



Computerized Fluid Power Series

Hydraulic Component Design and Selection

by E. C. Fitch and I. T. Hong

1 Introduction

- 1.1 Component Design Perspective
- 1.2 Hydraulic Power Evolution
- 1.3 Hydraulic Applications
- 1.4 Component Design Rationale
- 1.5 Why Computerized Component Design?

2 Fundamental Fluid Power Engineering

- 2.1 Introduction
- 2.2 Engineering System of Units
- 2.3 Behavior of Fluid in a System
- 2.4 Viscosity of Fluids
- 2.5 Pressure
- 2.6 Flow
- 2.7 Conduit Flow Models
- 2.8 Orifice Flow Models
- 2.9 Energy and Power
- 2.10 Design Safety Factors
- 2.11 Hydraulic Laws, Theorems, and Equations

3 Linear Actuators

- 3.1 Function and Configuration
- 3.2 Cylinder Nomographs
- 3.3 Hydraulic Cylinders
- 3.4 Hydraulic Cylinder Cushioning
- 3.5 Hydraulic Cylinder Design Considerations
- 3.6 Hydraulic Cylinder Structural Integrity
- 3.7 Hydraulic Cylinder Dynamics
- 3.8 Hydraulic Cylinder Selection
- 3.9 General Selection Considerations

4 Rotary Actuators

- 4.1 Introduction
- 4.2 Hydraulic Rotary Motors
- 4.3 Hydraulic Motor Selection
- 4.4 Limited Rotation Actuators
- 4.5 Oscillating Motor Applications

5 Fluid Distribution

- 5.1 Fluid Distribution Function
- 5.2 Directional Control Valves
- 5.3 Check Valves
- 5.4 Shuttle Valves
- 5.5 Spool Valve Characteristics
- 5.6 Spool Valve Selection
- 5.7 Valve Design Considerations
- 5.8 Solenoid Valves

- 5.9 Hydraulic Fuses and Circuit Protectors

6 Pressure Regulation

- 6.1 Pressure Regulation Function
- 6.2 Pressure Control Selection Factors
- 6.3 Relief and Safety Valves
- 6.4 Sequence Valves
- 6.5 Counterbalance Valves
- 6.6 Unloading Valves
- 6.7 Reducing Valves
- 6.8 Valve Noise and Cavitation

7 Flow Regulation

- 7.1 Flow Regulation Function
- 7.2 Uncompensated Flow Controls
- 7.3 Deceleration Valve
- 7.4 Compensated Flow Control
- 7.5 Bypass Flow Regulator
- 7.6 Priority Valve
- 7.7 Flow Divider and Combiner Valves
- 7.8 Positive-Displacement-Metering Valve
- 7.9 Flow Control Circuits
- 7.10 Valve Selection and Specification

8 Cartridge Valve Technology

- 8.1 Cartridge Valve Perspective
- 8.2 Poppet-Type Cartridges
- 8.3 Spool-Type Cartridge Valves
- 8.4 Cartridge Valve Models
- 8.5 Sizing of Cartridge Valves
- 8.6 Cartridge Manifold Design
- 8.7 Applications

9 Hydraulic Power Sources

- 9.1 The Energy Question
- 9.2 Prime Mover Considerations
- 9.3 Hydrostatic Power Generation
- 9.4 Pumping Models
- 9.5 Pump Characteristics
- 9.6 Pump Application Factors
- 9.7 Functional Aspects of Pumps
- 9.8 Fixed Displacement Pump Models
- 9.9 Noise in Pump Systems
- 9.10 Environmental Aspects of Pumps
- 9.11 Booster Pumps

10 Energy Storage and Transformation

- 10.1 Introduction
- 10.2 Energy Storage—Accumulators
- 10.3 Gas-loaded Accumulator Sizing Criteria
- 10.4 Accumulator Selection and Application
- 10.5 Accumulator Assessment
- 10.6 Energy Transformation Devices
- 10.7 Intensifier Application Factors
- 10.8 Intensifier Assessment and Selection

11 The Conduit System

- 11.1 The Role and Types of Conduits
- 11.2 Connector Seals
- 11.3 Conduit Connectors
- 11.4 An Overtorqued Connector Case
- 11.5 Rigid Conduit—Piping
- 11.6 Rigid Conduit—Tubing
- 11.7 Flexible Conduit—Hose
- 11.8 Manifolding and Modularizing
- 11.9 Energy Losses in Conduit Systems

12 Seals for Hydraulics

- 12.1 Introduction
- 12.2 Types of Seals
- 12.3 Mechanics of Sealing
- 12.4 Elastomer Technology
- 12.5 Seal Design and Selection Notes
- 12.6 Linear Seal Considerations
- 12.7 Cylinder and Piston O-ring Seal Force Model
- 12.8 Hydraulic Seal Models

Appendix A—Glossary of Hydraulic Terms

Appendix B—Symbols for Fluid Power Systems

Appendix C—Hydraulic Test Standards

Appendix D—FPRC/OSU Orifice Flow Nomograph

Appendix E—Tables of Conversion Factors

Supplemental Seminar Material

Special supplement included with seminar covers the detail modeling and analysis techniques for servo valves.



