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Abstract:

Downsizing of transmission boxes and economic pressures in manufacture has gradually led to changed sealing conditions in passenger cars. Radial shaft seals are widely used in power transmission systems to prevent oil leakage from the system. Leaking transmission systems can lead to both environmental pollution and excessive warranty costs. It is essential to develop a dedicated experimental rig to simulate the transmission system operation under controlled environment, providing access for various sensors and data acquisition systems. A pre-requisite for representative rig design is to determine the in situ vehicle conditions which must be replicated in such a design. The paper reports on the evaluation of these in situ conditions, particularly the imposed vehicular vibration conditions.

Keywords—oil leakage; radial shaft seals; surface topography; vibration; seal performance; test-rig

1-Introduction

All input/output transmission shafts are sealed in order to avoid oil leakage from the housing. Radial shaft seals are mounted stationary in the gearbox housing. At the inner side of the seal, a rotating shaft seat is in contact with a non-rotating sealing lip. Between the contact surfaces, a thin film of transmission fluid is formed due to rotation of the shafts. Owing to the importance of effective sealing, it is essential to examine and develop new generation of transmission sealing systems. A step towards achieving this is design of a testrig which can simulate the conditions in real transmission system. The advantage of such testrigs is to allow for more controlled environment, where the influential parameters can be studied more thoroughly. It also allows for placing various sensors at different locations of interest, which otherwise could be very difficult to implement. However, to design a suitable test rig for the purpose of examination of leakage from radial shaft seals, used in automotive transmission system, it is necessary to understand the conditions experienced in situ within a vehicle. In addition to geometry [1], loading [2], angular velocity, temperature, type of materials and transmission fluid [3, 4], the seal contact surface [5, 6] in real application is subjected to radial, axial and lateral vibrations. Thus, it is necessary to determine the extent of these vibrations in terms of their spectral content (frequency and amplitude).

Although it is quite common practice in industry to measure and monitor the conditions in various components of real vehicles through specifically designed real vehicle testbeds, there are quite a limited number of reports in the academic literature from such measurements in the context of the real transmission system seals. Nevertheless, there are a number of literatures which have focused on modelling aspects of the associated vibrations in transmission systems. For example, Kumar and Patil [7] report on FEA modelling and vibration analysis of transmission gearbox housing. A review of research on vibration analysis of crankshaft systems in internal combustion engines is given by Talikoti et al [8]. However, the potential implications of such vibrations in the engine driveline including its effect on the transmission sealing system have not been explored in their review. In the broader context, Lee et al [9] provide a review of prognostics and health monitoring of rotary machines and associated methodologies. However, the implications on the associated sealing system are not discussed in their review. Nevertheless, the vibrations and associated noise emissions from vehicular gearbox systems are investigated more commonly. For instance, Tuma [10] reviews the practical techniques to reduce vibrations and particularly emitted noises from gearboxes and transmission units. It is discussed that the gearbox noise and vibration analysis is conducted based on the time and frequency methods. As an another examples, time-frequency representation of gearbox vibrations is used by Oehlmann et al [11] to analyse the associated faults, while Lei et al [12] use and adaptive stochastic resonance method for this purpose. In none of such research works, no attempt has been made in using or linking the measured data to the leakage form the associated transmission systems, highlighting a lack of research in monitoring an measurement of vibrations in the automotive transmission system with the aim for use in the study of the leakage form such systems either through replicating the conditions in a specially designed test rigs or through numerical methods.

The aim of the study is to improve upon the understanding of vibrational conditions experienced in sealing of shafts of transmissions for passenger cars. This is achieved by taking measurements from real vehicles and post-processing of the relevant data. To ensure a realistic and representative testing environment a specific test vehicle was equipped with tri-axial miniature accelerometers [13] and a full road test was performed [14, 15].

In-field experience had shown that at the rotational input shaft speed of 4000 rpm with the transmission engaged in 5th gear leakage from the shafts' seals can occur, especially when load changes take place in gear changes. During the driving-tests, the shaft oscillates by as much as 2 mm axially out of the differential housing and back to the centre of the retaining bracket [5, 16, 17] (Z-direction in Fig. 1). Both, the axial movement of the shaft and the poor sealing performance at high speeds, are relevant in defining the testing procedure for the proposed test-rig in the subsequent research in future [18].

2-Preliminary Results

A non-contact rotational encoder is used to obtain the rotational engine speed. The range of vehicle speed chosen for measurements are: 80-160 km/h, with the tests mainly performed in motorways and the connecting country roads. During test-drive, accelerations at different directions and speeds with different ensuing levels of structural components such as the steering knuckle, prop-shaft bracket and the differential are measured (see Fig. 1).

