DETECTION OF PERIODIC ERROR AND STRUCTURE CHANGE USING WAVELET ANALYSIS

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ABSTRACT

Heterodyne displacement measuring interferometry provides important metrology for applications requiring high resolution and accuracy. Heterodyne Michelson interferometers use a two-frequency laser source and separate the two optical frequencies into one fixed length and one variable length path via polarization. Ideally these two beams are linearly polarized and orthogonal so that only one frequency is directed toward each path. An interference signal is obtained by recombining the light from the two paths; this results in a measurement signal at the heterodyne (split) frequency of the laser source. This measurement signal is compared to the optical reference signal. Motion in the measurement arm causes a Doppler shift of the heterodyne frequency which is measured as a continuous phase shift that is proportional to displacement. In practice, due to component imperfections, undesirable frequency mixing occurs which yields periodic errors. Ultimately, this error can limit the accuracy to approximately the nanometer level. Periodic error is typically quantified using a Fourier transform-based analysis of constant velocity motions. However, non-constant velocity profiles lead to non-stationary signals that require alternate analysis techniques for real-time compensation. A new discrete time continuous wavelet transform (DTCWT)-based algorithm has been developed, which can be implemented in real time to quantify and compensate periodic error for constant velocity motion in heterodyne interferometer. The objective of this study is to extend the application of this algorithm to compensate non-stationary periodic error. In non-constant velocity motion, the
frequency of periodic error varies as the velocity of the target. Also, the periodic error amplitude may fluctuate due to the use of fiber-coupled laser source. The algorithm is also applied into the situation where higher order periodic error occurs. To validate the effectiveness of the novel wavelet-based algorithm in practice, the algorithm is implemented on the hardware and operated in real-time.

Wavelet analysis is also applied in another application. Currently, there are nearly 70,000 t of used nuclear fuel in spent fuel pools or dry cask storage increasing by nearly 2,000 t per year. After being used in a reactor, this fuel is stored for 3 to 5 years in spent fuel pools. Eventually the spent fuel will be placed into dry cask storage for another 20 years to more than 100 years. From the spent fuel pool, used fuel rod assemblies are loaded into casks underwater. This water must be removed to avoid corrosion or potential creation of combustion gases. During the drying process, if this operation is rapid, the water retained in the failed rods is likely to form ice. In this case, the ice crystal is difficult to remove. Moreover, if the ice forms at some critical location on the water flow path (e.g., the failure on the fuel rod), it will prevent all the retained water inside the rod from removing. The objective of this research is to develop an integrated wavelet-based approach for structural health monitoring in dry cask storage. The key conditions (defect location, ice formation, etc.) of failed fuel rods in dry cask storage are monitored to acquire any possible structure change in real-time. The relationship between different conditions and wavelet transform results is investigated. Simulations and experiments are used to validate this approach.