Computerized Fluid Power Series

Hydraulic System Modeling and Simulation

by E. C. Fitch and I. T. Hong

1 Introduction

- 1.1 Hydraulic System Modeling Overview
- 1.2 Hydraulic System Design Process
- 1.3 System Modeling Considerations
- 1.4 System Model Solutions
- 1.5 The Dynamic Discipline
- 1.6 Engineering Approximations
- 1.7 Simulation versus Experimentation
- 1.8 Phenomena Modeled in Hydraulic Systems

2 Fundamentals of Fluid Dynamics

- 2.1 Introduction
- 2.2 System Approach
- 2.3 Control Volume Approach
- 2.4 Selection of a Control Volume in a System

3 Generic Fluid Element Models

- 3.1 Introduction
- 3.2 Conduit Flow Models
- 3.3 Orifice Flow Models
- 3.4 Clearance Flow Models
- 3.5 Porous Flow Models
- 3.6 Molecular Flow Models
- 3.7 Generic Flow Force Models

4 System Modeling Techniques

- 4.1 Need for Mathematical Models
- 4.2 Methods of System Representation
- 4.3 Mathematical Modeling Principles
- 4.4 Modeling Generalization
- 4.5 Generic Hydraulic Element Models

5 Visual Modeling and System Equation Formulation

- 5.1 Visual Modeling Rationale
- 5.2 Formulating System Equations
- 5.3 Nature of Simulation
- 5.4 Canonical Form of Simulation Equations

6 Solution Methods for Mathematical Models

- 6.1 Introduction
- 6.2 Analytical Solutions

- 6.3 Analog Simulation
- 6.4 The General Procedure

7 Graphical Methods For Design Analysis

- 7.1 Introduction
- 7.2 The Alignment Chart
- 7.3 The Static Performance Graph
- 7.4 The SPG Examples

8 Duty Cycle and Loading Analysis

- 8.1 Service Compliance
- 8.2 Service Requirements
- 8.3 Load Characteristics
- 8.4 Computer Mapping of Load-Locus
- 8.5 Load-Locus Application
- 8.6 Vibration and Shock Loads
- 8.7 Work Cycles
- 8.8 Duty Cycles
- 8.9 Transmission Losses

9 Digital Computation and Simulation

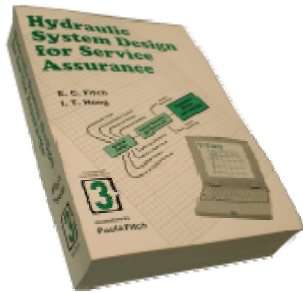
- 9.1 Historical Notes and Approaches
- 9.2 Scope of Digital Simulation
- 9.3 Design Rationale with Simulation
- 9.4 System Simulation Approaches
- 9.5 Selecting Simulation Program
- 9.6 Digital Simulations
- 9.7 Steady State Analysis
- 9.8 Transient State Analysis
- 9.9 The Explicit Integration Methods
- 9.10 Step Size Selection
- 9.11 Implicit Integration

10 Model Verification and Test Procedures

- 10.1 Introduction
- 10.2 Need for Model Verification and Validation
- 10.3 Model Verification Criteria
- 10.4 Specifications and Test Procedures
- 10.5 Static Test Procedures
- 10.6 Dynamic Test Procedures

Supplemental Seminar Material

Special supplement covers the detailed modeling and analysis techniques for servo control systems. Topics include servo system types, system stability analysis, control strategies, and control compensation techniques.