No.	Description
1	Outboard-Joint
2	Bumper & Clamps
3	Drive Shaft (LHS)
4	Tulip
5	Drive Shaft (RHS)
6	Bracket
7	Bearing
8	Linkshaft
9	Radial Shaft Seal
10	Transmission Case
11	Inboard-Joint
12	Tooth Belt

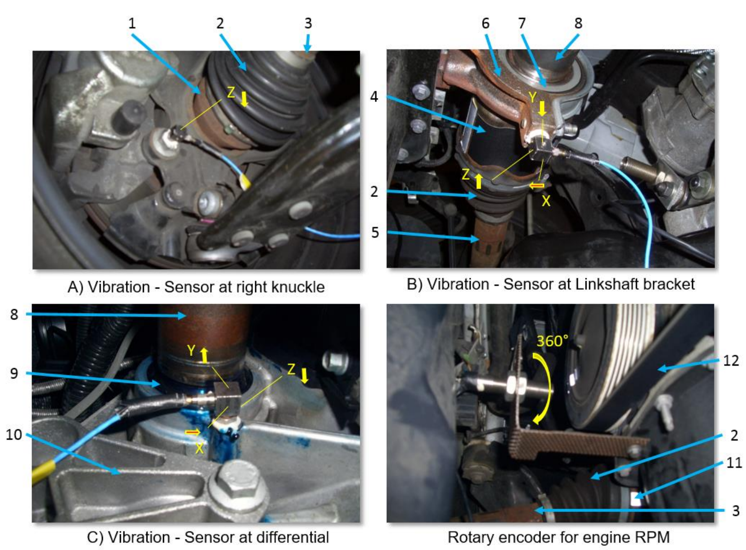

Fig. 1: Sensor equipment during test-drive

The acceleration in Z-Direction is measured as shown in Figure 1A. A sensor connected to the prop-shaft bracket detects the vibration in X, Y and Z-directions as shown in Fig. 1B. As an important spot near to the sealing gap, the vibrational movement in three directions can be determined. The rotary encoder shown in Fig 1 (D) measures the rotational speed of the engine at which all the vibrations are measured by the accelerometers at spots shown from Fig. 1A to C.

All the acquired data is transferred into Campbell diagrams [13, 19] for further analysis. Figure 2 shows test-drive results in the form of a Campbell diagram when the transmission is engaged in 3rd, 4th and 5th gears. The gear shifting stages are marked in green for the 3rd gear, in red for the 4th gear and in blue for the 5th gear. The rotational speed of the engine in RPM is displayed as the abscissa and the acceleration or vibration level as the ordinate. The excitation is expressed in Hz as a measure of frequency or pitch. Due to the transmission and reception of electromagnetic signals at a particular frequency, a certain amount of waves is transmitted at any instant of time. In the current case the excitations over 250 Hz in the X-direction occur at the linkshaft bracket.

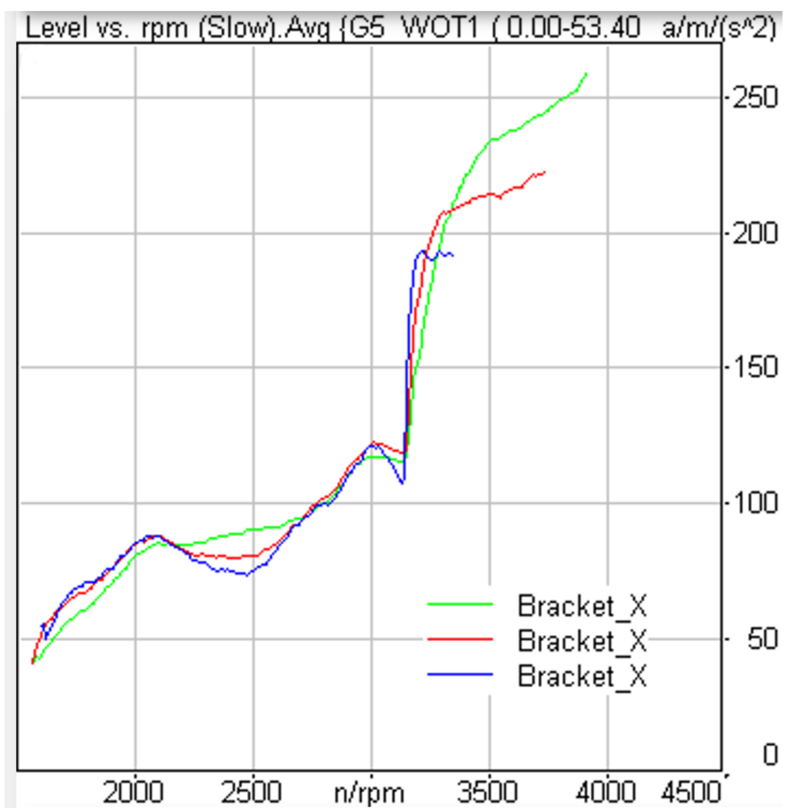

Fig. 2: Test-drive results divided into components

Figure 3 shows high levels of vibration in the X-direction at the engine speeds exceeding 3200 RPM. At this speed the engine exhibits a resonant response. Unknown eigenmodes can also be observed at the holding bracket with amplitudes at this engine speed with a wide frequency range of ~3 to ~5 KHz. The colour scale in the horizontal axis of Fig. 3 shows the amplitude of acceleration with peaks of up to 15 m/s². The diagonal lines indicate that the acceleration values rise proportionally to the increasing rotational speed. It becomes obvious that the resonances above 3200 RPM are independent of the rotational speed which may be associated with the modal responses of the structure.

