Fiber-optic vibration sensors could prevent train accidents

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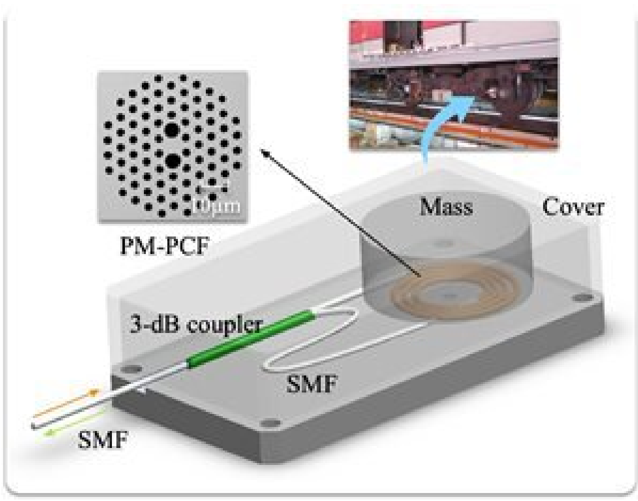

The new fiber-optic accelerometer features a polarization-maintaining photonic crystal fiber that is coiled into the shape of a disc only 15 millimeters in diameter. When a vibration occurs, the mass block presses on the coiled fiber at a frequency matching that of the vibration. This external force causes the wavelength of light in the fiber to shift in a measurable way. Credit: The Hong Kong Polytechnic University

Researchers have developed new sensors for measuring acceleration and vibration on trains. The technology could be integrated with artificial intelligence to prevent railway accidents and catastrophic train derailments.

"Each year, train accidents lead to severe injuries and even deaths," said research team leader Hwa-yaw Tam, from The Hong Kong Polytechnic University. "Our fiber accelerometers could be used for real-time monitoring of defects in the railway track or the train to pinpoint problems before an accident occurs."

The researchers describe their new accelerometers in The Optical Society (OSA) journal *Optics Express*. The devices can detect frequencies more than double that of traditional fiber-optic accelerometers, making them suitable for monitoring wheel-rail interactions. The durable sensors include no moving parts and work well in the noisy and high-voltage environments found in railway applications.

"In addition to railway monitoring, these new accelerometers can be utilized in other vibration monitoring applications, for example, structural health monitoring for buildings and bridges and vibration measurements of aircraft wings," said Zhengyong Liu.

All-optical railway sensing

For more than 15 years, the researchers have been working on condition-monitoring systems that use an all-optical sensing network to continuously monitor critical railway components. These systems can help replace inefficient and costly scheduled railway maintenance routines with predictive maintenance based on actual conditions. Systems developed by the researchers have been installed in Hong Kong and Singapore.

"An all-optical sensing network has many advantages as it is immune to electromagnetic interference, has long transmission distance and the sensors don't require electricity," said Liu. "However, there is a need for fiber-optic sensors that are optimized to measure different parameters in railway systems."

The fiber-optic accelerometers typically used in condition-monitoring systems are based on fiber Bragg gratings (FBGs) and cannot be used to detect vibrations higher than 500 Hz. Although this is adequate for most railway applications it can't be used to measure the wheel-rail interactions that are an important source of track wear.

To overcome this problem, the researchers designed a new fiber-optic accelerometer that uses a special optical fiber known as a polarization-maintaining photonic crystal fiber that is coiled into the shape of a disc only 15 millimeters in diameter. The coiled fiber is glued between a stainless-steel substrate and a cylindrical mass block. When a vibration occurs, the mass block will press on the coiled fiber at a frequency matching that of the vibration. This external force causes the wavelength of light in the fiber to shift in a measurable way.

"This interferometric configuration uses changes in the light inside the fiber to acquire precise information about the vibrations," said Liu. "Installing these accelerometers on the undercarriage of an in-service train allows them to monitor vibrations that would indicate defects in the track. They can also be used to detect problems in overhead lines used to power trains."

Comparison field tests

After thoroughly testing prototypes of the new accelerometer in the laboratory, the researchers carried out a field test by installing the device on an in-service train. They also installed an FBG-based accelerometer and a piezoelectric accelerometer for comparison.

They found that the new fiber accelerometer detected acceleration in a manner similar to the piezoelectric accelerometer. However, piezoelectric sensors require expensive shielded cables to reduce the effects of electromagnetic interference noise. Because the FBG-based accelerometer can't operate well at high frequencies, noise concealed some of the useful vibration information.

"Our results showed that our new accelerometers perform considerably better than existing accelerometers used for monitoring acceleration in trains," Liu said.

In this work, the researchers used a commercial polarization-maintaining photonic crystal fiber. They have since designed and fabricated a new type of fiber with smaller outer diameters, lower bending losses and higher birefringence, all of which would allow them to build a smaller accelerometer with even higher sensitivity.

"These new accelerometers could open new sensing and monitoring possibilities by providing data that supports implementation of artificial intelligence in the railways industry," said Tam. "Although railway monitoring is a good example of how fiber-optic sensing can be combined with artificial intelligence, we believe this combination is also promising for a number of other industries and applications."

More information: Zhengyong Liu et al, Novel accelerometer realized by a polarization-maintaining photonic crystal fiber for railway monitoring applications, *Optics Express* (2019). DOI: 10.1364/OE.27.021597

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