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Research Article

Experimental Analysis of Balance-Induced Vibrations in Vehicle Shafts

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Abstract: Extensive research has been conducted in recent years to mitigate damages caused by undesired vibrations in motor vehicles used for transportation. Vibrations occurring in highly active moving components of vehicles not only lead to discomfort in driving comfort but also reduce the material's service life, causing fatigue and structural damage. Rotating elements in vehicles, such as the shaft (cardan shaft), crankshaft, and gears, can be sources of problems. In this study, vibrations resulting from an imbalance problem in the vehicle shaft were experimentally investigated, and the effects of balancing on the vehicle shaft were evaluated. For this purpose, vibration data were measured at three different points on a vehicle. Vibrations generated by the shaft under different road conditions and vehicle speeds were recorded and compared before and after balancing. The results of the study demonstrated a one-third reduction in vibration amplitude at the point beneath the driver's seat, which is directly associated with the comfort of both driver and passengers. Specifically, under the most demanding conditions (80 km·h^{-1} speed and an uneven road surface), the vibration amplitude induced by the unbalanced driveshaft reached a high value of 2198 μm; after balancing, a reduction of approximately 65–70% in this amplitude was achieved at the measurement point under the driver's seat. In contrast, no significant difference was observed in the vibrations measured at the engine block and the luggage compartment. The findings indicate that vibrations originating from the vehicle driveshaft can be substantially mitigated through proper balancing.

Keywords: *Balancing, Driving comfort, Vehicle shaft, Vibrations*

I. INTRODUCTION

One of the most significant issues encountered in modern motor vehicles is the structural and functional problems caused by unwanted vibrations. Vibrations not only adversely affect driving comfort but also shorten the lifespan of vehicle components, accelerate fatigue behavior, and cause various mechanical failures. These vibrations, particularly prevalent in heavily loaded moving parts, directly influence the long-term performance and reliability of the vehicle.

A permanent solution to vibration problems can only be achieved by analyzing the root causes of these vibrations individually. Among the rotating elements operating in vehicles, the shaft (Fu et al., 2018), crankshaft, and gears are the primary components responsible for vibration-related issues. The propeller shaft is a critical transmission element that conveys the power and rotational motion generated by the engine to the wheels (Elanchezhian et al., 2018; Hu et al., 2020). This component must continuously operate under varying angles and dynamic stresses between the gearbox and the differential (Elanchezhian et al., 2018; Hu et al., 2020; Şen & Atik, 2025). Through universal joints, propeller shafts allow motion transmission between shafts operating on different planes and axes while maintaining functionality without being affected by limited axial displacements (Hummel & Chassapis, 2000).

Several studies in the literature have focused on components known to cause NVH (Noise, Vibration, and Harshness) problems due to imbalance in vehicles. Higley (2003) presented a method for calculating optimal balancing masses for symmetric system configurations. Hemingray (2004) summarized the relationship between automotive balancing limits and human perception. Duarte et al. (2005) performed experimental static and dynamic balancing tests on rotating machinery using the trial-weight method, which employs the Fast Fourier Transform (FFT) to identify vibration signals and bring the system to equilibrium. Liu and Orzechowski (2007) investigated axle imbalance measurements and balancing strategies.

Recent studies emphasize that shaft-related vibrations should be addressed not only as a balancing issue but also as a system-level NVH and durability driver. For instance, Zhao et al. (2020) employed an integrated CAE/testing methodology to investigate driveline torsional vibration–induced vehicle NVH response, highlighting the need for coupled modeling and validation at the vehicle level. Complementarily, Tchomeni and Alugongo (2021) presented a dynamic analysis of an unbalanced cardan shaft for vehicle propeller-shaft systems, showing how unbalance-related nonlinearities may propagate through the driveline. In a more recent and data-driven direction, Yongxu et al. (2025)

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proposed a real-time static unbalance evaluation approach for cardan shafts based on a nonzero frequency filter, underlining that unbalance detection and quantification can be executed efficiently in operational conditions. Furthermore, a contemporary review by Wu et al. (2024) synthesizes identification, control, and evaluation methods for vehicle drivetrain vibration/NVH, indicating a clear shift toward holistic NVH frameworks. Finally, recent applied studies on drive-shaft dynamic parameters also point to design-level opportunities to reduce vibration by tuning stiffness/mass and operational parameters (Danh, 2025).

