ANALYTICAL TESTING TECHNIQUES

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ABSTRACT

Structural Dynamic Analytical Testing Techniques can be a tool to determine the source of structural dynamic problems and the solution to these problems. Analytical testing techniques are based upon new and unique dynamic testing methods and analysis of test results. Thus, these methods apply primarily to constructed wind turbine systems. This paper gives a summary of these methods.

INTRODUCTION

Kaman Aerospace Corporation, for the past several years, has been doing research on structural dynamic analytical testing techniques. This research has been sponsored by the Army, NASA, and in-house, and has consisted of computer experiments, laboratory testing of a beam, laboratory testing of a helicopter dynamic model and full scale testing of an AH-1G helicopter. This research has led to new testing techniques that for helicopters, which can be applied to wind turbine systems, can eliminate moment shaking of the hub, allows for on-site checking of the test data, allows for the use of small shakers since near resonant testing is done, and allows for ease of shaker location. This research has also led to new methods of data analysis which can be used to predict system response from component testing, obtain equation of motion from test data, determine the best location of a structural change to improve the operating condition response, and determine the force and moment from the rotor. Although this research has been done primarily for helicopter testing, these techniques can be used in the development of wind turbine systems.

ANALYTICAL TESTING TECHNIQUES

Single Point Shaking

Single point shaking is a test technique that requires shaking the structure at a point of high response. For a helicopter, this could be at the nose or tail location as shown in Figure 1. For wind turbine systems, this would be near the top of the tower. However, it does not necessarily have to be at the point of force and moment input such as at the hub of the wind turbine system. As shown in Figure 1, the accelerometers and force must be recorded and analyzed to obtain the real and imaginary acceleration mobility. This data, then, can be analyzed to obtain the undamped natural frequencies, structural damping, and modal acceleration parameters. With these parameters a complete mobility matrix can be obtained and response of the system determined as if shaken at any pick up location of the structure.

Figure 2a illustrates this, in that testing was done on a beam in which the transfer mobility at Station 25 was obtained by shaking at Station 72.5. Identification of the structure was made from data obtained with the force at Station 72.5. Figure 2b shows the transfer mobility at Station 25 for shaking at Station 72.5 and the identification of the structure was made from data obtained with the force at Station 0.5. It is seen from this figure that excellent correlation was obtained from the identification procedure, in that the system response was predicted from data obtained at another shake point. A complete mobility matrix was obtained by shaking at only one point.

This single point shaking simplifies the shaking procedure, in that small shakers can be used because data near resonance is required and a point of high response is required. Shaker location can be selected for convenience rather than the point of force input to the structure.

Force Determination

Data obtained from the shake test can be analyzed to predict system response from component testing, to determine the best location on a structure for an impedance change, to determine the equation of motion of the structure, and to determine the magnitudes of excitation forces and moments. All of these methods of analyzing the test data can be applied to wind turbine systems. However, this paper will concentrate on force determination.

One of the major problems in helicopter development and field maintainability is high level low frequency vibration. The source of these vibration problems is usually the force and moment input from the main rotor. However, the magnitude of these forces and moments are usually unknown. Therefore, research on force determination has been sponsored primarily by Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM). This research is presently being conducted on an Army furnished AH-1G helicopter.

The magnitudes of the forces and moments inputs to any structure can be calculated from the following relationship:

$$\underset{N\times 1}{\{\ddot{y}\}} = \underset{N\times 6}{[\ddot{Y}]}\ \underset{6\times 1}{\{f\}}$$

where $\{\ddot{y}\}$ is the matrix of accelerations in the fuselage or structure which are measured with the system operating, $[\ddot{Y}]$ is the acceleration mobility matrix which is obtained in the shake test of the fuselage or tower, and $\{f\}$ is the three force and three moment hub excitation matrix. N is the number of locations of accelerometers in this fuselage or structure.

The procedure for force determination would then be to shake the structure and obtain the mobility matrix of the structure at the points of force input. Then obtain the acceleration response of the system under actual operating conditions. With these two results, the rotor forces and moments can be obtained.

For example, for the wind turbine system, the tower without the rotor as shown in Figure 3 should be shaken.

The tower can be shaken directly at the hub in the direction of the three forces and three moments and the required mobility matrix obtained directly or the tower can be shaken at a point of high response (single point shaking) and the mobility matrix constructed. The tower should be shaken without the rotor, since the forces and moments to be determined are those that would be acting at the rotor shaft and will include the inertia effects of the rotor.

