AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

A COMPUTERIZED MICRO ANALYZER FOR MODAL ANALYSIS OF MECHANICAL STRUCTURES

BY

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Thesis submitted for
The Degree of Doctor of Philosophy

IN
Mechanical Engineering

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1991

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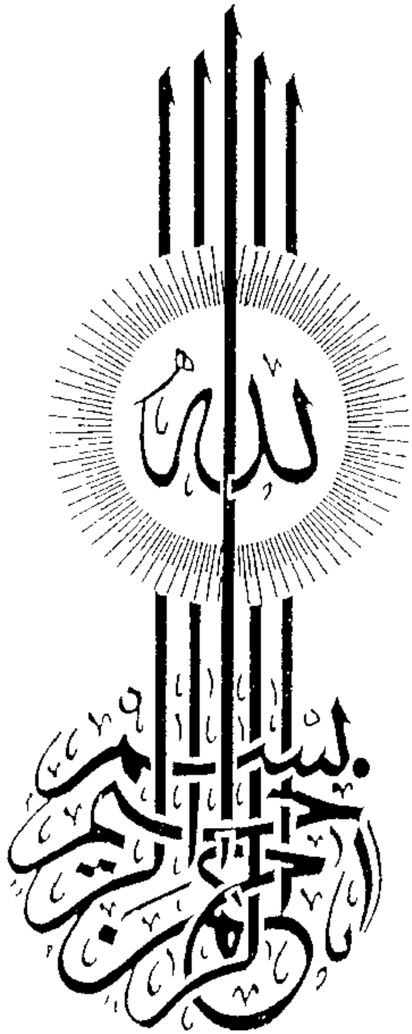
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STATEMENT

This dissertation is submitted to **Faculty of Engineering, Ain Shams University** for *the Degree of Doctor of Philosophy in Mechanical Engineering* .

The work included in this thesis was carried out by the author in the **Department of Design and Production Engineering**, Ain Shams University, from *February 1986 to February 1991*.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

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ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude and deepest thanks to *Professor* **SALAH M. EL-MAHDY** Professor of Applied Mechanics and Machine Design, Faculty of Engineering, Ain Shams University, for his valuable supervision throughout this work.

The author wishes also to extend his sincere thanks to *Professor* **M. A. EL-HAKIM** Professor of Production Engineering and *Assistant Professor* **MOHAMED ABDEL-SALAM ALI** for their continuous helps and great interest in carrying out this work.

Also great thanks to *assistant Professor* **M. I. KHATTAB** for his valuable advices.

ABSTRACT

The aim of the present investigation is to develop a new computerized methods used for studying the dynamic performance of mechanical structures.

An integrated theoretical model is proposed for determining the performance of structures in both time and frequency domains. The performance is determined under different types of exciting forces (harmonic, impulse, and random).

A new computerized technique named by multi channel micro analyzer is proposed for measuring and analyzing the dynamic performance of the real structures. The analyzer is provided by an automatic hammer for controlling the impulsive force during impulse excitation test.

Experimental harmonic excitation test is carried out to check the validity of the present theoretical and experimental techniques.

Experimental and theoretical results are found to be in fair agreement which proves the powerfulness of the proposed techniques.

CONTENTS

NOMENCLATURE

Symbol	Unit	Definition
A	mm^2	Cross-sectional area
a	mm	Displacement
[C]	N.S/m	Damping matrix
$[\ulcorner C \lrcorner]$	N.S/m	Generalized damping matrix
C	N.S/m	Damping coefficient
C_c	N.S/m	Critical Damping coefficient
[D]		Dynamic matrix
D	–	Damping ratio
d	mm	Diameter
E	N/mm^2	Young's modulus
{F}	N	Force vector
F	N	Exciting force
F_i	N	Modal exciting force
F_o	N	Amplitude of impulsive force
F_r	Hz	Resonance frequency
F(t)	N	Time function of force vector
F_{max}	N	Maximum exciting random force
F_{min}	N	Minimum exciting random force
F_u	Hz	Upper limiting Frequency
f	Hz	Exciting frequency
f_n	Hz	Natural frequency
f_s	Hz	Sampling frequency
Δf	Hz	Frequency interval
G	N/mm^2	Modulus of rigidity
I	mm^4	Moment of inertia
[J]	μ/N	Flexibility matrix
j	μ/N	Flexibility
[K]	N/μ	Stiffness matrix
$[\ulcorner K \lrcorner]$	N/μ	Generalized stiffness matrix
K	N/μ	Modal static stiffness