The imbalance issues of drive shafts or propeller shafts have been extensively addressed in the literature. Meinhardt et al. (2011) developed a model predicting the NVH response of a vehicle drivetrain based on imbalance and oscillation distributions. Yu and Higley (2009) proposed an algorithm addressing phase uncertainty caused by clutch interactions and isolating transmission imbalance without the need to measure individual imbalance components at the system level. Becker et al. (2005) introduced two vehicle-level test methods to demonstrate the relationship between first-order cabin noise and drivetrain imbalance components. Braun et al. (2005) developed a methodology for testing drivetrain imbalance sensitivity. Higley and Hiatt (2001) investigated the effects of errors in initial imbalance measurements and correction processes on residual imbalance in automotive drivetrains. Hill et al. (2017) developed an analytical method that evaluates and optimizes half-shaft joint angles to prevent excessive third-harmonic half-shaft vibrations under wide-open throttle (WOT) and light launch conditions. Behera and Sivalingam (2017) proposed a mathematical model to investigate wobble instability in two-wheeled vehicles. Saveliev (2018) emphasized that the propeller shaft is one of the primary sources of vibration in vehicles and that it can both transmit vibrations to and receive them from connected components. His findings revealed that after balancing, the critical speed increased by approximately 20%, accompanied by a significant reduction in vibration amplitude. Kalkat et al. (2003) used artificial neural networks Zhao et al. (2020) to predict vibration parameters (such as amplitude, velocity, and acceleration) related to rotor dynamics in rotating machinery. Fedák et al. (2014) developed a simulation model to analyze the vibrations of both statically and dynamically unbalanced rotating bodies and examined the effect of eccentricity on vibration behavior. Using MATLAB-based modeling, they reported that post-balancing vibration amplitudes decreased by up to 60% in the resonance region. White (2017) conducted studies on experimental measurement techniques to determine the critical speeds of propeller shafts and noted that even the best-balanced shafts retain a certain degree of imbalance. He stated that after optimal balancing, a “residual imbalance” remains, but vibration amplitudes are reduced by approximately 40–55% on average. Kirmizi (2022) reported that balance problems in propeller shafts lead to pronounced increases in vibration amplitudes at critical speeds, resulting in severe negative effects on both mechanical performance and driving comfort. His experimental findings showed that when balancing and mass reduction were applied together, vibration amplitudes decreased by 55%, and critical speed increased. Quang (2021) simulated the operating conditions of a car running at a constant speed of 60 km.h-1 and observed that when the shaft was balanced, vibration amplitudes decreased by approximately 50–60% during both static and dynamic balancing conditions.

While these studies provide valuable insights, they reveal two notable limitations. First, much of the existing research is either simulation-based or focused primarily on the shaft itself rather than on how imbalance-induced vibrations propagate to different regions of the vehicle. Second, the influence of shaft balancing on passenger comfort parameters, particularly vibration levels measured at the driver’s seat, remains underexplored. This gap underscores the need for experimental investigations under real road conditions that assess how balancing interventions directly impact not only the shaft but also other critical vehicle locations affecting both performance and comfort.

In this study, the vibrations in the vehicle’s propeller shaft caused by imbalance were experimentally analyzed, and the effects of balancing on the overall system were evaluated. Vibration measurements were carried out at three strategic points—above the engine block, beneath the driver’s seat, and inside the trunk—under varying road conditions and vehicle speeds, both before and after balancing. By comparing vibration responses across these locations, the research provides a comprehensive perspective on how balancing mitigates vibration transmission throughout the vehicle.

The primary aim of this work is therefore twofold: (i) to provide experimental evidence regarding the effectiveness of balancing in reducing imbalance-induced vibrations in the propeller shaft, and (ii) to assess how such reductions reflect on driving comfort and vehicle reliability. The findings are expected to offer practical insights for automotive engineers and manufacturers by emphasizing the potential of shaft balancing as a cost-effective strategy to enhance both passenger comfort and the service life of drivetrain components.

A.1. Imbalance

A rotor is defined as a mass or a system of masses rotating around an axis, typically possessing a rotational structure and assumed to be rigid. Imbalance occurs when the principal axis of inertia passing through the center of mass does not coincide with the axis of rotation. Two specific forms of imbalance are generally identified: static imbalance and dynamic imbalance.

A.1.1. Static Imbalance

If the center of gravity of a rotating machine component does not coincide with its axis of rotation, the component is said to be statically imbalanced. When the axial dimension of a machine part is significantly smaller than its radial dimension, it is assumed that the rotating masses lie in the same plane and that the system exhibits only static imbalance. Typical examples of such elements include gears, disks, and flywheels.

A simple experimental method can be used to determine whether a machine component has static imbalance (Figure 1). In this method, the part (e.g., a disk) is mounted on a straight and balanced shaft and placed on two horizontally rigid supports with springs. By allowing the system to move freely, the presence of imbalance can be identified.

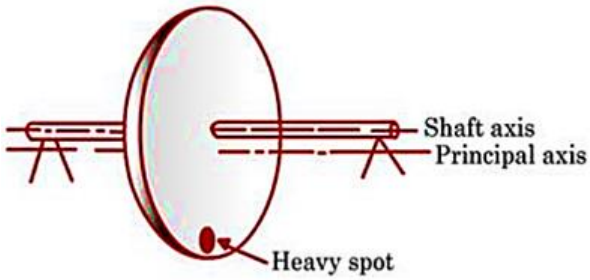


Figure 1. Static imbalance (Bhelsekar et al., 2019)

As illustrated in Figure 1, a disk mounted on a shaft is allowed to roll slowly along the shaft. When the disk comes to a complete stop, the lowest point of the disk is marked. This procedure is repeated four or five times. If the marks on the disk are distributed around its circumference, the part is considered free from static imbalance. However, if the marks consistently coincide in the same region, the part is statically imbalanced. In the case of imbalance, the center of mass of the part lies on the straight line connecting the geometric center of the disk with the clustered marks. Accordingly, the angular position of static imbalance is determined, while its magnitude remains undefined (Uzmay & Sarıkaya, 1990).