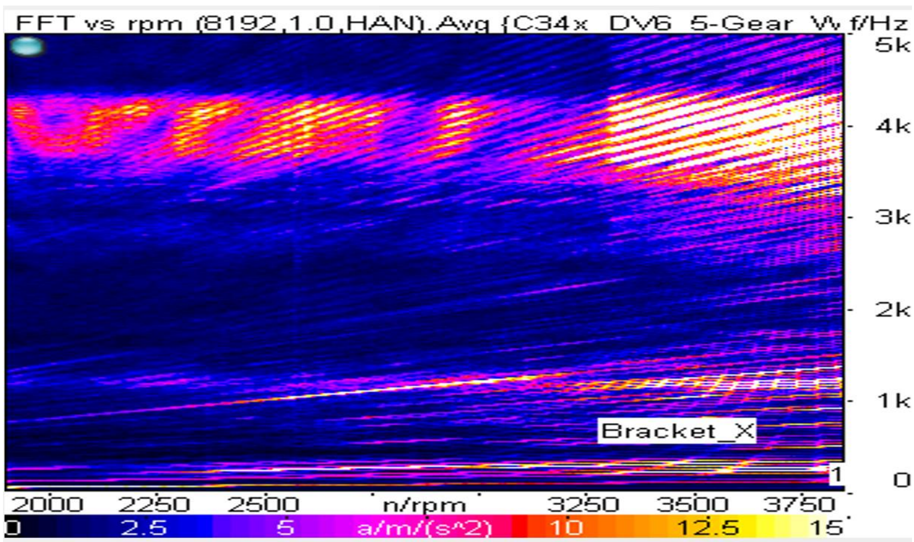

Fig. 3: FFT vs. RPM of the prop-shaft-bracket in X-direction

The bracket is connected to the linkshaft through a ball bearing. Through this connection, which is only slightly damped by tripod joint of the linkshaft, the vibrations are transferred into the differential gearbox. The Campbell diagrams shown in Fig. 4 show the relevant frequencies at the differential in the Z-direction. From the system, the clearest response could be determined in the Z-direction. In 5th gear, an unknown eigenfrequency occurs at the differential. Quite high acceleration amplitudes occur (approx. 5 m/s²) in the frequency range of ~3 to ~4 KHz.

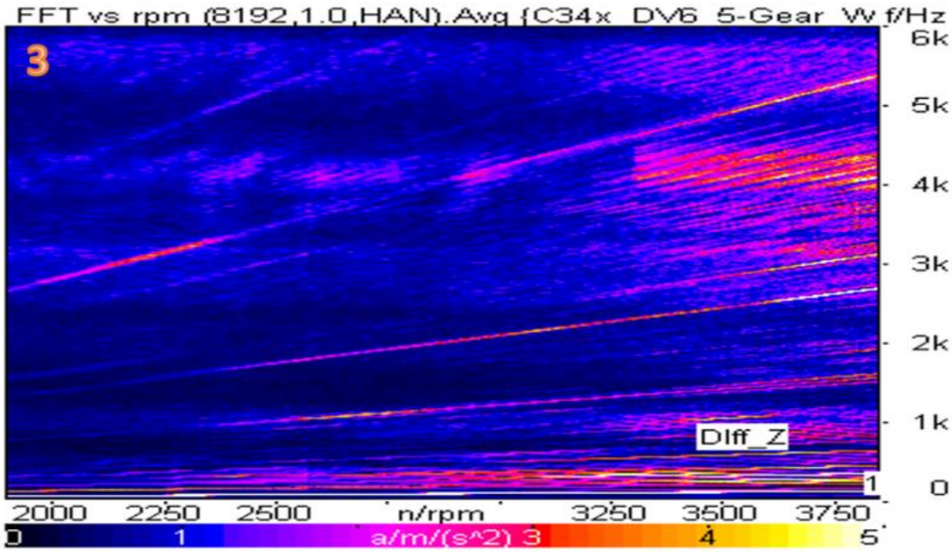

Fig. 4: FFT vs. RPM of the differential in Z-direction

Conclusion

In conclusion, it is observed that the driving conditions at rotational speed of approximately 4000 RPM corresponding to vehicle speed of 160-180km/h in 5th gear can generally cause a leakage in the transmission system, especially when load changes in the form of additionally harsh gear changes. During the driving-tests severe prop-shaft vibrations with axial displacements of the order of 2mm out of the differential could be observed. Therefore, measurement of axial shaft vibration with high accuracy is critical for the design and development of a relevant test rig. A successful vibration measurement method from a real vehicle was introduced. Identifying both, the axial vibration in the Z-direction of the shaft and the potentially resulting poor sealing performance at high speeds are directly relevant to the design of a tailored testing procedure for the new test-rig. It is worthy of note that a more accurate method of measurement could be through use of laser vibrometry [20, 21], providing that optical access to the desired parts during the field tests could be maintained, while also the relatively higher cost of using such systems is not considered to ab an issue. Use of such high precision measurement methods in the controlled environment of a specifically developed testrig can, however, be an advantageous.

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