IDENTIFICATION OF ADDITIONAL DAMPING AND STIFFNESS IN BOLTED LAP JOINTS BY LASER DOPPLER VIBROMETER

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Introduction

The effect of friction in bolted lap joints is of great importance for structure to maintain its integrity and performance. In the case of structural connection, additional damping caused by friction at joint part is desirable since it dissipates energy, and thereby diminishing response level. Therefore, in order to assess the performance of connection such as bolted lap joints it is necessary to measure the additional damping and its changes to monitor the integrity of connection. This paper presents the method to identify and quantify the additional damping and stiffness in joints along with their changes, by inverse analysis of their modal parameters. Dynamic responses of a jointed plate were measured in laboratory experiments using Laser Doppler Vibrometer (LDV) and ambient vibration excitation. An Eigensystem Realization Algorithm (ERA) was used to obtain the structural modal parameters. To study the presence of additional damping and stiffness and their changes, a different torque settings on the bolt was simulated

Identification of Modal Parameters

Two lasers were used in the measurement; one measures responses at a reference point, where measurement was carried out at all time. The other laser scans responses point-by-point throughout the entire measured surface. After averaging the cross correlation functions of responses at each point, the impulse responses were obtained. These responses were used as the input of system identification (ERA) to identify structural modal parameters (Hong 2001). Detail process of data acquisitions and modal parameters identification are summarized in Fig.1.

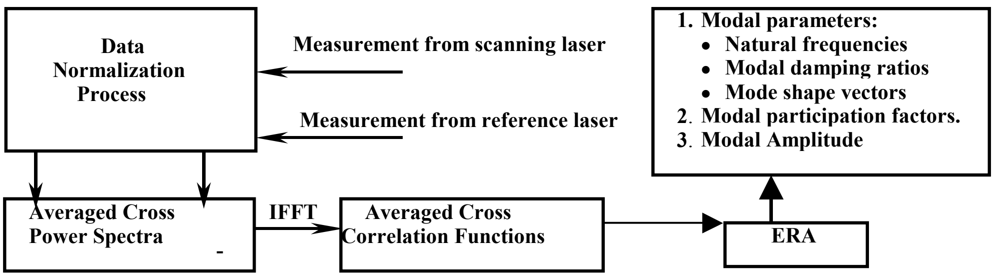

***Figure 1**. Data Acquisition and Modal Parameters Identification Procedures*

Identification of Changes in Additional Damping and Stiffness

Damage in the joints is modeled as changes in additional damping and stiffness at joint location caused by bolts loosening. Modal parameters of undamaged and damaged cases were compared to quantify and locate the damage of joints. The objective of the identification is to solve Eq.(1), where [**Φ**] is the matrix of the eigenvector and [**Λ**] is the matrix of eigenvalues; and the subscripts *u* and *d* refer to undamaged and damaged case respectively. The terms $\delta\mathbf{a}$ and $\delta\mathbf{b}$ in Eq.(2) are vectors of length, $4N^2$ containing the unknown matrices [δ**A**], and [δ**B**] of *N* degree of freedom system and *Ne* number of measurable mode shapes, further details can be found in (Abe 2002).

$$[\Phi_u]^T[\delta A][\Phi_d][\Lambda_d]+[\Phi_u]^T[\delta B][\Phi_d]=[\Lambda_u][a_u][\Theta]-[a_u]\Theta[\Lambda_d] \quad (1)$$

$$[\Phi_u]^T[\delta A][\Phi_d][\Lambda_d]\rightarrow[G]\delta\mathbf{a} \quad \text{and} \quad [\Phi_u]^T[\delta B][\Phi_d]\rightarrow[H]\delta\mathbf{b} \quad (2)$$

The additional information needed to solve Eq.(1)., is only the estimation of mass matrix [**M**], which is relatively easier than the estimation of stiffness or damping matrices. Furthermore, to map the changes of stiffness and damping in the

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physical coordinates, connectivity matrix, defined as the degree of connectivity of each DOF, is needed.