The rotor of the wind turbine system should be shaken as a free-free system and the driving point acceleration mobility versus frequency obtained, as shown in Figure 4. From this data, the natural frequencies of the blade as a cantilever and as a free-free system can be obtained. The antiresonant frequencies of the real acceleration mobility are the cantilever modes and the natural frequencies of the acceleration mobility are the free-free natural frequencies of the system. For large wind turbine systems, in which rotor rpm is very low, the frequencies obtained in test will be essentially the frequencies of the rotor since centrifugal stiffening is negligible. Therefore, when installed on the system, the natural frequency of the rotor will be between the cantilever frequency and the free-free system since that cantilever frequency is for infinite hub impedance and the free-free frequency is for a zero hub impedance.

It must be remembered that the rotor mobility data is effectively in the rotating system. By converting this test data to fixed system test data and combining with the tower shake test data, complete system response can be obtained.

Therefore, by shaking the blade and tower in this manner, the forces and moments of the rotor can be obtained. Knowing these forces and moments will permit better correlation with rotor loads programs, as well as determine the problem areas in the rotor that are the source of large vibration in the tower structure.

Further, by shaking the tower and rotor by this procedure, the complete response versus frequency of the system can be determined and the magnitude and location of an impedance change on the structure to improve the response can be determined.

Also, if required, equations of motion of the system can be determined from the test results and correlated with the finite element model.

DISCUSSION

Q. When coupling rotor and tower, did you use two blades?

A. This is a suggested procedure for shake testing a wind turbine system. I have not combined test rotor test results with hub test results.

Q. Do you have a way of determining the collective edgewise mode including the on-line generator?

A. I have no way of determining that mode from test results. However, calculating the impedance of the on-line generator and combining with the test results of the rotor could give a good estimate of that mode.

Q. Would you not get (determine) the power coming from the rotor, to the nacelle independently of the characteristics of the rotor, i.e., independent of the number of blades, the periodic coefficients effects, etc.?

A. Force determination does not depend on the type of rotor system or number of blades. Therefore, the vibratory forces and moments would be obtained for any rotor system. Thinking of power as a steady term, the theory could be extended to include steady forces.

Q. Briefly explain how we would proceed if we wished to apply this technique to the Mod-O WTG, for example?

A. I would remove the rotor and shake the tower using additional accelerometers, approximately thirty, and obtain mobility versus frequency for all these pickups and analyze this data to determine damping and natural frequencies and obtain hub mobility data to use for force determination.

I would shake the rotor as a free-free system and obtain driving point mobility versus frequency of the rotor and determine cantilever and free-free natural frequencies.

This data is now useful for either an upwind or downwind system. Reassemble the system, and obtaining acceleration data under actual operation, rotor forces and moments can be obtained.