A.1.2. Dynamic Imbalance

Dynamic imbalance occurs when the center of mass of the rotor lies on the axis of rotation, but the principal axis of inertia passing through the center of mass is not parallel to the axis of rotation. The condition of dynamic imbalance is illustrated in Figure 2.

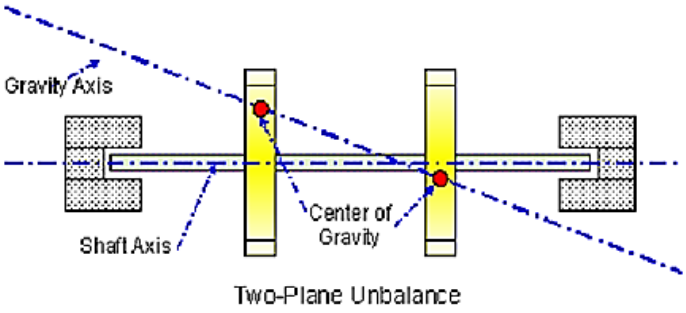


Figure 2. Dynamic imbalance (Bhelsekar et al., 2019)

High rotational speeds in machinery often lead to the generation of significant inertial forces, even when the unbalanced masses are relatively small. These inertial forces may cause severe vibrations depending on the operating conditions. The resulting vibrations impose dangerous stresses on moving components, supporting structures, and foundations. Depending on the intended use of the machine, such vibrations may also lead to noise, fatigue, or fracture; therefore, they must be thoroughly investigated and mitigated. For instance, consider a shaft: if a manufacturing defect or misalignment occurs during production or assembly, the shaft may fracture under operating conditions. Failures in moving parts caused by mass imbalances not only reduce operational efficiency but also pose substantial risks. For these reasons, it is essential that moving components are balanced as precisely as possible.

A.2. Balancing Methods

Balancing is the technique of correcting or eliminating unwanted inertial forces and moments that arise during the operation of a machine component. Inertial forces and moments in rotating parts cannot generally be eliminated completely, as they result from unavoidable design and manufacturing imperfections or wear that develops over the service life of the component. Unbalanced machine parts give rise to large inertial forces, which consequently cause

undesirable vibrations. Although these vibrations may not always be extremely large, the resulting alternating stresses subject machine elements to fluctuating loads, leading to fatigue failures over time. Various methods are employed to achieve balancing of machine components.

A.2.1. Static Balancing

Static balancing is the process of adding or removing a mass (or masses) in a single plane in order to bring the center of mass of a rotor closer to the axis of rotation. The objective of static balancing is to achieve $r_1 = 0$, thereby eliminating the inertial force. As a result, no forces are generated in the bearings due to static imbalance.

A.2.2. Dynamic Balancing

Dynamic balancing is the process of adding or removing a mass (or masses) in two different planes in order to bring the principal axis of inertia, which passes through the center of mass of the rotor, closer to the axis of rotation.

II. MATERIAL AND METHOD

In the experimental study, a 1971 model vehicle was utilized. Due to the age of the vehicle, it was assumed that certain components had developed unbalanced masses over time as a result of fatigue. The vehicle's propeller shaft was manufactured from St40 material, and its dimensions are provided in Figure 3.

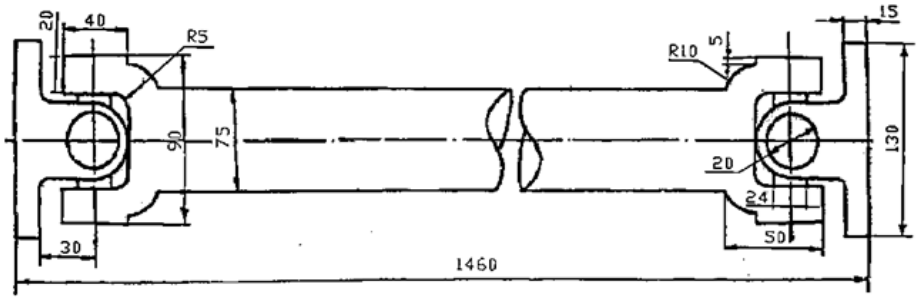


Figure 3. Shaft dimensions.

