

Estimation Technique of Differential Pressure–Flow Characteristics of Shock Absorber Valves Based on Machine Learning

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Shock absorber damping performance depends on the differential pressure–flow (ΔP – Q) characteristics of the piston valve. In the early design phase, ΔP – Q characteristics must be estimated rapidly and accurately to determine damping force. Physical simulation is a common approach; however, 1D simulations have difficulty representing the deformation of stacked disks, whereas 3D analyses can consider detailed valve geometry but tend to require long computation time. Therefore, both practical accuracy and computational efficiency are required for piston-valve design.

This study proposes the Machine-learning-based estimation technique for piston valve ΔP – Q characteristics. As shown in Fig.1, the ΔP – Q characteristic curve is divided into low-speed, transition, and high-speed range according to valve opening behavior. In the low-speed range, oil flows mainly through a notch formed in a disk mounted on the valve while the valve remains closed. In the transition and high-speed ranges, the valve is open and oil flows through the valve opening area. In the high-speed range, the valve is fully open. The transition range corresponds to the intermediate state between the low-speed and high-speed ranges, where the valve lift increases with differential pressure.

The characteristics differ among the ranges since the valve state and lift vary with differential pressure. The dominant flow path and flow-controlling factors differ among the low-speed, transition, and high-speed ranges. By transforming the entire nonlinear curve into a limited number of approximation parameters, the learning problem is simplified while the main physical characteristics of the piston-valve behavior are preserved.

Each range is represented by an approximation function: quadratic functions are used for the low-speed and high-speed ranges, and a Bezier curve is used for the transition range. The coefficients of these functions and the boundary flow rates between the ranges are estimated from piston-valve design information using a linear support vector regression model. Six explanatory variables are prepared from disk geometry and stacking configuration. The technique was trained 36 valve specifications and validated using 12 specifications that are not training data.

The validation results shows that the technique estimated with high accuracy (Fig.2). For the 12 validation cases, the average relative error was 5.5% (3.2–11%). The average computation time was 0.93 seconds. The results indicate that the technique can estimate ΔP – Q characteristics with practical accuracy and computational efficiency for shock absorber piston valve design.

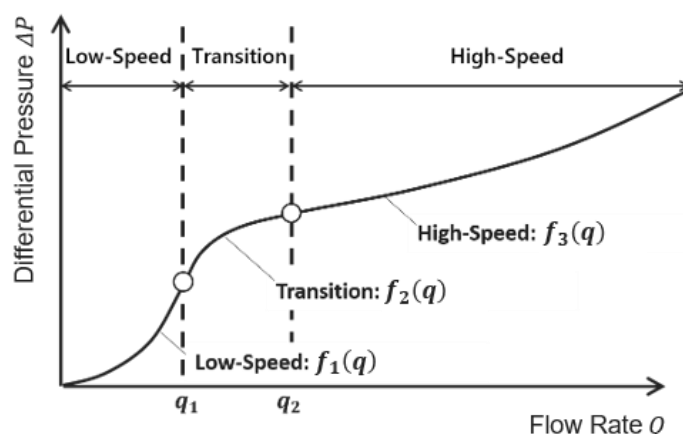


Fig.1 Regional Approximation of ΔP – Q Characteristics

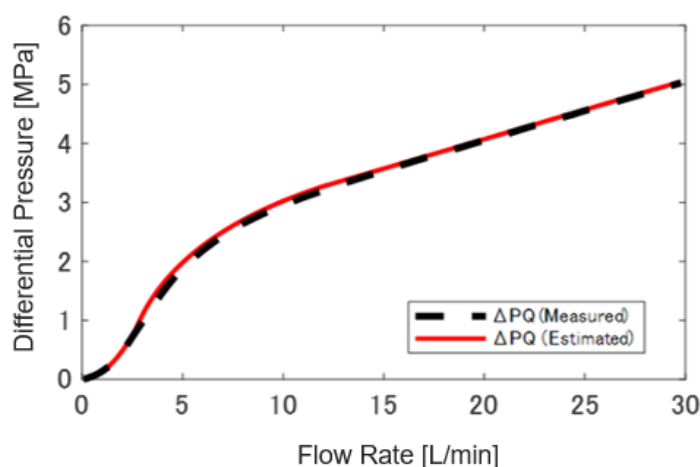


Fig.2 Comparison of Estimated and Measured ΔP – Q