# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Acknowledgements</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xi</td>
</tr>
</tbody>
</table>

## CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION 1

1.2 CAMS 1

1.3 OPTIMIZATION 3

1.4 OBJECTIVES OF THE WORK 6

1.5 ORGANISATION OF THE THESIS 6

## CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION 8

2.2 LITERATURE REVIEW 8

2.3 SCOPE OF THE WORK 20

## CHAPTER 3: CAM MECHANISM AND B-SPLINE BASED CAM PROFILE

3.1 INTRODUCTION 21

3.1.1 Application of Cam Follower Mechanism 21

3.1.2 Classification of Cam Follower Mechanism 21

3.1.2.1 Type of Follower Motion 23

3.1.2.2 Type of Cam 23

3.1.2.3 Type of Follower 24

3.1.2.4 Type of Joint Closure 25

3.1.2.5 Type of Follower Arrangement 26

3.2 NOMENCLATURE OF CAM FOLLOWER MECHANISM 26

3.3 MOTION OF THE FOLLOWER 28

3.4 DESIGN OF CAM PROFILE 28

3.5 SYNTHESIS OF CAM PROFILE 30

3.6 DYNAMICS OF CAM FOLLOWER SYSTEMS 31

3.6.1 Lumped Parameter Dynamic Model 32

3.6.2 Equivalent System of Cam Follower Mechanism 33

3.6.2.1 Mass of Moving Parts 33

3.6.2.2 Stiffness of Spring 34

3.6.2.3 Damping of System 35

3.6.2.4 Lever Ratio 36
3.7 VALVE TRAIN MODELLING
3.8 FORMULATION OF MODEL EQUATION
3.9 BOUNDARY CONDITIONS OF DISPLACEMENT CURVE
3.10 CONSTRAINTS ON THE CAM PROFILE
  3.10.1 Jamming of the Follower
  3.10.2 Radius of Curvature
    3.10.2.1 Undercutting of Cam-Roller Radius
  3.10.3 Surface of Compressive Stress
  3.10.4 Follower Jump
3.11 FOLLOWER MOTION ANALYSIS
  3.11.1 Basic Curves
    3.11.1.1 Simple Polynomial Curves
    3.11.1.2 Trigonometric Curves
    3.11.1.3 Disadvantages of Basic Curve
  3.11.2 Advanced Curves
    3.11.2.1 Polynomial Curves
    3.11.2.2 Modified Motions Curves
  3.11.3 Disadvantages of Conventional Curves
  3.11.4 Synthetic Curves
3.12 B–SPLINE CURVES
3.13 EVALUATION OF B–SPLINE CURVES
3.14 CHARACTERISTICS OF B–SPLINE CURVES
3.15 UNIFORM PERIODIC B–SPLINE
3.16 NON UNIFORM PERIODIC B–SPLINE
3.17 OPEN UNIFORM B–SPLINE
3.18 SHAPE MODIFICATION OF B–SPLINE CURVES
3.19 CAM PROFILE DESIGN WITH B–SPLINE
3.20 B–SPLINE REPRESENTATION
  3.20.1 Computer Code for B–Spline

CHAPTER 4: OPTIMIZATION TECHNIQUES AND FOLLOWER DESIGN

4.1 INTRODUCTION
4.2 STATEMENT OF THE OPTIMIZATION PROBLEM
4.3 OPTIMIZATION TECHNIQUES
  4.3.1 Genetic Algorithm
    4.3.1.1 Overview of Natural Selection
    4.3.1.2 Working Procedures of Genetic Algorithm
      4.3.1.2.1 Encoding
      4.3.1.2.2 Creation of Initial Population
      4.3.1.2.3 Evaluation of Fitness Assignment
      4.3.1.2.4 Reproduction

v
4.4 OPTIMIZATION OF THE FOLLOWER TREATED AS COLUMN

4.4.1 Follower Design
4.4.2 Problem Formulation for Optimal Follower Design
4.4.3 Optimization by Genetic Algorithm
   4.4.3.1 Chromosome Coding Scheme
   4.4.3.2 Tournament Selection
   4.4.3.3 Cross Over
   4.4.3.4 Mutation
4.4.4 Constraint Handling
4.4.5 Methodology
   4.4.5.1 Description of the Algorithm
   4.4.5.2 Pseudo code of the Algorithm
   4.4.5.3 Results of the Optimum Follower Design