Amplitude, velocity, and acceleration measurements were performed using a uniaxial piezoelectric accelerometer (Figure 4). The analog voltage signal (mV) obtained from the accelerometer under the specified road and vehicle speed conditions was recorded via a data acquisition system (datalogger) providing constant current excitation. The acceleration data acquired in the time domain were converted into digital form, and after the required filtering processes were applied using the Mastertrend software, velocity and displacement values were calculated through numerical integration. The measurements were recorded for a duration of 1 minute, corresponding to a travel distance ranging between 333 m and 1333 m, depending on the vehicle speed.

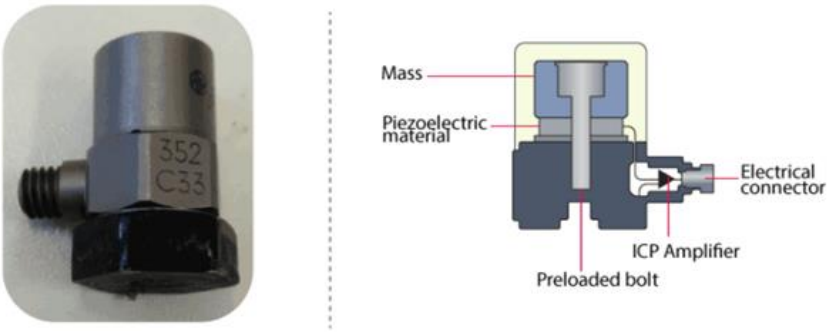
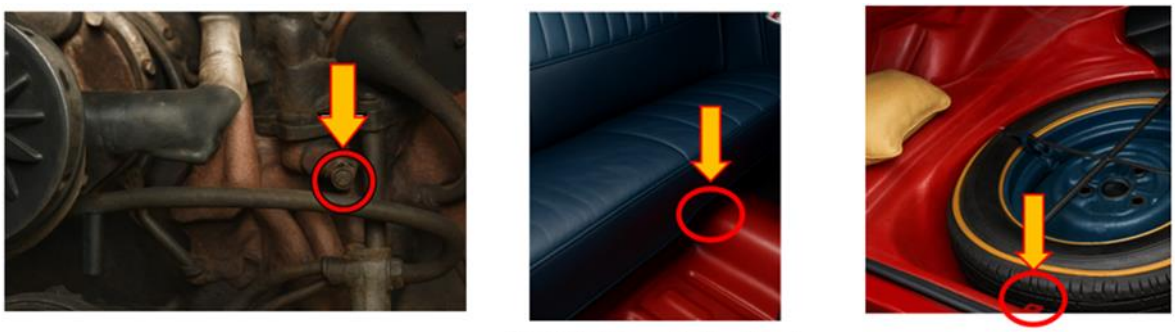


Figure 4. Accelerometer

The vehicle was operated under different road conditions at varying vehicle speeds and engine rotations per minute (rpm), and the corresponding vibration values were measured. A uniaxial (vertical axis) piezoelectric accelerometer was employed to record the vibration data. Since the vehicle shaft exhibited dynamic imbalance due to mass non-homogeneity, vibrations induced at 1100 rpm were analyzed in terms of amplitude, velocity, and acceleration. To investigate the influence of various factors, three measurement points were selected on the vehicle: above the engine mount (Point 1), beneath the front seat inside the cabin (Point 2), and inside the trunk (Point 3) (Figure 5).



Point 1: Above the engine mount

Point 2: Beneath the front seat (cabin interior)

Point 3: Inside the trunk

Figure 5. Measurement points on the vehicle.

The balancing process of the shaft was carried out using the shaft balancing machine shown in Figure 6. This machine operates based on the dynamic balancing principle, aiming to align the center of mass of the rotating system with its axis of rotation. During the balancing procedure, the shaft was rotated at 1100 rpm on appropriate supports, and vibration responses induced by imbalance were measured using acceleration or displacement sensors. The measured signals were evaluated together with their amplitude and phase information to determine the magnitude and angular position of the imbalance. Accordingly, balance correction was performed by adding or removing weights at appropriate locations on the shaft. As a result, the dynamic forces generated by the shaft during operation were minimized, leading to an effective reduction in vibration levels.

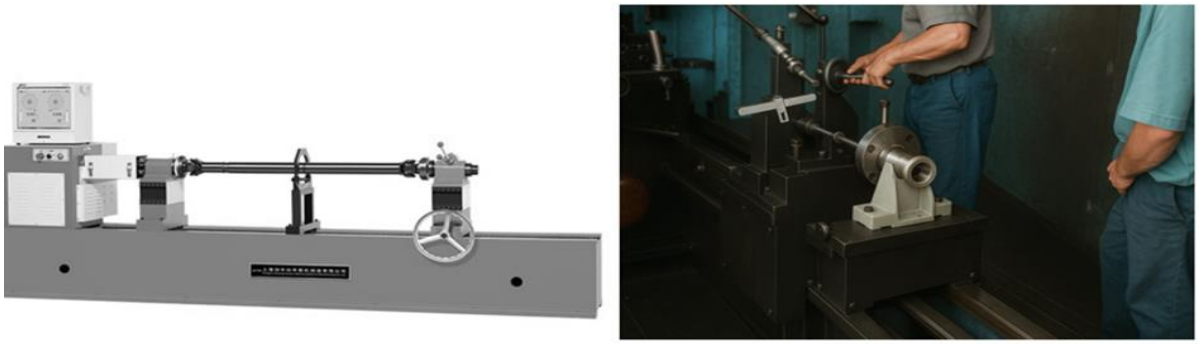


Figure 6. Shaft balancing process.

