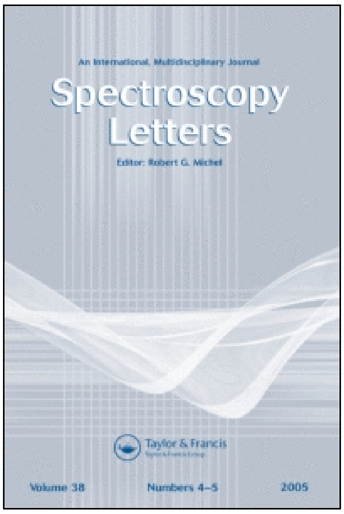

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Measurement of Reflected and Scattered Light for Monitoring Fluctuation of Structures

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MEASUREMENT OF REFLECTED AND SCATTERED LIGHT FOR MONITORING FLUCTUATION OF STRUCTURES

Keywords: Fluctuation, structure, laser, safety

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ABSTRACT

A laser spectroscopic technique for studying fluctuations of structural objects is presented, together with some results of our investigations including an observation of forced vibration of a refrigerator, intrinsic vibrations of buildings, and appearance of a

fluctuation in rotational speed due to fatigue. An alternative detection technique which uses the scattered light for monitoring in place of the mirror-reflected beam is also presented. A leak of water out of a pipeline was detected with this method.

The results obtained with this laser spectroscopic technique should form a useful collection of data regarding fluctuation analysis of various objects.

INTRODUCTION

In today's large and complex technological society, a great deal of effort is required to establish effective safety guideline and controls.[1] However, many fields still lack in basic and comprehensive safety studies.[2,3]In the study of the safety of structural objects, such as buildings, bridges, airplanes and turbines in electric power plants, measurement and analysis of the fluctuations of these objects are fundamental. The fluctuation of a structure is defined as the natural change in the location of any point of the structure.

A great deal of effort has been directed towards improving the accuracy and efficiency of measurements in this field; for instance, the stochastic excitation or "correlation" technique.[4,5] A conventional method of measuring the fluctuations of structural objects is to attach a mirror to an appropriate position on the face of the objects and to monitor the reflected laser beam from the mirror. However, there frequently occur the inconvenient arrangements of geometry where the detector must inevitably be set very apart from the laser beam source, since the mirror may not always be attached to the desired position and/or orientation on the object.

An alternative method of detection, which is a point of the present paper, is to use the scattered light in place of the mirror-reflected light for monitoring. Since the laser beam irradiated on the object is back-scattered to a certain spatial region, the detector is only to be placed somewhere within the spatial region. The collection of the scattered light must be made because the scattered light is much weaker than the mirror-reflected light. This is conducted by the use of a reflecting telescope. In this case the mirror is not needed to be attached on the wall of the structural object. Thus the detector can always be set in most cases at the same place with the irradiating laser beam source, as is very convenient for outdoor works.

Our final intention is to measure the fluctuations of buildings, bridges, airplanes and turbines in power plants. Before we work on those large objects, however, some smaller structures were measured to check the feasibility of the proposed technique. Some preliminary experimental results showing the usefulness of the system are given.

Experimental

Figure 1 shows the schematic diagram of the new system for measuring the scattered light from the structural objects. Since the scattered light is very weak compared to the direct mirror-reflected beam, a higher power of the laser source would be favorable for detecting the scattered weak light. The He-Ne laser (NEC GLG5014, 5mW) was used.

A commercially available reflecting telescope (KENKO, SPACIA-100C) was used to collect the scattered light. This was replaced by a bigger reflecting telescope with the diameter 20cm (VIXEN, SPDX-SC200L), when higher sensitivity was needed for weak signals.

The reflected beam was focused by a lens on a position sensitive detector (PSD, Hamamatsu Photonics, Model S3932, one-dimensional type, 12mm long). The PSD generated a voltage signal proportional to the distance between the light spot and the center of the PSD. Any movement of the structure changed the position of the light spot on the PSD, which produced a fluctuating time