Kd	N/μ	Modal dynamic stiffness
L, ℓ	mm	Length
[M]	N/(m/s^2)	Mass matrix
[$\ulcorner M_\lrcorner$]	N/(m/S^2)	Generalized mass matrix
M	N/(m/S^2)	Modal mass matrix
M_x	N. mm	Moment in direction X
M_y	N. mm	Moment in direction Y
M_z	N. mm	Moment in direction Z
N		Number of samples
Q	–	Magnification factor
[S]		Direction cosine matrix
T, t	ms	Time
Tr	ms	Truncation time
Δt	ms	Time interval
[W]		Connection matrix
{X}	mm	Original coordinate
X	mm	Distance in direction X
$\dot{X}$	mm/S	Velocity
$\ddot{X}$	m/S^2	Acceleration
Y	mm	Distance in direction Y
Z	mm	Distance in direction Z
α	–	Deflection ratio (shear/bending)
γ	mm	displacement function
λ	(rad/S)^2	Eigenvalue
ρ	N/mm^2	Density
δ	μ	Deflection
θ	[o]	Angular rotation
ω	rad/S	Exciting angular frequency
ω_n	rad/S	Natural angular frequency
[ϕ]		Modal matrix
{ϕ}		Eigenvector
{η}	mm	Modal coordinate vector
η	mm	modal coordinate

INTRODUCTION

Design of mechanical structures (machine frames) are mostly depend on the dynamic performance due to forces encountered during process. It is necessary therefore to study the dynamic performance of structures both theoretically during design and experimentally during operation to reach a satisfactory behaviour.

Previous studies in this field were mainly in two approaches. The first comprises study of theoretical simulation of structures, while the second is devoted to experimental techniques. It was noticed that high expensive and complicated measuring devices were adopted to perform the usual experimental methods, in addition to several limitations of the theoretical models.

The theoretical approach in the present work is carried aiming at developing an amenable mathematical model based on modal analysis technique. This model may help in setting up the appropriate design of structures under different exciting forces (harmonic, impulse, and random).

Further experimental study is carried out in this work aiming at proposing a low cost computerized system to measure and analyze the dynamic performance of real structures. The proposed system is named in the present work as a multi channel micro analyzer.

Theoretically, any mechanical structure can be represented as a simplified lumped parameter model. The structural elements and joints are divided to a sufficient number of segments, where a significant representation of structure flexibility, and mass distribution can be obtained in matrix form.

Power method using matrix deflation is selected to solve the eigenvalue and eigenvector problem of the lumped model. The natural frequencies and mode shapes of this model can be gradually obtained up to the highest mode of the interested range.

Modal Analysis technique is introduced to determine the system modal parameters (mass, stiffness, and damping) and presenting the corresponding modal equations of motion.

Runge-Kutta method is convenient to calculate the modal time spectrum during each mode of the theoretical model. Harmonic, impulse, and random exciting forces are theoretically generated and fed to this method to simulate structures under different working conditions. Consequently, discrete Fourier transformation method is used to transform each modal time spectrum to the corresponding frequency spectrum. Successive calculations are performed to couple the modal spectra to obtain the total response at each point on structure.

Computer programs are presented in this work to manipulate the above mentioned methods, where all response functions (Bode, Nyquist, Phase, Real, and Imaginary) can be theoretically deduced.

Experimentally, the present work is started by proposing a low cost and simplified micro analyzer. PC micro computer is incorporated with a high precision analog to digital (A/D) interface card to facilitate high frequency data acquisition from sixteen selectable analog channels.

Two types of triggering methods are built-up in the micro analyzer to suit random excitation as well as the impulse excitation technique. During impulse test, the structures are excited using the manual hammer or a proposed automatic hammer designed to provide an impulse force whose duration and magnitude can be controlled.

Computerized collection of the time response signals are carried out by the aid of calibrated piezoelectric accelerometers mounted at different points on structure under test. A computational procedure is presented to