

STUDIES IN IDENTIFICATION AND MODIFICATION OF
DYNAMIC MECHANICAL SYSTEMS

THESIS SUBMITTED TO THE INDIAN INSTITUTE OF TECHNOLOGY, DELHI,
FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

TEJINDER K. KUNDRA

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI,

APRIL, 1986

DEDICATED

TO

PROFESSOR B.C. NAKRA

ABSTRACT

The present studies deal with System Identification for extracting a physical model of a linear dynamic multi degree of freedom (MDOF) mechanical system, directly from its multipoint harmonic mobility data. The studies also include the development of System Modification techniques for which the parameters of the extracted models provide the input data base. The dynamic behaviour of systems predicted from their identified models and of modified systems predicted from the modified-identified models has been extensively studied.

The application of System Identification technique has been demonstrated by identifying the parameters of equations of motion of two d.o.f. 'Vibration Absorber' system and an eight d.o.f. lumped linear representation of a machine tool like continuous system - an F-structure, from the analytically generated mobility data base.

The mobility data base has also been polluted with controlled measurement errors to study the effect of Bias and Random errors on System Identification and Modification. The model identified from exact mobility data base (I-Model), the one identified from polluted mobility data base (DT-Model), and the Exact Model (exact analytical formulation) are used to predict the dynamic behaviour of the unmodified and modified MDOF systems.

The changes occurring in the mass, stiffness, and damping matrices of the equations of motion of a MDOF system due to

the physical mass, stiffness and damping modifications on the system have been identified. The modification procedures to incorporate the corresponding changes in the parameter-matrices have been developed. The procedures also include the possibility of attaching a tuned absorber to the system. Several System Modification studies by modifying the mass, stiffness and damping matrices of the directly identified physical models have been undertaken to explore the feasibility of employing the identified model data base and evaluate their utility for System Modification purposes.

The dynamic behaviour of the modified systems has been evaluated in terms of those drive point and relative responses which affect the performance of the system. For a mechanical system like that of a machine tool it is also important to study the influence of modifications on its stability or chatter behaviour. Accordingly the studies also include the evaluation of the resulting negative real part of receptance which influences the dynamic stability of a machine tool.

The developed System Identification and Modification software implementable on a digital computer has been observed to be an effective tool in the hands of a dynamicist for improved MDOF system design or modification without resorting to time consuming and expensive hit and trial experimental dynamic testing-modification cycle. The conclusions in greater detail and some suggestions for further work have been included in the last chapter.

CERTIFICATE

This is to certify that the Thesis entitled "Studies in Identification and Modification of Dynamic Mechanical Systems" being submitted by Mr. Tejinder K. Kundra to the Indian Institute of Technology, Delhi, for the award of the Degree of 'Doctor of Philosophy' in Mechanical Engineering, is a record of bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this Thesis, which has reached the requisite standard.

The results contained in this Thesis have not been submitted in part or in full, to any other University or Institute for the award of any degree or diploma.



(Dr. B.C. Nakra)
Professor,
Mechanical Engineering Department
and
Head,
ITMMEC
I.I.T. New Delhi-110016

April, 1986

ACKNOWLEDGEMENTS

The author wishes to express his appreciation and feels obliged to his supervisor Dr. B.C. Nakra, Professor, Mechanical Engineering Department, I.I.T. Delhi, for his patient, diagnostic and encouraging help all the time this work has been in progress.

Thanks are due to author's colleagues in the Mechanical Engineering Faculty who have been extending their cooperation and help whenever the need for the same arose particularly due to author's preoccupation with this work.

The author is specially thankful to Mr. R.P. Suri, System Programmer, Computer Centre, I.I.T. Delhi, for being helpful and making useful suggestions for getting better outputs from the developed software of these studies.

The author is also thankful to Mr. V.P. Gulati for typing the manuscript with interest and Mr. N.K. Choudhary for tracing the figures patiently.

Tejinder K. Kundra

(TEJINDER K. KUNDRA)

CONTENTS

	<u>PAGE</u>
ABSTRACT	.. i
CERTIFICATE	.. iii
ACKNOWLEDGEMENTS	.. iv
CONTENTS	.. v
TERMINOLOGY	.. x
LIST OF FIGURES	.. xiii
LIST OF TABLES	.. xx
 <u>CHAPTER 1</u>	
<u>INTRODUCTION</u>	.. 1-23
1.1	.. 1
1.1.1	.. 5
1.2	.. 6
1.2.1	.. 16
1.3	.. 18
1.3.1	.. 18
1.3.2	.. 21
 <u>CHAPTER 2</u>	
<u>IDENTIFICATION OF A TWO DEGREE FREEDOM SYSTEM</u>	.. 24-46
2.1	.. 24
2.1.1	.. 24
2.1.2	.. 26

CONTENTS (contd.)

