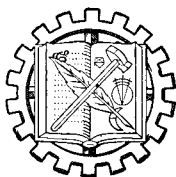


Dynamical Analogies

By

HARRY F. OLSON, E.E., PH.D.

*Acoustical Research Director
RCA Laboratories, Princeton, New Jersey*



NEW YORK

D. VAN NOSTRAND COMPANY, INC.

250 FOURTH AVENUE

1943

Copyright, 1943, by
D. VAN NOSTRAND COMPANY, INC.

All Rights Reserved

*This book, or any parts thereof, may
not be reproduced in any form without
written permission from the publishers.*

Printed in U. S. A.

PREFACE

Analogies are useful for analysis in unexplored fields. By means of analogies an unfamiliar system may be compared with one that is better known. The relations and actions are more easily visualized, the mathematics more readily applied and the analytical solutions more readily obtained in the familiar system.

Although not generally so considered the electrical circuit is the most common and widely exploited vibrating system. By means of analogies the knowledge in electrical circuits may be applied to the solution of problems in mechanical and acoustical systems. In this procedure the mechanical or acoustical vibrating system is converted into the analogous electrical circuit. The problem is then reduced to the simple solution of an electrical circuit. This method has been used by acoustical engineers for the past twenty years in the development of all types of electro-acoustic transducers. Mechanical engineers have begun to use the same procedure for analyzing the action of mechanisms.

The importance and value of dynamical analogies to any one concerned with vibrating systems have led to a demand for expositions on this branch of dynamics. Accordingly this book has been written with the object of presenting the principles of dynamical analogies to the engineer.

This book deals with the analogies between electrical, mechanical rectilinear, mechanical rotational and acoustical systems. The subject matter is developed in stages from the simple element through to complex arrangements of multielement systems. As an aid in the establishment of these analogies a complete theme is depicted in each illustration.

The text assumes on the part of the reader a familiarity with the elements of alternating circuit theory and physics.

The author wishes to express his gratitude to his wife, Lorene E. Olson, for compilation and assistance in preparation and correction of the manuscript.

The author wishes to acknowledge the interest given by Mr. E. W. Engstrom, Research Director, in this project.

HARRY F. OLSON

JANUARY, 1943

CONTENTS

CHAPTER	PAGE
I. INTRODUCTION AND DEFINITIONS	
1.1 INTRODUCTION.....	1
1.2 DEFINITIONS.....	4
II. ELEMENTS	
2.1 INTRODUCTION.....	12
2.2 RESISTANCE.....	12
A. Electrical Resistance.....	12
B. Mechanical Rectilinear Resistance.....	13
C. Mechanical Rotational Resistance.....	13
D. Acoustical Resistance.....	13
2.3 INDUCTANCE, MASS, MOMENT OF INERTIA, INERTANCE.....	15
A. Inductance.....	15
B. Mass.....	15
C. Moment of Inertia.....	15
D. Inertance.....	16
2.4 ELECTRICAL CAPACITANCE, RECTILINEAL COMPLIANCE, ROTATIONAL COMPLIANCE, ACOUSTICAL CAPACITANCE.....	17
A. Electrical Capacitance.....	17
B. Rectilinear Compliance.....	17
C. Rotational Compliance.....	18
D. Acoustical Capacitance.....	18
2.5 REPRESENTATION OF ELECTRICAL, MECHANICAL RECTILINEAL, ME- CHANICAL ROTATIONAL AND ACOUSTICAL ELEMENTS.....	19
III. ELECTRICAL, MECHANICAL RECTILINEAL, MECHANICAL RO- TATIONAL, AND ACOUSTICAL SYSTEMS OF ONE DEGREE OF FREEDOM	
3.1 INTRODUCTION.....	25
3.2 DESCRIPTION OF SYSTEMS OF ONE DEGREE OF FREEDOM.....	25
3.3 KINETIC ENERGY.....	27
3.4 POTENTIAL ENERGY.....	28