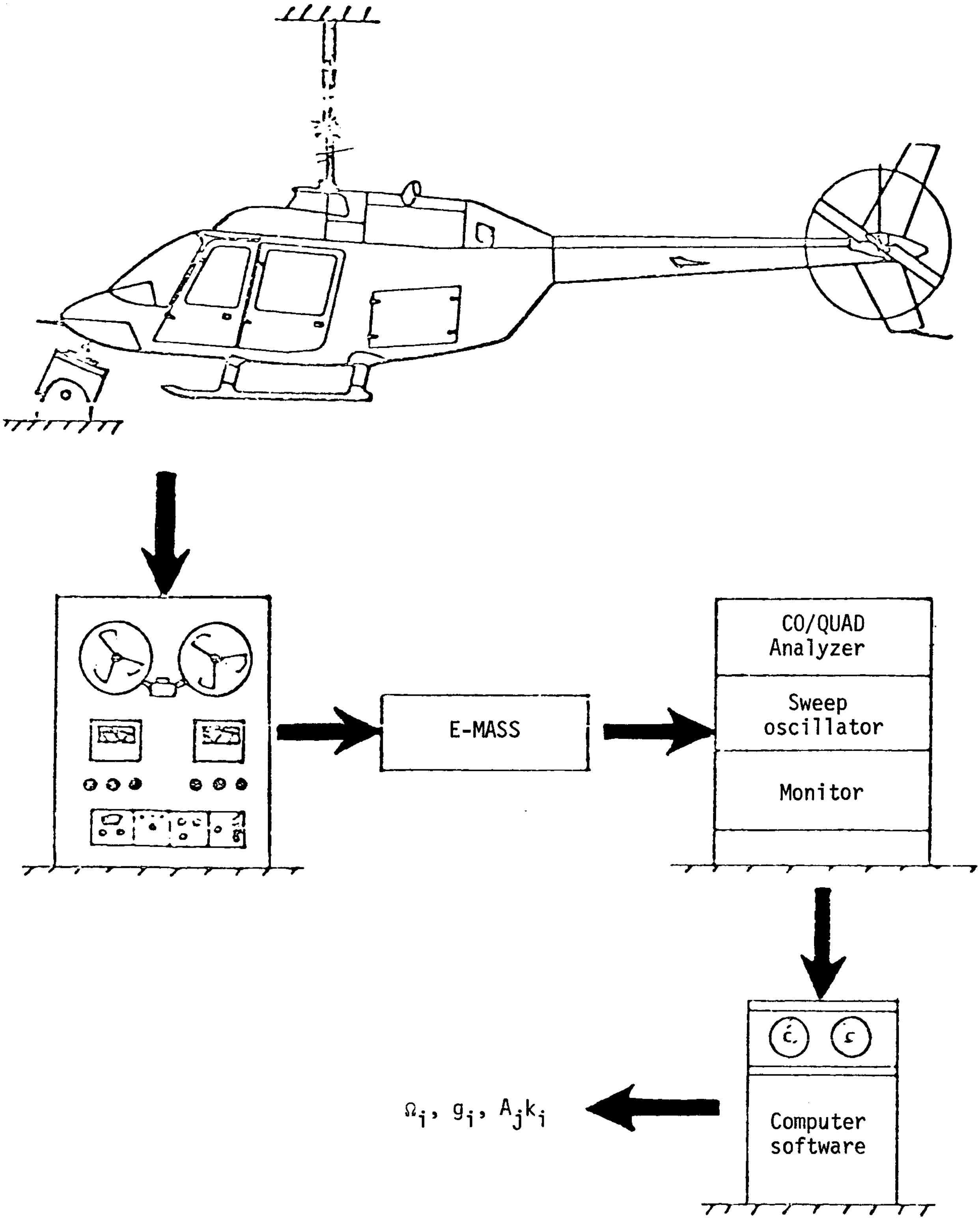
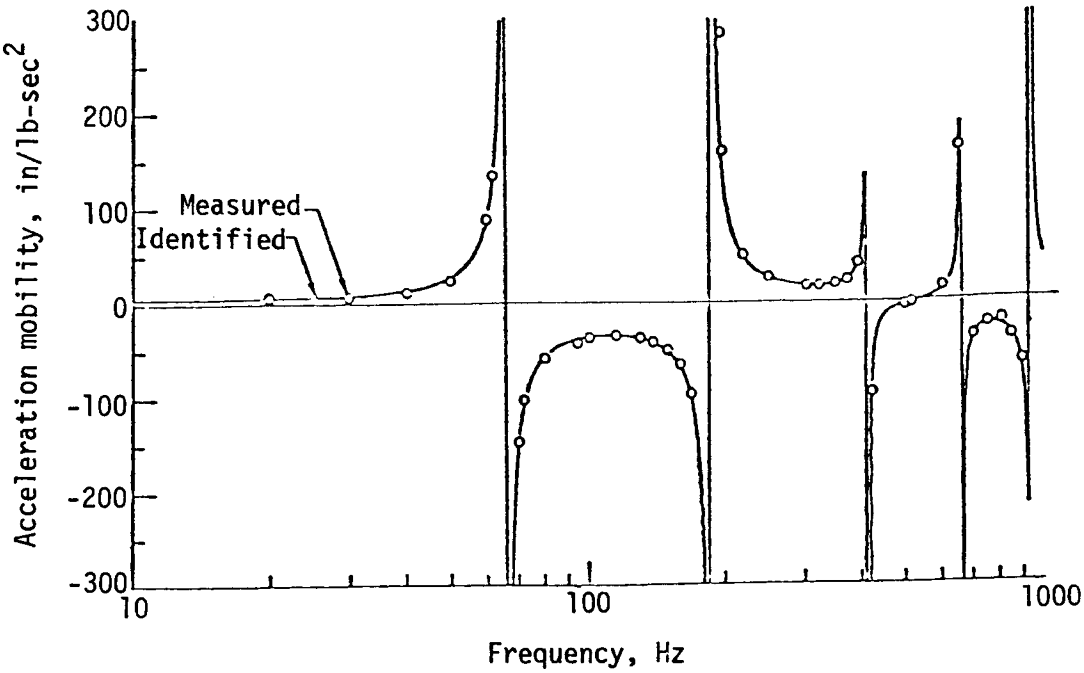
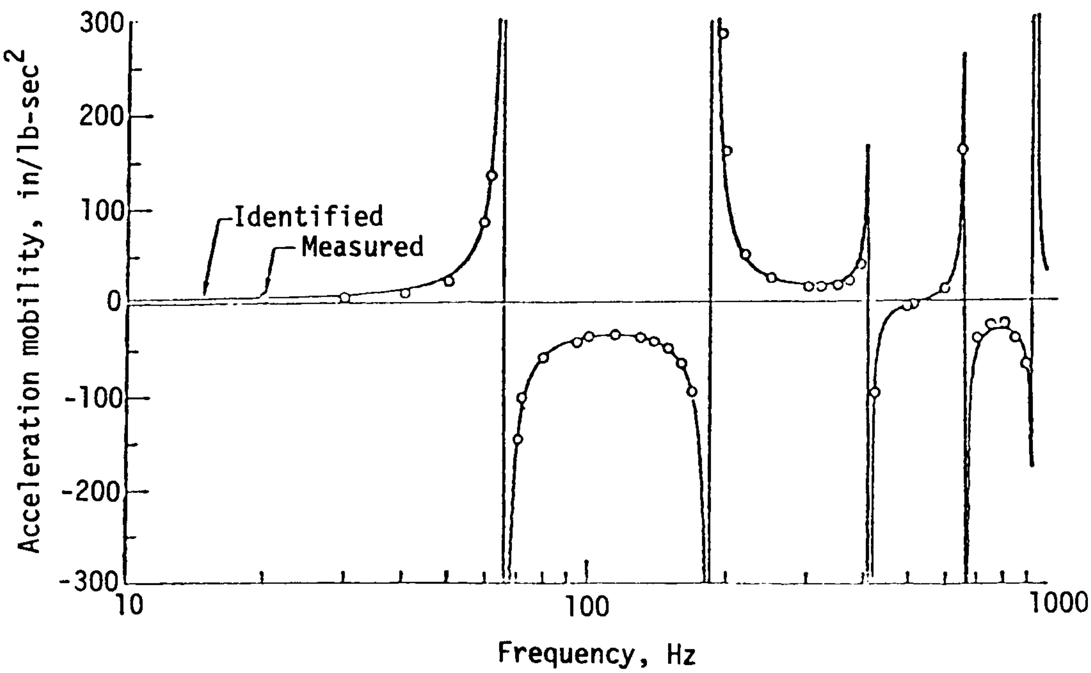