Experimental verification was carried out on bolted plate joint to test the algorithm for two cases. A series of completely tightened bolts were used to simulate the “healthy” structure for the first case, while one bolt is completely loosened (Fig.3.b) in the second case to simulate the presence of damage. For both cases plate was divided into 33 DOFs according to the scanning mesh location, and responses at each point were sampled by LDVs at the rate of 10 kHz using sampling number of 2^{15} (32768). Utilizing ERA, fifteen mode shapes were identified for the undamaged case meanwhile only twelve mode shapes were identified for the damaged one. By confining the damage location into joint portion only (i.e. changes of additional damping and stiffness are considered only at joint portion) and assuming no mass change in both damage cases, number of unknowns in Eq.(2) can be reduced until the rank of matrix is equal to number of the unknowns. (Cha 2001)

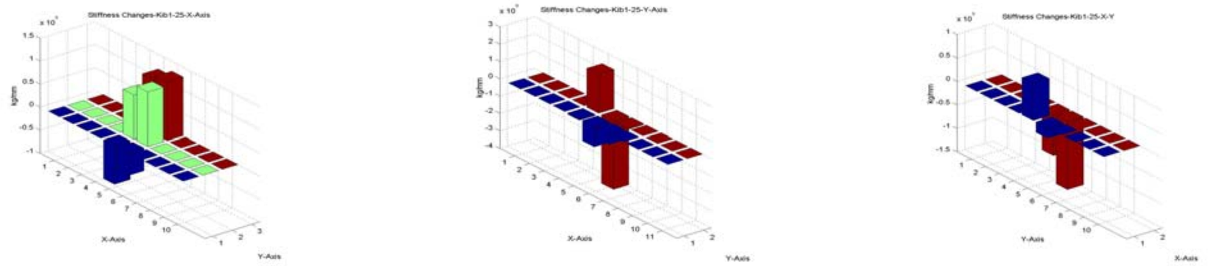

***Figure.2**: Changes of Additional Stiffness*

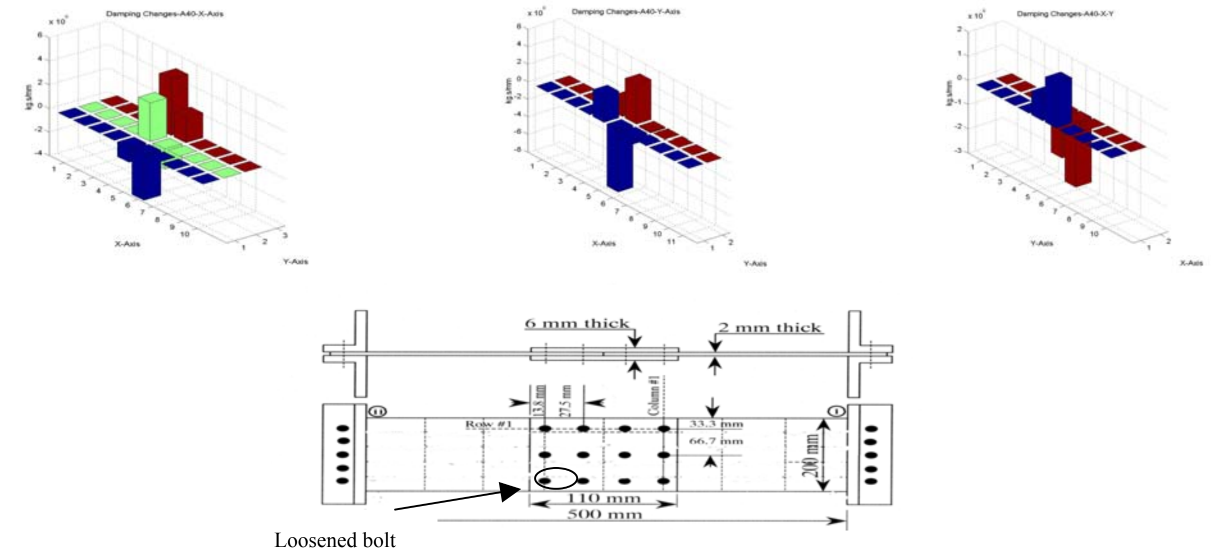

***Figure.3.a**: Changes of Additional Damping, **b**. Detail of Bolted Lap Joint and Location of Loosened Bolt*

Results and Discussion

It can be observed from Fig.2 and 3 that the detection algorithm resulted in the changes of additional stiffness and damping. These results were obtained using 39 unknowns, and with the matrix rank of 39, which guarantees the exact solutions. The maximum changes of stiffness and damping are mainly concentrated on the location of loosened bolts. This result indicates that the changes of bolts torque settings correspond to the changes of additional stiffness and damping in bolted lap joints; and can be further used as indicators to detect damage in structural connection.

Conclusion

Identification of additional damping and stiffness in bolted lap joints using *LDVs* was developed and tested. The changes of these properties can be used as indicators of damage for damage detection in structural connection.

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