

Loosening Progression of Wheel Nuts at Zero Axial Force

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Clarifying wheel-nut loosening after axial-force loss is essential for determining appropriate warning timing in wheel-detachment prevention systems. Although loosening during axial-force reduction has been widely studied, progression under zero axial force remains insufficiently clarified. In this study, a zero-axial-force condition was reproduced using a tire test rig, and the subsequent loosening progression was experimentally investigated.

Fig. 1 shows the experimental setup. A flat-belt tire test rig simultaneously measured nut loosening displacement and three-axis bolt forces. Loosening was obtained from the change in distance between the nut head and a laser displacement sensor mounted on a plate fixed to the hub adapter, with signals transmitted through a slip ring. Bolt forces were measured using strain gauges near each bolt root. For onset observation, the plate was replaced with a camera mount to record nut motion. Toyota genuine-type nuts and a genuine five-hole aluminum wheel were used. The initial tightening torque was set to the minimum controllable value of 0.5 N·m. Simulated wheel rotation and loads for acceleration/deceleration and cornering were then applied.

Fig. 2 shows the nut loosening displacement and resultant bolt force under an acceleration/deceleration pattern. The nuts did not loosen uniformly; nut No. 5 exhibited the largest loosening, whereas Nos. 3 and 4 showed little loosening. The average bolt force over five-wheel rotations was smaller for No. 5 than for No. 4, indicating that Nos. 3 and 4 carried a larger portion of the load. This reduced the force acting on the loosening nuts and provided clearance for nut motion. The tendency of No. 5 to loosen was reproduced when the same wheel, bolts, and nuts were used.

Fig. 3 shows the nut-loosening timing and bolt forces during one tire revolution. From State A to State B, the nut moved outward while rotating in the loosening direction at tire rotation angles of 114–165° from the contact position. In this range, all force components decreased to 0 N, indicating that loosening occurred when load transmission between the nut and wheel disappeared.

Fig. 4 illustrates the proposed loosening mechanism. In State A, drive-torque-induced force acts on the wheel hole through the bolt and nut. In State B, circumferential wheel runout creates clearance between the nut and wheel hole, reducing the bolt force to 0 N. The unconstrained nut then moves outward under centrifugal force. Its contact point moves without slipping along the curved inner surface of the wheel hole, generating a force in the nut's rotational direction and thereby promoting loosening.

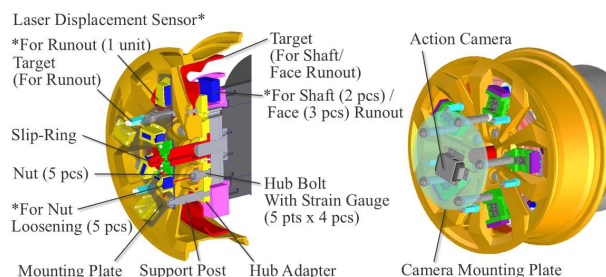


Fig. 1 Experimental Setup

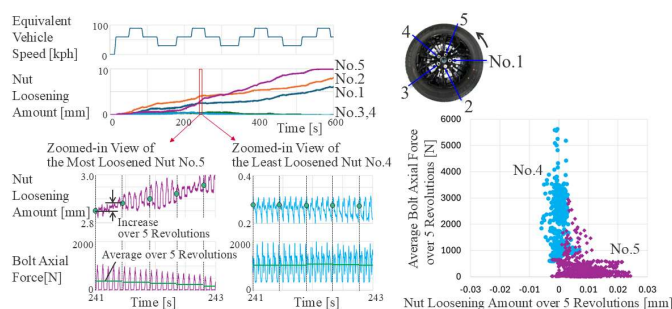


Fig. 2 Relationship between Nut Loosening and Bolt Force

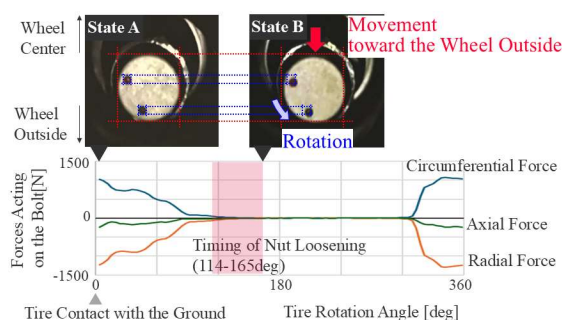


Fig. 3 Change in Bolt Force during the Loosening Process

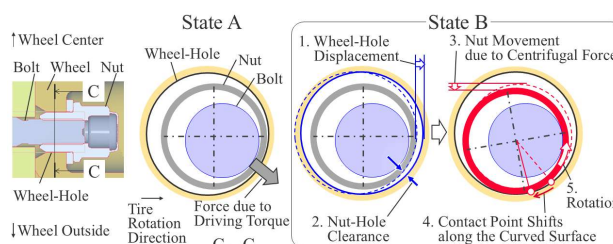


Fig. 4 Schematic Illustration of Nut Loosening (Not to Scale)