CHAPTER		PAGE
3.5	DISSIPATION.....	29
3.6	EQUATIONS OF MOTION.....	30
3.7	RESONANT FREQUENCY.....	32
3.8	KIRCHHOFF'S LAW AND D'ALEMBERT'S PRINCIPLE.....	33
IV.	ELECTRICAL, MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL SYSTEMS OF TWO AND THREE DEGREES OF FREEDOM	
4.1	INTRODUCTION.....	37
4.2	TWO DEGREES OF FREEDOM.....	37
4.3	KINETIC ENERGY.....	38
4.4	POTENTIAL ENERGY.....	39
4.5	DISSIPATION.....	39
4.6	EQUATIONS OF MOTION.....	40
4.7	THE ELECTRICAL SYSTEM.....	41
4.8	THE MECHANICAL RECTILINEAL SYSTEM.....	41
4.9	THE MECHANICAL ROTATIONAL SYSTEM.....	42
4.10	THE ACOUSTICAL SYSTEM.....	42
4.11	COMPARISON OF THE FOUR SYSTEMS.....	43
4.12	ELECTRICAL INDUCTIVE AND CAPACITIVE COUPLED SYSTEMS OF TWO DEGREES OF FREEDOM AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	45
4.13	ELECTRICAL, MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL SYSTEMS OF THREE DEGREES OF FREEDOM.....	48
V.	CORRECTIVE NETWORKS	
5.1	INTRODUCTION.....	52
5.2	TWO ELECTRICAL, MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL OR ACOUSTICAL IMPEDANCES IN PARALLEL.....	52
5.3	SHUNT CORRECTIVE NETWORKS.....	56
5.4	INDUCTANCE IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES....	58
5.5	ELECTRICAL CAPACITANCE IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	60
5.6	INDUCTANCE AND ELECTRICAL CAPACITANCE IN SERIES, IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	62
5.7	INDUCTANCE AND ELECTRICAL CAPACITANCE IN PARALLEL, IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	64
5.8	ELECTRICAL RESISTANCE, INDUCTANCE AND ELECTRICAL CAPACITANCE IN SERIES, IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES....	67

CONTENTS

ix
PAGE

CHAPTER

5.9	ELECTRICAL RESISTANCE, INDUCTANCE AND ELECTRICAL CAPACITANCE IN PARALLEL, IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	69
5.10	SERIES CORRECTIVE NETWORKS.....	71
5.11	INDUCTANCE IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES....	72
5.12	ELECTRICAL CAPACITANCE IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	74
5.13	INDUCTANCE AND ELECTRICAL CAPACITANCE IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL, AND ACOUSTICAL ANALOGIES.....	76
5.14	INDUCTANCE AND ELECTRICAL CAPACITANCE IN PARALLEL, IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	78
5.15	ELECTRICAL RESISTANCE, INDUCTANCE AND ELECTRICAL CAPACITANCE IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	80
5.16	ELECTRICAL RESISTANCE, INDUCTANCE AND ELECTRICAL CAPACITANCE IN PARALLEL, IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	83
5.17	RESISTANCE NETWORKS.....	85
5.18	ELECTRICAL RESISTANCE IN SERIES WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL, AND ACOUSTICAL ANALOGIES.....	85
5.19	ELECTRICAL RESISTANCE IN SHUNT WITH A LINE AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	86
5.20	"T" TYPE ELECTRICAL RESISTANCE NETWORK AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	87
5.21	"π" TYPE ELECTRICAL RESISTANCE NETWORK AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES.....	87
5.22	ELECTRICAL, MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL TRANSFORMERS.....	88

VI. WAVE FILTERS

6.1	INTRODUCTION.....	92
6.2	TYPES OF WAVE FILTERS.....	92
6.3	RESPONSE CHARACTERISTICS OF WAVE FILTERS.....	93
6.4	LOW PASS WAVE FILTERS.....	94
6.5	HIGH PASS WAVE FILTERS.....	95
6.6	BAND PASS WAVE FILTERS.....	97
6.7	BAND ELIMINATION WAVE FILTERS.....	101

