Structural health monitoring of structure is one of the foremost researched area in the field of engineering in the present times. Damage identification as part of SHM plays a significant role in ensuring the safety and reliability of operation. It consists of a two-step process - experimental measurements and data analysis. It is very evident that each of these steps plays a vital role in the reliability and robustness of a system, thereby making the choice of strategies for each of these steps all the more important.

In the present study, a health monitoring system based on an impulse response excited by laser ablation is proposed to detect a bolted joint loosening. The purpose of this study is to determine an appropriate location of laser irradiation as excitation point and to develop a damage detection method. A high power Nd:YAG pulse laser is used to generate an ideal impulse excitation on a structural surface which offers the potential to measure high frequency vibration responses of the structure. A health monitoring apparatus is set up using this vibration testing system and a damage detecting algorithm. The test piece is irradiated with the pulse laser at two different locations i.e. the bolt and on the flange, and the vibration responses, under the tight and loose bolt conditions, are measured using an accelerometer fixed at a point. In the selection of the laser irradiation location, it can be observed that choosing the excitation point on the bolt surface yields a significant change in vibration properties between tight and loose bolt conditions and provides an appropriate system for bolt loosening detection. It is also observed that the difference in frequency responses in tight and loose bolt conditions is small in the low frequency region and becomes more distinct in the high frequency region. The bolt loosening can be identified by introducing a damage index by statistical evaluation of the frequency response data using the Recognition-Taguchi (RT) method. A comparison can be made between damage index values obtained from the frequency responses with respect to the two points of irradiation further demonstrating the above observation. In the study, the author tries to ascertain the most appropriate point of laser excitation for detection of a loose bolt.

OUTLINE OF EXPERIMENT

A health monitoring system for detecting loosening in a bolted joint using laser excitation is developed. Vibration testing based on non-contact impulse excitation using laser ablation is conducted. A high power Nd:YAG pulse laser is used for imparting an impulse on the surface of the structure. Frequency response of the structure is then measured at two selected points (bolt and flange). Vibration measurement loose bolt conditions are done by reducing the tightening torque in the bolted joint assembly. The change in vibration characteristics due to such a reduction in tightening torque can be evaluated by laser excitation vibration measurement.

Accelerometer is attached to the measuring point of the structure using an adhesive for measuring the vibration response. A spectrum analyzer (A/D; NI-4472B, Software; Catec CAT-System) is used for measuring the acceleration response and analyzing the Fourier spectrum of the structure. The maximum measurement frequency is set to 40 kHz. Based on the specifications, the natural frequency of the accelerometers used in this experiment is above 50 kHz, and it was verified that the natural frequency of the accelerometers is sufficiently higher than the maximum measurement frequency of 40 kHz.
Subsequently, vibration responses were measured and analyzed using the Recognition-Taguchi method.

**Fig.1** Frequency response of one-bolted joint in the vertical direction when impact is on the flange and bolt, respectively, with the tightening torques of 25Nm, 20Nm, 15Nm.

**RESULTS AND DISCUSSIONS**

The Recognition-Taguchi (RT) method is a statistical evaluation method used for detecting loose bolts in this study. The frequency response measurements were conducted in the normal condition of the bolt and 10 sets of power spectrum data were recorded for laser excitation on the aluminium flange to get the unit space. The measurements for damage condition of the bolt were then conducted and 1 set of frequency data was recorded. The same process was repeated for the laser excitation on the bolt. By comparing the data from the damage condition to the unit space, a damage index was calculated for both the cases of excitation points.
The graphs for the damage indices highlight the fact that the damage indices are generally greater in the case of excitation on the bolt as compared to excitation on the flange. Fig. 4.1 indicates that the values of damage indices in both the excitation cases are close to 1, indicating that the bolt is in the tightened state. In Fig. 4.2, the values of damage indices at 20Nm tightening torque in the high frequency region are considerably higher when the point of laser excitation is on the bolt. Similar inference can be obtained from Fig. 4.3 where the values of damage indices are higher in case of excitation on the bolt. Therefore, it can be concluded that the bolt in a bolted joint is the more suitable point of laser excitation as compared to other parts of the structure.