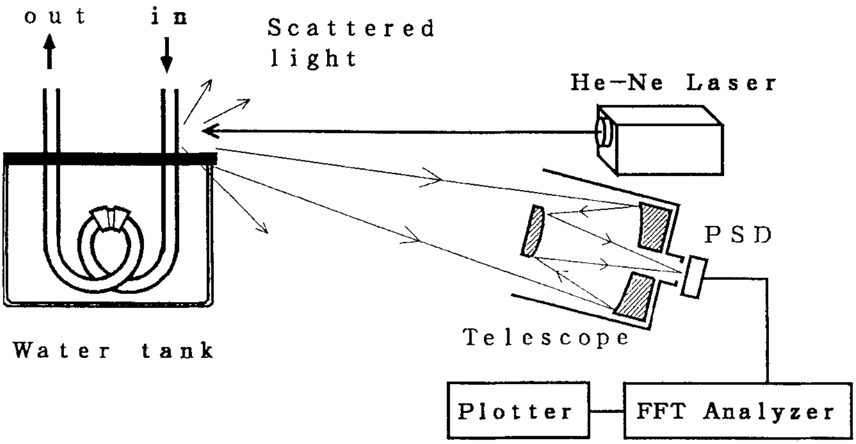

Fig.1 Diagram showing the measuring system of the scattered light from the structural objects.

series signal. The signal was then fed to a signal analyzer (ADVANTEST, Model R9211C), where it was digitized by a 16-bit AD converter, and converted to a frequency spectrum. The number of sampling points was usually 800, which produced frequency resolutions of 1.25Hz (1kHz spectral range) and 2.5Hz (2kHz spectral range). The Hanning window was employed before applying a FFT. The spectrum was averaged within the frequency domain.

The detector for the scattered light was set on the same experimental board with the laser beam source which is 10m apart from the object.

In the measurement of an electric motor, a mirror was not used to reflect light. Instead, diffused reflection from a rotating shaft of the motor was focused on the PSD.

RESULTS AND DISCUSSION

Forced vibration of a refrigerator

The forced vibration of a refrigerator was measured by detecting a laser beam which is reflected from a mirror attached to one side of the refrigerator. A small vacuum pump was placed on the top of the refrigerator in order to produce the forced vibration. Three distinct vibrational peaks were observed in the power spectra. In the case where neither the compressor nor the pump was working, the Fourier spectrum of the reflected beam consisted of a fundamental peak at 100Hz with its many overtones. Several weak overtone peaks of a fundamental peak at 50Hz were also observed. In the case when only the compressor was working, the intensity of the low frequency region (100-300Hz) of the spectrum increased and that of the several overtone peaks (between 1.3 and 2.0kH) of the fundamental one (50Hz) increased. Finally, in the case when both of the compressor and the pump were working, strong new peaks appeared at frequencies of 50, 150, 250, and 350Hz in addition to the peaks produced by the compressor which were observed earlier. The new peaks show the forced vibration due to the vacuum pump.

Intrinsic vibrational frequency of a building

In this case, the laser beam was reflected from a mirror attached to the side of a opposite building outside of a window of our laboratory. Under these conditions, we measured the fluctuation of the building relative to our laboratory. A peak at 18.75Hz was clearly observed on a spectrum which slowly decreased as the frequency increased. Since buildings are known to vibrate at about 20Hz, this peak may represent the natural vibration of the building.

Rotational speed and fluctuation of an electric motor

A small electric motor (10W) with variable rotation speed was used as a model of a turbine in an electric power plant. Changes in the power spectrum were measured at different rotational speeds. The results showed that the rotational speed of the motor could be determined by this laser beam technique. Figures 2A-C show the power spectra measured at three different rotational speeds of the motor: slow, medium, and fast, respectively. Each spectrum consists of a fundamental peak, which indicates the rotational speed of the motor, and its many overtones. As the rotational speed increases, the separation between peaks also increases. The frequency of the oscillation of the envelopes of peaks also increases at higher rotational speed, which may suggest that the frequency of the oscillation of the envelope is given by the reciprocal of the length of time the light spot deviates appreciably from the center of the PSD.

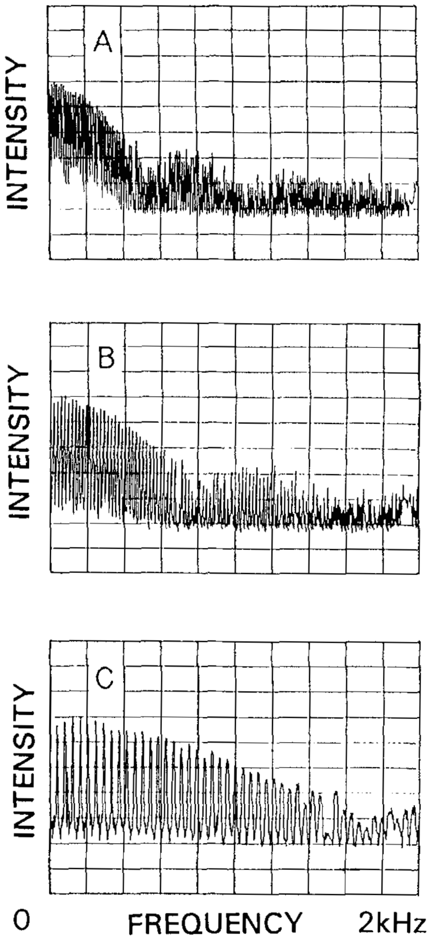

Fig.2 Detection of the rotational frequency of an electric motor.