III. RESULTS AND DISCUSSIONS

Taking into account all road conditions and different speed levels, measurements of the shaft were performed both before and after the balancing process, and the results were compared. The data obtained from these measurements are presented in the tables (Table 1-4) below.

Table 1. Measurement values obtained from the vehicle while stationary with the engine running.

	Amplitude (µm)		**Velocity (mm.s^{-1})**		**Acceleration (g·s)**	
	Unbalanced	**Balanced**	**Unbalanced**	**Balanced**	**Unbalanced**	**Balanced**
V = 0 km.h^{-1} (forward speed)						
Point 1	174.1	155.0	13.42	11.39	0.2013	0.2025
Point 2	21.53	61.89	2.28	2.494	0.03185	0.06102
Point 3	18.10	24.39	1.271	0.7717	0.03450	0.02020

While the vehicle was stationary (v = 0 km·h^{-1}), the engine was operated, and amplitude, velocity, and acceleration data were measured at three predetermined locations using the accelerometer, both before and after the shaft balancing process. The measurement results indicated that the highest vibration amplitude was recorded at the first measurement point located near the engine, with a value of 174.1 µm. After the balancing of the shaft, this value decreased by approximately 11%, reaching 155 µm.

Table 2. Measurement values obtained from the vehicle while driving on a rough road.

	Amplitude (μm)		Velocity (mm.s^{-1})		Acceleration (g·s)	
	Unbalanced	**Balanced**	**Unbalanced**	**Balanced**	**Unbalanced**	**Balanced**
V = 20 km.h^{-1} (forward speed)						
Point 1	1019	1451	44.33	38.36	1.3950	1.763
Point 2	618	347.3	15.99	9.291	0.5266	0.2742
Point 3	29.78	37.97	0.8592	0.7257	0.02210	0.02094
V = 40 km.h^{-1} (forward speed)						
Point 1	1795	1783	42.48	122.5	1.9160	1.875
Point 2	801.6	656.5	24.34	14.24	0.4050	0.3380
Point 3	31.59	25.70	0.5743	0.6295	0.02235	0.02244
V = 60 km.h^{-1} (forward speed)						
Point 1	1211	1374	54.81	51.00	1.820	2.179
Point 2	526.7	531.6	14.42	18.92	0.5520	0.5322
Point 3	25.10	47.31	0.7710	0.9093	0.02090	0.02376
V = 80 km.h^{-1} (forward speed)						
Point 1	2198	2028.59	150.3	57.85	2.430	2.201
Point 2	42.12	564.5	0.6506	20.88	0.02072	0.8385
Point 3	34.85	27.40	0.7540	0.8211	0.02340	0.02179

Under rough road conditions, the vehicle was driven at four different forward speeds (20, 40, 60, and 80 km·h^{-1}), and amplitude, velocity, and acceleration data were measured at three predetermined locations both before and after the shaft balancing process. The measurements indicated that, in the unbalanced condition, the highest vibration amplitude was recorded at the first measurement point at a vehicle speed of 80 km·h^{-1}, with a value of 2198 μm, whereas in the balanced condition, the corresponding amplitude decreased to 2028.59 μm, representing a reduction of approximately 8%. Under rough road conditions, the greatest reduction in vibration amplitude was observed at the second measurement point at a vehicle speed of 40 km·h^{-1}, with a decrease of approximately 44%. These results highlight the importance of shaft balancing, particularly at lower vehicle speeds under rough road conditions.

Table 3. Measurement values obtained from the vehicle while driving on an asphalt road.

	Amplitude (μm)		Velocity (mm.s^{-1})		Acceleration (g·s)	
	Unbalanced	**Balanced**	**Unbalanced**	**Balanced**	**Unbalanced**	**Balanced**
V = 20 km.h^{-1} (forward speed)						
Point 1	534.0	758.6	30.70	33.37	1.326	1.386
Point 2	388.5	37.43	5.427	0.6136	0.2159	0.02025
Point 3	34.05	36.34	0.5891	0.5953	0.02327	0.02072
V = 40 km.h^{-1} (forward speed)						
Point 1	882.8	628.32	41.64	42.83	1.586	1.824
Point 2	290.7	24.75	11.08	0.5468	0.2221	0.02144
Point 3	28.22	22.28	0.7844	0.6076	0.02416	0.02584
V = 60 km.h^{-1} (forward speed)						
Point 1	1104	727.3	39.53	38.10	1.785	1.635
Point 2	269.4	40.54	9.977	0.6980	0.2385	0.02261
Point 3	18.72	25.50	0.8564	0.9360	0.2197	0.02144
V = 80 km.h^{-1} (forward speed)						
Point 1	2087	985.0	70	51.20	2.424	2.481
Point 2	426.5	33.37	11.34	0.7138	0.1566	0.02122
Point 3	31.83	42.24	0.5911	0.5764	0.02244	0.03026