VII. TRANSIENTS

7.1	INTRODUCTION	105
7.2	THE HEAVISIDE OPERATIONAL CALCULUS	106
7.3	TRANSIENT RESPONSE OF AN INDUCTANCE AND ELECTRICAL RESISTANCE IN SERIES AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES	107
7.4	TRANSIENT RESPONSE OF AN ELECTRICAL RESISTANCE AND ELECTRICAL CAPACITANCE IN SERIES AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES	111
7.5	TRANSIENT RESPONSE OF AN ELECTRICAL RESISTANCE, INDUCTANCE AND ELECTRICAL CAPACITANCE IN SERIES AND THE MECHANICAL RECTILINEAL, MECHANICAL ROTATIONAL AND ACOUSTICAL ANALOGIES	114
7.6	ARBITRARY FORCE	120

VIII. DRIVING SYSTEMS

8.1	INTRODUCTION	124
8.2	ELECTRODYNAMIC DRIVING SYSTEM	124
8.3	ELECTROMAGNETIC DRIVING SYSTEMS	126
	A. Unpolarized Armature Type	127
	B. Polarized Reed Armature Type	130
	C. Polarized Balanced Armature Type	134
8.4	ELECTROSTATIC DRIVING SYSTEM	138
8.5	MAGNETOSTRICTION DRIVING SYSTEM	141
8.6	PIEZOELECTRIC DRIVING SYSTEM	148

IX. GENERATING SYSTEMS

9.1	INTRODUCTION	153
9.2	ELECTRODYNAMIC GENERATING SYSTEM	153
9.3	ELECTROMAGNETIC GENERATING SYSTEMS	155
	A. Reed Armature Generating System	155
	B. Balanced Armature Generating System	157
9.4	ELECTROSTATIC GENERATING SYSTEM	158
9.5	MAGNETOSTRICTION GENERATING SYSTEM	162
9.6	PIEZOELECTRIC GENERATING SYSTEM	165

X. THEOREMS

10.1	INTRODUCTION	171
10.2	RECIPROCITY THEOREMS	171
	A. Electrical Reciprocity Theorem	171
	B. Mechanical Rectilinear Reciprocity Theorem	172
	C. Mechanical Rotational Reciprocity Theorem	173
	D. Acoustical Reciprocity Theorem	173

CONTENTS

CHAPTER	xi PAGE
E. Mechanical-Acoustical Reciprocity Theorem.....	175
F. Electrical-Mechanical Reciprocity Theorem.....	176
G. Electrical-Mechanical-Acoustical Reciprocity Theorem.....	177
H. Electrical-Mechanical-Acoustical-Mechanical-Electrical Reciprocity Theorem.....	177
I. Acoustical-Mechanical-Electrical-Mechanical-Acoustical Reciprocity Theorem.....	178
10.3 THEVENIN'S THEOREMS.....	178
A. Thevenin's Electrical Theorem.....	178
B. Thevenin's Mechanical Rectilinear Theorem.....	178
C. Thevenin's Mechanical Rotational Theorem.....	178
D. Thevenin's Acoustical Theorem.....	178
10.4 SUPERPOSITION THEOREM.....	179
XI. APPLICATIONS	
11.1 INTRODUCTION.....	180
11.2 AUTOMOBILE MUFFLER.....	180
11.3 ELECTRIC CLIPPER.....	182
11.4 DIRECT RADIATOR LOUD SPEAKER.....	183
11.5 ROTATIONAL VIBRATION DAMPER.....	184
11.6 MACHINE VIBRATION ISOLATOR.....	185
11.7 MECHANICAL REFRIGERATOR VIBRATION ISOLATOR.....	186
11.8 SHOCKPROOF INSTRUMENT MOUNTING.....	187
11.9 AUTOMOBILE SUSPENSION SYSTEM.....	188
INDEX.....	191

Download scientific diagram | Rheological-dynamical analogy: (a) damage state of a rod; (b) rheological model; and (c) dynamical model. from publication This is a study of viscoelastoplastic (VEP) vibrations and their use for the analysis of low cycle fatigue in internally damped inelastic frame structures (IDIFSs). The background of this inelastic theory is presented in the framework of a mathematical-physical analogy between the rheological model and a dynamical model with viscous damping. The rh View. Dynamic Modeling and Analogies. Copyright information. © Springer Science+Business Media, LLC 2012. (2012) Dynamical Analogies. In: Seel N.M. (eds) Encyclopedia of the Sciences of Learning. Springer, Boston, MA.