C.M.A. Vasques
J. Dias Rodrigues *Editors*

Vibration and Structural Acoustics Analysis

Current Research and Related Technologies

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Preface

Vibration and structural acoustics analysis is nowadays an essential requirement for high-quality structural and mechanical design in order to assure acoustic comfort and the integrity, reliability and fail-safe behavior of structures and machines. In some conditions vibration and radiated sound in structures and machines is desirable, as is the case of the motion of a tuning fork, the enjoyable melody that a classical guitar may produce or the motion induced by vibration conveyors. More often, vibration and the underlying radiated noise are undesirable and inconvenient, as is the case of the vibrational motion of internal combustion engines, the noise generated by railway traffic, the imperfections in the milling and turning processes due to machine tool chatter or the vibration instability of light-weight aerospace structures.

The underlying technologies of this field of multidisciplinary research are evolving very fast and their dissemination is usually scattered over different and complementary scientific and technical publication means. In order to make it easy for developers and technology end-users to follow the latest developments and news on the field, this book collects into a single volume selected, extended, updated and revised versions of the papers presented at the *Symposium on Vibration and Structural Acoustics Analysis*, coordinated by J. Dias Rodrigues and C.M.A. Vasques, of the *3rd International Conference on Integrity, Reliability & Failure* (IRF'2009), co-chaired by J.F. Silva Gomes and Shaker A. Meguid, held at the Faculty of Engineering of the University of Porto, Portugal, 20–24 July 2009. The selected papers where chosen among the more than 60 papers presented at the conference symposium.

Written by experienced practitioners and researchers in the field, this book brings together recent developments in the field, spanning across a broad range of themes: vibration analysis, analytical and computational structural acoustics and vibration, material systems and technologies for noise and vibration control, vibration-based structural health monitoring/evaluation, machinery noise/vibration and diagnostics, experimental testing in vibration and structural acoustics, applications and case studies in structural acoustics and vibration. Each chapter somewhat presents and describes the state of the art, presents current research results and discusses the need for future developments in a particular aspect of vibration and structural acoustics analysis.

The book is envisaged to be an appellative text for newcomers to the subject and a useful research study tool for advanced students and faculty members. Practitioners and researchers may also find this book an appellative reference that addresses current and future challenges in this field. The variety of case studies is expected to stimulate a holistic view of sound and vibration and related fields and to appeal to a broad spectrum of engineers such as the ones in the mechanical, aeronautical, aerospace, civil and electrical communities.

With the synergistic combination of efforts of authors, editors and invited reviewers, this book brings together so many interrelated and yet diverse topics in a single volume. Hopefully, the editors expect it allows the readers to get an updated sense of the interest, technical diversity and applicability of this ever evolving research field, and that it may be used as a road-map to the required practical understanding and technical skills required to analyze and engineer new solutions for problems on vibration and structural acoustics fields.

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The editors strongly acknowledge the valuable efforts of all book contributors and authors. Putting forward this book was only possible due to their positive answer to the call for papers and to the number of contributions submitted and evaluated from where the best were selected.

The contributions in this volume have undergone a full peer-review. In view of this, we are particular indebted to all peer reviewers that have kindly accepted the invitation to take part in the reviewing process and that provided valuable comments which certainly led to improvements in the chapters contained in this book. In particular, we would like to acknowledge the collaboration of:

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Chapter 1
The Dynamic Analysis of Thin Structures Using a Radial Interpolator Meshless Method

L.M.J.S. Dinis, R.M. Natal Jorge, and J. Belinha

Abstract In this chapter an improvement of the Natural Neighbour Radial Point Interpolation Method (NNRPIM), a recently developed meshless method, is presented. A new approach of the NNRPIM is proposed, the NNRPIM 3D Shell-Like formulation, in order to analyse dynamically thin three-dimensional structures. The NNRPIM uses the Natural Neighbour concept to enforce the nodal connectivity and to construct the integration background mesh (totally node-dependent), which is used in the numerical integration of the NNRPIM interpolation functions. The essential and natural boundaries are imposed directly once the NNRPIM interpolation functions possess the delta Kronecker property. Several dynamic plate and shell problems are studied to demonstrate the effectiveness of the method.

1.1 Introduction

In this chapter it is presented a recently developed meshless method, the Natural Neighbour Radial Point Interpolation Method (NNRPIM), applied to the dynamic analysis of thin three-dimensional structures. The scope of this chapter is to show the flexibility and the accuracy of this meshless method. The main motivation in the development of the NNRPIM was, without doubt, to create a meshless method: (a) easy to implement; (b) with interpolation functions (to simplify the essential and natural boundary imposition); (c) accurate; (d) with a low computational cost.

All these purposed goals were successfully achieved, however the authors felt that the efficiency of the method could be improved, particularly in the analysis of

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thin three-dimensional structures. As so, for this kind of structures, a new NNRPIM approach was developed, the NNRPIM 3D Shell-Like formulation.

The outline of this chapter is as follow: In Sect. 1.3 the NNRPIM 3D Shell-Like approach is presented, the creation of the influence-cells and the used integration scheme are summarized, as well as the construction of the interpolation functions. In Sect. 1.4 the dynamic discrete system of equations is presented and developed. In Sect. 1.5 benchmark dynamic examples of plates and shells in free and force vibration are solved. The article ends with the prospects for the future in Sect. 1.6 and the conclusions and remarks in Sect. 1.7.

1.2 Overview of the State of the Art

The assemblage of spatial thin shells structures permits the construction of several engineering structures, such as roof structures, boat hulls and aeroplane fuselages, among many others. Nowadays, shell structures are design to be light, being the shells themselves the load main supporting structure, reducing the number of structure stiffeners. On the other hand this structural material optimization has a design disadvantage, it leads to lower fundamental frequencies, increasing the risk of collapse by resonance. Thus the dynamic analysis became an important part in shell structures design. Numerical methods are an important tool in the modulation of such complex structures. For many years the Finite Element Method (FEM) was the most widespread numerical method used [1]. However in the last fifteen years meshless methods [2] enlarge their application field, and are today a competitive and alternative approach in structural analysis.

Numerous shell structures present elaborated curvatures and several holes or discontinuous essential boundaries, and for these conditions meshless methods are efficient. As it was in the beginning with the FEM, in this work the analysed thin structures are solved as three-dimensional (3D) problems, with some awareness in the integration along the smallest dimension in order to obtain the most reliable results. In meshless methods [3], generally, the nodes discretizing the problem domain can be randomly distributed, since the field functions are approximated within a flexible influence domain rather an element. In meshless methods the influence domains may and must overlap each other, in opposition to the no-overlap rule between elements in the FEM.

Meshless methods that use the weak form solution can be divided in two categories, the ones that use approximation functions [4–9] and others that use interpolation functions. Meshless methods based in approximation functions have been successfully applied in computational mechanics and even its difficulty on imposing the essential and natural boundary conditions, due to the lack of the delta Kronecker property, has been overcome with the use of efficient numerical methods [10]. At the time, to solve the mentioned difficulty of the approximation functions, several meshless methods, using interpolation functions, were developed [11–17].

More recently meshless methods [2] were extended to numerous engineering fields. In the biomechanical field [18] meshless methods were applied from bone