Under asphalt road conditions, the vehicle was driven at four different forward speeds (20, 40, 60, and 80 km·h^{-1}), and amplitude, velocity, and acceleration data were measured at the same locations both before and after the shaft balancing process. The measurement results indicated that, in the unbalanced condition, the highest vibration amplitude was recorded at the first measurement point at a vehicle speed of 80 km·h^{-1}, with a value of 2087 μm, whereas in the balanced condition, this value decreased to 985 μm. Under asphalt road conditions, the most pronounced change in vibration amplitude was observed at the second measurement point at a vehicle speed of 80 km·h^{-1}, with a reduction of approximately 93%.

Table 4. Measurement values obtained from the vehicle while driving on a highway.

	Amplitude (µm)		Velocity (mm.s^{-1})		Acceleration (g·s)	
	Unbalanced	**Balanced**	**Unbalanced**	**Balanced**	**Unbalanced**	**Balanced**
V = 20 km.h^{-1} (forward speed)						
Point 1	501.6	310	30.37	30.35	1.723	1.741
Point 2	201.2	224.3	6.521	6.942	0.1881	0.1491
Point 3	38.76	21.36	0.9847	0.8763	0.02131	0.02144
V = 40 km.h^{-1} (forward speed)						
Point 1	750	1104	37.83	41.15	1.928	1.984
Point 2	385.2	335	8.21	6.665	0.267	0.2253
Point 3	37.57	39.78	0.8121	0.5911	0.0209	0.02085
V = 60 km.h^{-1} (forward speed)						
Point 1	743.1	795	39.78	43.76	2.85	2.916
Point 2	259	225	8.381	8.98	0.2931	0.2436
Point 3	35.43	36.47	0.643	0.6353	0.02252	0.02053
V = 80 km.h^{-1} (forward speed)						
Point 1	765.4	615.9	34.34	51.2	2.456	2.031
Point 2	230.7	252.1	9.015	0.7138	0.2226	0.2226
Point 3	21.65	28.58	0.836	0.7589	0.0202	0.01997

Under highway conditions, at the same forward speeds (20, 40, 60, and 80 km·h^{-1}), the highest vibration amplitude in the unbalanced shaft condition was recorded at a vehicle speed of 80 km·h^{-1}, with a value of 765.4 µm. The largest change in vibration amplitude was observed at the third measurement point at a vehicle speed of 20 km·h^{-1}, corresponding to a reduction of approximately 45%.

High vibration levels are expected under rough road conditions at a vehicle speed of 80 km·h^{-1}. As shown in Table 2, the maximum vibration amplitude reached 2198 µm at a forward speed of 80 km·h^{-1}. Based on the measurement results, the vibration amplitude data obtained before and after the shaft balancing process are presented in Figure 7.

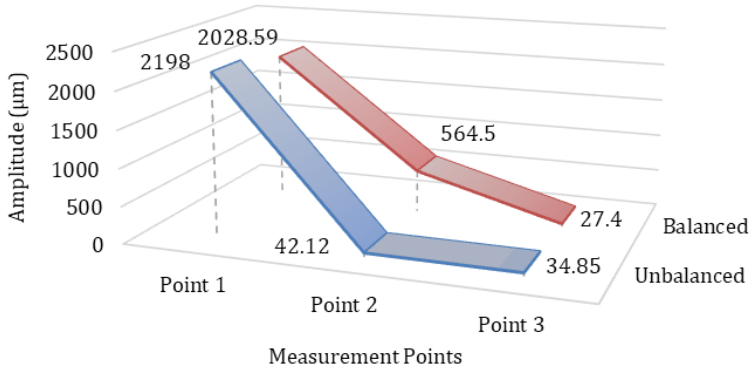


Figure 7. Amplitude data of the shaft before and after balancing.

Based on the measurement results obtained under rough road conditions at a vehicle speed of 80 km.h^{-1}, the velocity measurements of the shaft before and after balancing are presented in Figure 8.

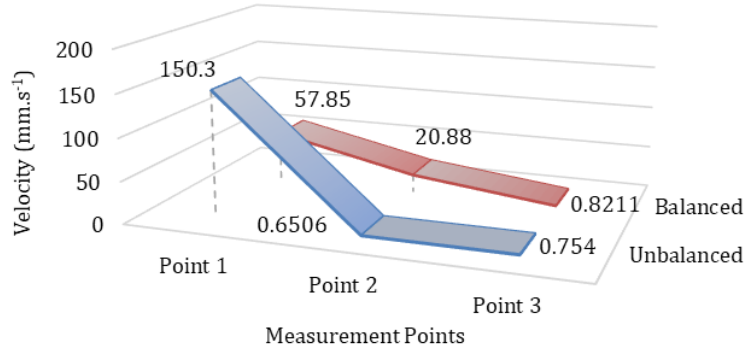


Figure 8. Velocity data of the shaft before and after balancing.

