U-Doppler, a Non-contact Vibration Measuring System for Diagnosis of Railway Structures

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The development of a simple and accurate method of monitoring railway structures, including viaducts, bridges and embankments, has long been sought. Such a method would allow large numbers of civil engineering structures to be more efficiently maintained and would make it easier to detect deformations in a timely manner following a natural disaster. For this reason, inspection techniques using vibration measurement of structure have been developed in the field of health monitoring of railway structures. The inspection techniques make use of the vibration characteristics of structures, such as maximum response, natural frequency and mode shape as the index of the soundness of structures. The vibration induced by sources such as passing trains, shock from weight impact and microtremors, is used in order to obtain the indices for inspection. When measuring vibrations using this method, the installation and removal of sensors is extremely time-consuming and, in many cases, work must be performed in dangerous locations such as high places or near railway tracks or structures damaged by natural disasters.

The author therefore developed the U-Doppler (Fig. 1, Table 1), a long-distance non-contact vibration measuring system for the diagnosis of railway structures that offers enhanced safety and efficiency by implementing various improvements to the Laser Doppler Velocimeter (LDV) for use in the field. The U-Doppler sensor is placed on a tripod near the structure to be measured and the laser is irradiated to the structure (Fig. 2). The vibration (velocity) of the structure can be measured using this approach in the same way as when a sensor is fitted to the structure. It is possible to measure vibrations of a variety of magnitudes from several dozen meters away, from relatively large vibrations of structures from a passing train to microtremors—microscopic vibrations under normal conditions due to natural and artificial sources, such as tidal waves, winds, traffic noise, and industrial vibration. U-Doppler saves considerable time, as it does not require sensors to be installed or removed, and eliminates the risk associated with having to work in dangerous locations.

The main technical feature of the U-Doppler is the compensation function using the built-in sensor. Because the LDV is a device that detects the relative velocity between the LDV itself and the object being measured, accuracy decreases when it is used to measure structural vibrations outdoors, as a result of the vibration of the LDV itself caused by various ground vibrations and/or the wind. In addition to the LDV optical sensor, the sensor unit of the U-Doppler incorporates a contact vibrometer with the same sensitivity and phase properties as the optical sensor. The influence of U-Doppler sensor vibration is removed by using the time-history data recorded by the installed vibrometer (Fig. 3 (a)). Also, when performing measurements on civil engineering structures, in many cases, the direction of the structural vibrations and the optical axis of the irradiation laser do not correspond (Fig. 3 (b)), which means the amplitude of vibration of the object is not measured correctly. The U-Doppler has thus been fitted with an internal sensor to measure the inclination of the unit and automatically adjust the amplitude measurement data as necessary.

The U-Doppler data recorder displays a variety of data in real time (Fig. 4), including velocity before compensation, vibration of the sensor unit, velocity after compensation, spectra for all data and the sensor inclination. Analysis of data, including spectrum analysis, differentiation and integration and filter processing, can be performed at the measurement site.

The U-Doppler is already being used to estimate the natural frequency of viaducts and bridge piers and to measure the deflection of bridge beams, and further use is planned.

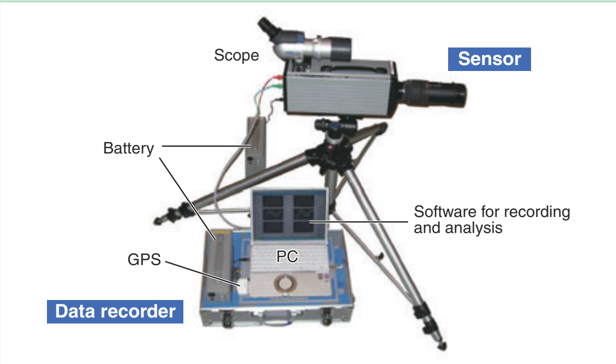

Fig. 1 Non-contact vibration measuring system "U-Doppler"

Table. 1 Specifications of sensor unit

Dimensions and weight	113 (W) × 141 (H) × 351 (D) mm, 5.5 kg
Power supply	Battery (operation time: 8 hours) or AC adapter
Laser protection class	Eye-safe Class II visible He-Ne gas laser
Velocity range	0.2 μm/s to 100 mm/s
Frequency range	DC to 600 Hz
Working distance	1.0 to 100 m (surface dependent)

Fig. 2 Measurement of bridge pier vibration by U-Doppler

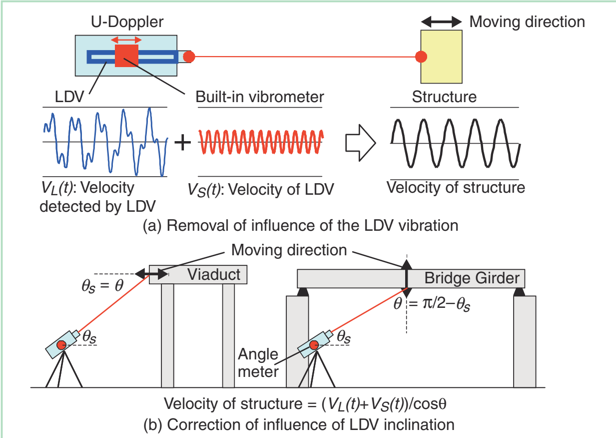

Fig. 3 Correction of detected velocity by using built-in sensors

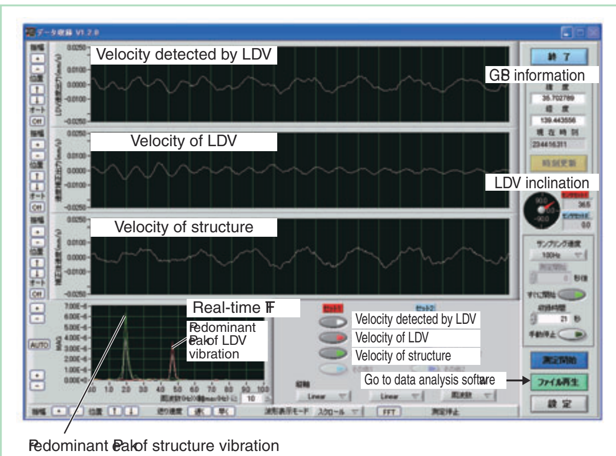

Fig. 4 Display of data recording software