Figure 1. - Analytical testing.



(a) Identification made from data obtained with force at 72.5-inch station.



(b) Identification made from data obtained with force at 0.5-inch station.

Figure 2. - Acceleration mobility for response at 25-inch station and force at 72.5-inch station.

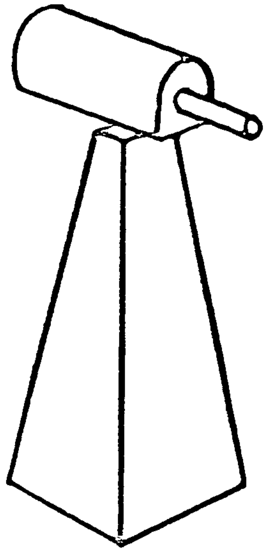
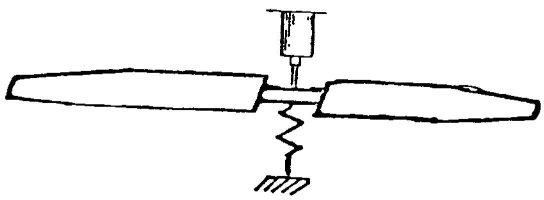
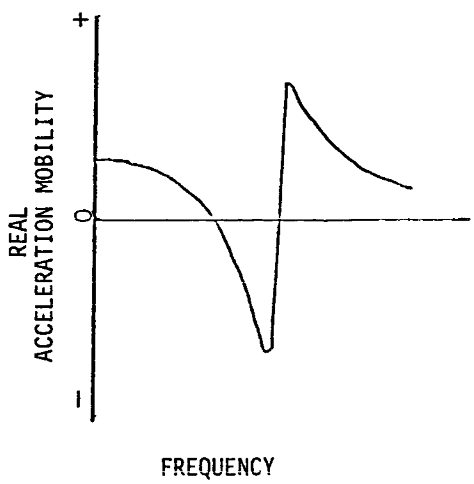


Figure 3. - Structural dynamic testing of tower and rotor (mobility of tower versus frequency).



(a) Test setup.



(b) Mobility.

Figure 4. - Rotor shake test.