CHAPTER 5: OPTIMAL DESIGN OF CAM PROFILE

5.1 SELECTION OF OPTIMIZATION TECHNIQUE FOR CAM PROFILE
5.2 MULTI OBJECTIVE OPTIMIZATION
   5.2.1 Principles of Multi Objective Optimization
   5.2.2 Aim of Multi Objective Optimization
   5.2.3 Concept of Dominance
   5.2.4 Pareto Optimality
5.3 NON DOMINATING SORTING GENETIC ALGORITHM (NSGA)
   5.3.1 Non dominating Sorting of a Population
   5.3.2 Crowding Distance
   5.3.3 Crowded Tournament Selection
   5.3.4 Cross Over
   5.3.5 Mutation
5.4 SEARCHING FOR PREFERRED SOLUTION
   5.4.1 Post Optimal Techniques
   5.4.2 Optimization Level Techniques
   5.4.3 Pseudo-Vector Approach
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>PROBLEM FORMULATION FOR OPTIMAL CAM PROFILE DESIGN</td>
<td>105</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Selection of Design Variables</td>
<td>105</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Selection of Design Constraints</td>
<td>106</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Development of Objective Functions</td>
<td>107</td>
</tr>
<tr>
<td>5.6</td>
<td>OPTIMIZATION OF CAM PROFILE BY MULTI OBJECTIVE GENETIC ALGORITHM</td>
<td>111</td>
</tr>
<tr>
<td>5.6.1</td>
<td>Cam Profile Representation</td>
<td>111</td>
</tr>
<tr>
<td>5.6.2</td>
<td>Initial Population</td>
<td>112</td>
</tr>
<tr>
<td>5.6.3</td>
<td>Evaluation</td>
<td>112</td>
</tr>
<tr>
<td>5.6.4</td>
<td>Ranking</td>
<td>112</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Selection</td>
<td>113</td>
</tr>
<tr>
<td>5.6.6</td>
<td>Cross Over</td>
<td>113</td>
</tr>
<tr>
<td>5.6.7</td>
<td>Mutation</td>
<td>114</td>
</tr>
<tr>
<td>5.6.8</td>
<td>Evaluation of Cam Profile</td>
<td>115</td>
</tr>
<tr>
<td>5.6.9</td>
<td>Elitism</td>
<td>115</td>
</tr>
<tr>
<td>5.6.10</td>
<td>Evaluation of Next Generation</td>
<td>116</td>
</tr>
<tr>
<td>5.6.11</td>
<td>Last Generation</td>
<td>116</td>
</tr>
<tr>
<td>5.6.12</td>
<td>Searching for Preferred Solution</td>
<td>117</td>
</tr>
</tbody>
</table>

CHAPTER 6: RESULTS ANALYSIS 119-147

6.1 INTRODUCTION 119
6.2 DATA RELATED TO VALVE MECHANISM 119
6.3 PARAMETERS OF GENETIC ALGORITHM 120
6.4 B – SPLINE CURVE PARAMETERS 120
6.5 DISCUSSION ON OPTIMAL SOLUTION OBTAINED BY NSGA 121

CHAPTER 7: CONCLUSIONS AND SCOPE FOR THE FUTURE WORK 148-150

7.1 CONCLUSIONS 148
7.2 SCOPE FOR THE FUTURE WORK 150

REFERENCES 151-162

APPENDIX: COMPUTER PROGRAMS 163-206