Based on the measurement results obtained under rough road conditions at a vehicle speed of 80 km.h^{-1}, the acceleration measurements of the shaft before and after balancing are presented in Figure 9.

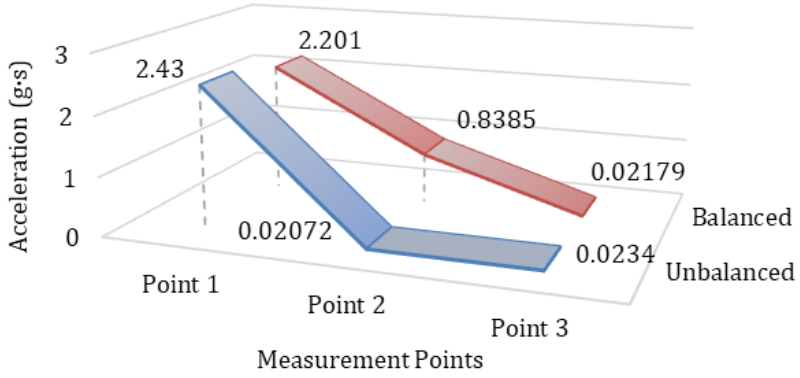


Figure 9. Acceleration data of the shaft before and after balancing.

The road condition with the lowest vibration was measured on the asphalt road at a vehicle speed of 20 km.h^{-1}. Based on the measurement results, the amplitude measurements of the shaft before and after balancing are presented in Figure 10.

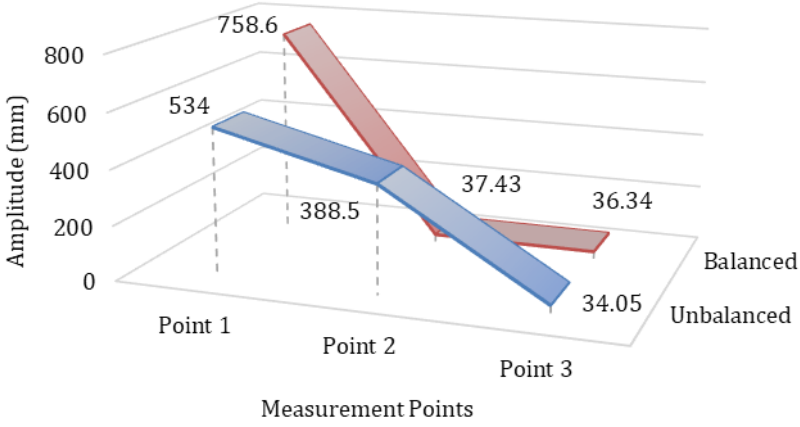


Figure 10. Amplitude data of the shaft before and after balancing under the condition with the lowest vibration.

According to the measurement results obtained under the condition with the lowest vibration, the velocity measurements of the shaft before and after balancing are presented in Figure 11.

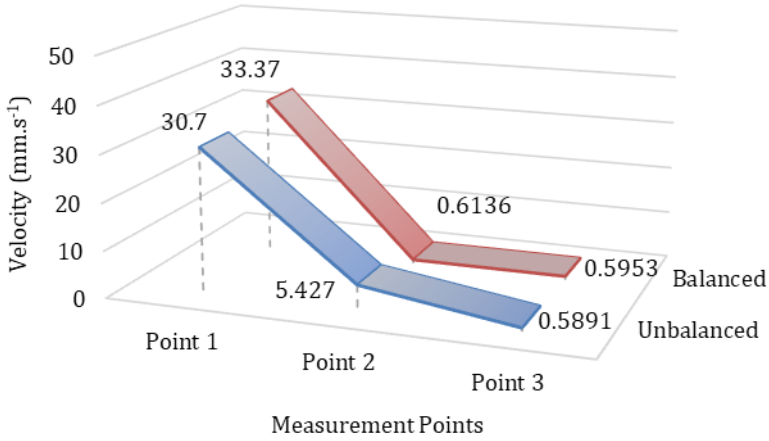


Figure 11. Velocity data of the shaft before and after balancing under the condition with the lowest vibration.

According to the measurement results obtained under the condition with the lowest vibration, the acceleration measurements of the shaft before and after balancing are presented in Figure 12.