We found evidence of fatigue in a small electric motor (a few W) 6 weeks after the start of rotation. The fatigue appeared as fluctuation in the rotational speed. In the spectrum which was obtained immediately after the motor started running, a fundamental vibration at 50Hz was observed along with its many overtones. Six weeks later, the rotational speed of the motor changed, as seen in a damping of the peaks of the averaged spectrum. This change is due to the fluctuation of rotational speed, which may represent a type of motor fatigue.

Leak of water from the pipe in the watertank

Figure 3 shows the results of the measurement for a water tank where water flow comes in and out through a pipe at a certain flow rate. This system might be considered as a simple simulation system of the heat exchanger of an atomic power plant. The laser beam was irradiated at the wall of the pipe just outside the water tank and the scattered light was detected as in the way shown in Figure 1. Figure 3a shows the power spectrum of the fluctuation obtained when there was no flow of water through the pipe. The spectrum shows the weak vibrations of the water tank arising from the background vibrations of the laboratory room. Figure 3b shows the results when water flowed through the pipe at the rate of 8.7 l/min. Figure 3c shows theresults when there was a leak of water about 15 ml/min at the joint on the pipe inside the water tank. The water leak was intentionally made by loosing the joint bolt, as simulates the occurrence of a crack on the pipe.

The results shown in Figs. 3 show that the anomalous change of the flow occurred in the water tank was clearly observed in the spectral patterns although no sign of the anomaly was seen from outside.

The results presented here show that our system with a mode of detection of the scat tered light works effective. This system is free from any geometricalrestriction in setting up the laser source and the detector.

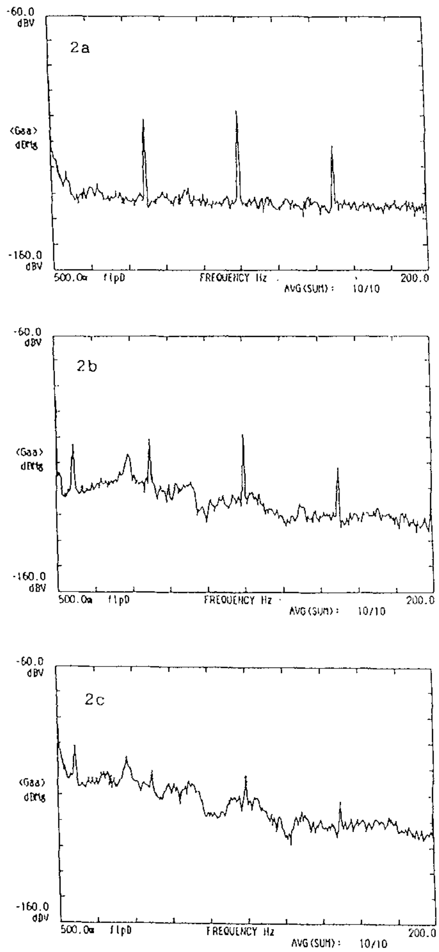

Fig.3 Spectra of the scattered light from the water tank; in the case without water flow through the pipe (3a), with water flow 8.7 L/min through the pipe (3b), and with the leak of water 15 mL/min out of the pipe (3c).

A handy and smaller system of measurement is now in attempt. The system will be applicable to many structural objects such as buildings, bridges, chemical plants, atomic plants and so on, in detecting the small sign of anomaly immersed in an apparent safety.

CONCLUSION

Using the laser spectroscopic technique proposed here, the intrinsic vibration of structures, forced vibration, and the resonance of the intrinsic vibration to an external force were observed. The water leak out of the pipeline was also detected. The appearance of resonance peaks depends upon the type of the external force applied. For the periodic excitation produced by a refrigerator compressor or a pump, resonance occurred at an intrinsic vibration which had a frequency nearly equal to the excitation frequency. The frequency of rotational motion and the appearance of fatigue in a moving object were also observed. To our knowledge, this simple optical technique has not been applied to the diagnosis of large structural objects. It would be able to evaluate the safety of buildings, bridges, and turbines in power plants by using the portable measuring system here described.

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