		<u>PAGE</u>
2.2	IDENTIFICATION THEORY APPLIED TO A TWO DEGREE FREEDOM SYSTEM ..	33
2.2.1	Mobility Data Generation for the two d.o.f. System ..	35
2.2.2	Extracted Model ..	38
2.2.3	Model Response ..	41
<u>CHAPTER 3</u>	<u>IDENTIFICATION STUDY OF AN EIGHT DEGREE OF FREEDOM SYSTEM</u> ..	47-99
3.1	MULTI DEGREE OF FREEDOM SYSTEM AND ITS LUMPED REPRESENTATION ..	48
3.2	STIFFNESS AND DAMPING MATRICES OF THE F-STRUCTURE ..	52
3.2.1	Determination of Stiffness Matrix for the F-Structure ..	53
3.2.2	Determination of Damping Matrix ..	63
3.3	F-STRUCTURE CHARACTERISTICS AND MOBILITY DATA BASE FOR IDENTIFICATION ..	64
3.3.1	Eigenvalues and Eigenvectors of the F-Structure ..	64
3.3.2	Mobility Data Base ..	65
3.4	IDENTIFICATION-STUDY-SOFTWARE ..	68
3.5	F-STRUCTURE IDENTIFICATION ..	72
3.5.1	Analytical Generation of Mobility Data Base for a Typical F-Structure ..	74
3.5.2	F-Structure Identification and Results ..	78
<u>CHAPTER 4</u>	<u>INFLUENCE OF EXPERIMENTAL ERRORS ON IDENTIFICATION</u> ..	100-120
4.1	INCORPORATION OF EXPERIMENTAL ERRORS ..	100
4.2	NATURE AND MAGNITUDE OF EXPERIMENTAL ERRORS ..	101

CONTENTS (Contd.)

		<u>PAGE</u>
4.3	IDENTIFICATION FROM THE POLLUTED MOBILITY DATA	.. 102
4.4	INFLUENCE OF EXPERIMENTAL ERRORS ON IDENTIFICATION-THE RESULTS	.. 103
4.5	CONCLUSION	.. 120
<u>CHAPTER 5</u>	<u>SYSTEM MODIFICATION: LUMPED MASS AND OVERALL STRUCTURAL DAMPING MODIFICATIONS</u>	.. 121-163
5.1	NEED OF MODIFICATION TECHNIQUES	.. 121
5.2	MASS MODIFICATION TECHNIQUE	.. 123
5.2.1	Influence of Mass Changes at one Location	.. 125
5.2.2	Studying Influence of Modifications on System's Stability	.. 131
5.2.3	Effect of Mass Modifications on Relative Responses	.. 132
5.2.4	Influence of Successive Mass Modi- fications	.. 139
5.2.5	Comparison of Effect of Mass Changes at Each of the Several Individual Locations	.. 146
5.3	OVERALL STRUCTURAL DAMPING MODIFICATIONS	.. 146
5.4	CONCLUDING REMARKS	.. 157
<u>CHAPTER 6</u>	<u>SYSTEM STIFFNESS MODIFICATION</u>	.. 164-214
6.1	STIFFNESS MODIFICATION TECHNIQUE	.. 164
6.1.1	Mass Matrix of the Modified System	.. 165
6.1.2	Stiffness Matrix of the Modified System	.. 166
6.1.3	Structural Damping Matrix of the Modified System	.. 169

CONTENTS (Contd.)

		<u>PAGE</u>
6.2	STUDYING THE INFLUENCE OF STIFFNESS MODIFICATION ON THE DYNAMIC BEHAVIOUR OF A MDOF SYSTEM ..	170
6.2.1	Comparison of Influence of Stiffening Each one Beam of the F-Structure ..	174
6.2.2	Influence of Successive Stiffness Modifications ..	190
6.2.3	Effect of Stiffness Modifications With Varying Damping ..	196
6.3	SIMPLIFIED STIFFNESS MODIFICATION TECHNIQUE ..	200
6.3.1	Dynamic Response Predictions with the Simplified Stiffness Modification Technique ..	209
6.4	CONCLUDING REMARKS ..	209
<u>CHAPTER 7</u>	<u>TUNED ABSORBER AS A SYSTEM MODIFIER</u> ..	215-251
7.1	TECHNIQUE TO MODIFY A SYSTEM WITH A TUNED ABSORBER ..	215
7.1.1	Determination of Modified Mass Matrix ..	218
7.1.2	Modified Stiffness Matrix ..	220
7.1.3	Modified Structural Damping Matrix ..	220
7.2	STUDYING THE INFLUENCE OF ATTACHING A TUNED ABSORBER TO A MDOF SYSTEM ..	221
7.2.1	Modification Technique Validation and Effect of Attaching an Absorber ..	222
7.2.2	Comparison of Effect of Attaching a Tuned Absorber Along Each One of Several Coordinates (or d.o.f.) ..	228
7.2.3	Influence of Changing Absorber Parameters on the Response of the Modified System ..	240

CONTENTS (Contd.)

			<u>PAGE</u>
7.2.4	Second Mode Tuned Absorber	..	247
7.3	CONCLUDING REMARKS	..	251
<u>CHAPTER 8</u>	<u>CONCLUSIONS AND FURTHER WORK</u>	..	252-259
<u>REFERENCES</u>	..	..	260-278
<u>APPENDIX-A</u>	LISTING OF THE PROGRAM SSTMIDENT AND CALLED SUBPROGRAMS	..	279-308
<u>APPENDIX-B</u>	LISTING OF THE PROGRAM ABSORBER	..	309-320