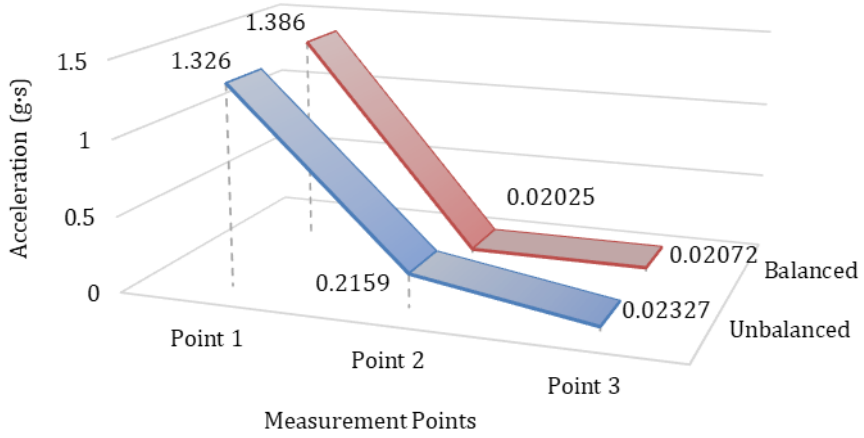


Figure 12. Acceleration data of the shaft before and after balancing under the condition with the lowest vibration.

In this study, the unbalances arising from mass inhomogeneity in the vehicle driveshaft were investigated, and significant reductions in vibration levels were observed following the balancing process. According to the experimental findings: The highest vibration amplitudes were recorded under rough road conditions at a vehicle speed of 80 km.h^{-1}, particularly on the engine mount, reaching a critical level of 2198 µm. Conversely, the lowest vibration amplitudes were measured under asphalt road conditions at 20 km.h^{-1} beneath the front seat, where the balanced shaft reduced the amplitude to as low as 37 µm.

The balancing of the shaft provided approximately a 65–70% improvement in the vibration levels measured beneath the seat, which directly affects driver and passenger comfort. The findings of this study are highly consistent with those reported in the literature regarding the vibration-reducing effect of driveshaft balancing. In particular, the results closely correspond to the simulation-based study conducted by Quang (2021). Similarly, Fedák et al. (2014), who analyzed the post-balancing behavior of long shafts in MATLAB, reported that amplitudes in the resonance region decreased by approximately 60%. Although our study has not been statistically tested, the 65-70% reduction achieved under the driver's seat after balancing is largely consistent with the data in the literature. When compared with the experimental results of White (2017), it was found that balancing reduced the vibration amplitude in the critical speed region by an average of 40–55%, which aligns with the reductions observed at 80 km·h^{-1} in this study. Saveliev (2018) reported that balancing increased the critical speed by about 20%, consequently reducing vibration amplitudes; this trend is also supported by the vibration reductions observed at higher speeds (60–80 km·h^{-1}) in the current research. Furthermore, the analytical study conducted by Şen and Atik (2025) stated that balancing applications enhance the fatigue strength of the driveshaft and significantly reduce vibrations. In this respect, the experimental findings of the present study practically validate these theoretical approaches.

In conclusion, when compared with the findings reported in the literature, this study demonstrates that balancing provides not only a mechanical improvement at the shaft level but also a meaningful enhancement in driver comfort. Moreover, through vibration measurements conducted under real road conditions, this research makes an experimental contribution to the existing body of knowledge.

IV. CONCLUSION

In this study, the imbalance in the vehicle driveshaft caused by mass inhomogeneity was investigated at three different points on the vehicle under varying speeds and road conditions. After dynamic balancing, new measurements were performed to determine the changes in amplitude, velocity, and acceleration values.

The results indicated that vibration levels were concentrated at the second measurement point, located beneath the front seat inside the cabin. Following the balancing process, vibration amplitudes at points close to the universal joints of the driveshaft decreased by approximately one-third. However, the change rate observed at the engine mount and the trunk measurement points were less significant, as these areas were also influenced by the vibrations transmitted from the engine and other rotating components driving the system.

Since driver and passenger comfort were prioritized, the obtained results clearly demonstrate that driveshaft balancing significantly reduces vibration levels, contributing to improved ride comfort and overall system stability.

The recommendations to be drawn from this study are,

- Periodic balance checks of vehicle shafts should be carried out to play a critical role in preventing vibration-induced mechanical failures.
- The implementation of dynamic balancing practices is particularly recommended for vehicles operating under heavy road conditions.
- Future studies should focus on predicting vibrations using artificial intelligence-based models, which may contribute to optimizing maintenance processes within a predictive maintenance framework.
- The findings of this study can be directly integrated into automotive design and manufacturing processes aimed at improving driving safety and riding comfort.

The dynamic balancing of shafts used in vehicles reduces the inertial forces arising from unbalanced masses, thereby alleviating the cyclic loads on the shaft. The balancing process diminishes the mechanical stresses imposed on the shaft and its connected components. Consequently, material fatigue is delayed, extending the service life of the components. Moreover, the reduction in vibration levels minimizes the risk of premature wear and failure in the vehicle's drivetrain. In conclusion, the balancing procedure not only enhances driving comfort but also improves the mechanical reliability and durability of the shaft system.

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