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Modal analysis and experimental research into improved centering–leveling devices

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ABSTRACT

Centering–leveling devices are often used together with rotary tables to improve measuring process in various fields of metrology. The most important factor of measurement quality – accuracy – is affected by numerous external and internal factors. To ensure the optimum quality of measurements, several factors have to be well known and thus taken into account in the final measurement to minimize their influence. Analysis of structural dynamics provides data on sensitivity as well as an appropriate method to verify the analytical model. The paper deals with an analysis of structural dynamics of a plain structure centering–leveling device by performing appropriate modal analysis. The experimental setup for vibration monitoring and measurement principle underpinning the work is described in the paper. Measurement results of table dynamics as well as a comparison of theoretical and experimental modal shapes are discussed.

1. Introduction

The monitoring of the position of an object is very important while performing a wide range of other measurements on the object. Coordinate tables, which come in a wide range of sizes, have been developed to adjust the position of a measured object. Some are produced with small dimensions and are designed to have high sensitivity to the adjustment of the object displacement. However, coordinate tables are designed to adjust the position of measured object only in one plane and this causes some problems in practical measurements if there is a need to set up the devices coaxially or to perform a displacement of the object in a vertical plane.

In order to address these issues, the centering–leveling device developed here and investigated in this work can be implemented in association with other precision measurement systems, i.e., it can be attached to a rotary or indexing table with a circular scale on the top of it. One of the advantages of the device is its simplified structure and therefore it simplifies the operational alignment procedure. Moreover, the measured object can be adjusted in both horizontal and vertical planes [9,19] which is an important advantage.

Analysis of structural dynamics using modal response to vibration modes is a critical component of analytical model verification as well as sensitivity analysis [1,2]. Detailed modal analysis allows the determination of the fundamental vibration mode shapes and the corresponding frequencies [20]. Such information is crucial for the further measurements that can be performed by using a centering–leveling device, along with other components.

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2. Means and methods for modal analysis

2.1. Overview of the state-of-the-art modal analysis methods

Although operational modal analysis is often used in the fields of earthquake engineering and structural engineering including buildings and other great structures to determine modal parameters under real operational conditions [8,12,13], it can also be applied in laboratories for testing the individual devices or various sets of laboratory equipment.

Modal analysis is a process in which the structure is characterized by dynamic features, such as an eigenvalue (resonance) frequency, damping and modal shapes. Most of widely used constructions and machinery are affected by some specific form of fluctuation. To understand the problems and the nature of such fluctuations in different types of construction, it is necessary to evaluate the system resonance frequencies. It is common practice to acquire these data by defining the key modal parameters which leads to a mathematical model of the dynamics in the system. Such a model consists of the appropriate mode shapes, where each represents a frequency and the modal damping. It is these parameters which provide the dynamic description of the construction.

Modal analysis is categorized into two main sections – classical modal analysis (experimental modal analysis) and operational modal analysis. Of these, classical modal analysis allows the calculation of the frequency response function, based on the measured forces of excitation and the response of the construction. Operational modal analysis is based on the measurement of the output signals, including environmental noise and forces as a non-measured input signal [5]. The latter is used when there is a physical construction and controlling of artificial construction excitation is complicated or impossible. There are many methods for the application of modal analysis described in literature. One of these – fully automated (operational) modal analysis – was developed to avoid parameters that need to be specified or tuned by the user. This modal analysis produced similar results as in a manual analysis. Also, an improved modal analysis for three-dimensional problems using face-based smoothed finite element method is discussed in [10], where the main focus is on the Finite Element Method which is used together with meshfree methods and the generalized gradient smoothing techniques [3,13,14,17].

In every research there are certain circumstances which have to be dealt with while performing an experiment. Therefore, the method and means for modal analysis are chosen depending on measurement object shape, size, material, etc. The nature of the proposed experimental approach is based on the principles of the experimental modal analysis. Observing the performance of the proposed experimental approach provides sufficient data to conclude the experimental approach results and therefore, to compare theoretical and experimental mode shapes.

Also, a brief review and analysis of the current state-of-the-art of circular scale measurement research has revealed the key problematic areas to be scale precision, as well as taking steps to increase measurement effectiveness [9,19].

2.2. The centering–leveling table

To determine the angular position of raster scale grating, the centering–leveling device is very useful when scanning the surface of the scale. Raster scales can be made of glass, plastic, etc. The research undertaken here reports a novel technique, using a standardized Optical Disk [7] as a measuring scale as well as several other issues originating from this idea. Also, the experimental modal analysis performed on this novel setup provides essential data for measurement accuracy improvement. Most significantly, the positioning of an object (its centering and leveling) which has the highest impact on the accuracy of the measurement results is addressed. The research carried out reports on a new centering–leveling precision positioning table for raster scale measurement, which has the following key features:

- A main frame (outer ring) on which the rest of the components are mounted;
- A centering–leveling disk (inner ring);
- A lower ring allowing mounting of the system on other measuring systems;
- Two micro-traverses for centering;
- Additional supporting components (springs, spheres and cone-shaped heads) for motion transfer.

The initial layout for the centering–leveling system, designed to increase the accuracy of the measurements that can be made, is presented in Fig. 1.

The position of centering and leveling can be adjusted on the same surface, along two perpendicular axis. The mechanisms for this process are positioned concentrically and the motion is transferred to two supports of the disk. The two mechanisms are specifically positioned to improve the accuracy of the motion and consequently the centering and leveling pitches, using mechanisms that are independent from each other. The centering position is adjusted using two circular elements with a 0.2 mm slope, and to do so this operation includes moving the main circular element. Further, the leveling position is adjusted using two cams with cone-shaped endings mounted on their end. Thus rotating the cams to one side or the other provides the motion required for leveling. The device developed can be easily utilized for other measuring systems to eliminate the type of errors caused by the position of the measured object.

3. Experimental approach

3.1. Modeling and system design

The experimental identification of modal parameters was carried out and is described further in the paper. This experiment is based on an empirical approach, where the data is gathered from monitoring the experimental performance.