Computerized Fluid Power Series

Hydraulic System Design for Service Assurance

by E. C. Fitch and I. T. Hong

- 1 Introduction**
 - 1.1 Service Reliability Perspective
 - 1.2 An Approach to the Failure Dilemma
 - 1.3 The General Contents
 - 1.4 Why Computerize Service Assurance Aspects
 - 1.5 Computerized Service Assurance Examples
- 2 Hydraulic Fluids**
 - 2.1 Status of Hydraulic Fluids
 - 2.2 Composition of Hydraulic Fluids
 - 2.3 Stability of Hydraulic Fluids
 - 2.4 Physical Properties of Fluids
 - 2.5 Viscosity
 - 2.6 Bulk Modulus
 - 2.7 Vapor Pressure (Volatility) and Aeration
 - 2.8 Aeration and Foam
 - 2.9 Specific Gravity/Density
 - 2.10 Surface Tension
 - 2.11 Hygroscopicity
 - 2.12 Obliteration Stability
 - 2.13 Flammability Characteristics
 - 2.14 Chemical Properties of Fluids
 - 2.15 Oxidation Stability
 - 2.16 Thermal Stability
 - 2.17 Hydrolytic Stability
 - 2.18 Material Compatibility
 - 2.19 Anti-Rust and Corrosion Stability
 - 2.20 Antiwear Stability
 - 2.21 Antiwear Assessment
 - 2.22 Hydraulic Fluid Selection
- 3 Contamination Control and Filtration**
 - 3.1 Contamination Control Overview
 - 3.2 Scope of Contamination
 - 3.3 Particulate Contaminants
 - 3.4 Water Contaminant
 - 3.5 Contaminant Analysis
 - 3.6 Cleanliness Level Descriptions
 - 3.7 Wear Debris Analysis
 - 3.8 Contaminant Ingression Control
 - 3.9 Contamination Level Reference State
 - 3.10 Component Contaminant Sensitivity
 - 3.11 Fluid Filtration
 - 3.12 Filtration Mechanics
 - 3.13 Filtration Structural Integrity
 - 3.14 Particle Capture Assessment
 - 3.15 Filtration Models
 - 3.16 Interpreting Filter Performance
 - 3.17 Filter Performance Irregularities
 - 3.18 Filter Location Options
 - 3.19 Omega Rating Rationale
- 4 Hydraulic Reservoir and Suction Line Dynamics**
 - 4.1 Scope of Fluid Conditioning
 - 4.2 Reservoir Function and Design
 - 4.3 The Conventional or JIC Hydraulic Reservoir
 - 4.4 The Bootstrap Reservoir System
 - 4.5 The Mobile Reservoir
 - 4.6 The Critical Volume Reservoir (CVR)
 - 4.7 CVR Design Considerations
 - 4.8 Selecting and Assessing Hydraulic Reservoirs
 - 4.9 Suction Line Hydraulics
 - 4.10 Pump Filling Characteristics
 - 4.11 Reservoir Pump Outlet Port Pressure
 - 4.12 Pump Supercharging Options
 - 4.13 Dehydration System
 - 4.14 Deaeration or Degassing System
- 5 Heat in Hydraulic Systems**
 - 5.1 Heat Control
 - 5.2 Heat Generation
 - 5.3 Modes of Heat Transfer
 - 5.4 The Overall Heat Transfer Coefficient
 - 5.5 Thermal Steady State Analysis
 - 5.6 Thermal Transient Analysis
 - 5.7 Sizing of Heat Exchangers
 - 5.8 Air Coolers
 - 5.9 Pre-Heating Hydraulic Fluid
- 6 Leakage in Hydraulic Systems**
 - 6.1 Leakage
 - 6.2 Leakage Causality
 - 6.3 Effects of Leakage
 - 6.4 Leakage Classification
 - 6.5 External Leakage Assessment
 - 6.6 Internal Leakage Assessment
 - 6.7 Leakage Sources
 - 6.8 External Leakage Sites
 - 6.9 Static Seal Leakage Sites
 - 6.10 Dynamic Seal Leakage Sites
 - 6.11 Internal Leakage Sites
 - 6.12 Leakage Summary
- 7 Tribological Wear**
 - 7.1 Scope of Tribological Wear
 - 7.2 Abrasion Wear
 - 7.3 Adhesion Wear
 - 7.4 Surface Fatigue Wear
 - 7.5 Delamination Wear
 - 7.6 Fretting Wear
 - 7.7 Erosion Wear
 - 7.8 Cavitation Wear
 - 7.9 Corrosion Wear
 - 7.10 Hydrogen-Induced Wear
 - 7.11 Electrokinetic Wear
 - 7.12 Radiation Wear
- 8 Motion Impediment**
 - 8.1 Overview of Motion Failures
 - 8.2 Mechanical Lock
 - 8.3 Mechanical Overload
 - 8.4 Surface Lubrication
 - 8.5 Thermal Lock
 - 8.6 Thermal Shock
 - 8.7 Hydraulic Lock
 - 8.8 Adhesive Lock
 - 8.9 Contaminant Lock
 - 8.10 Static or Bridgement Jam
 - 8.11 Shear or Coincidence Jam
 - 8.12 Dynamic Jam or Silt Lock Seizure
 - 8.13 Obliterant Choke
 - 8.14 Viscous Lock
 - 8.15 Flow Lock
 - 8.16 Magnetic Lock
 - 8.17 Bernoulli Spring Force
 - 8.18 Port/Orifice Obstruction
 - 8.19 Interstitial Closure By Obliteration
- 9 Design Mechanics**
 - 9.1 Introduction
 - 9.2 Material Strength Considerations
 - 9.3 Mechanical Static Loads
 - 9.4 Material Fracture Loads
 - 9.5 Stress Concentrations
 - 9.6 Mechanical Dynamic Loads
 - 9.7 Synergistic Effects of Loading Conditions
 - 9.8 Material Damage Modes
 - 9.9 Material Failure Factors
 - 9.10 Failure of Basic Component Elements
 - 9.11 Failure of System Interconnecting Elements
- 10 Condition Monitoring of Hydraulic Systems**
 - 10.1 Onset and Progression of Failure
 - 10.2 Role of Condition Monitoring
 - 10.3 Features of Condition Monitoring Systems
 - 10.4 The Diagnostic System
 - 10.5 Measurement Methods
 - 10.6 Internal State Diagnostics
 - 10.7 System Prognosis
 - 10.8 Prescriptive Action
 - 10.9 Weak Points of Systems
 - 10.10 Fuzzy Logic Approach to Condition Monitoring
- 11 Hydraulic System Reliability**
 - 11.1 Reliability Concepts
 - 11.2 Characterizing Reliability
 - 11.3 Reliability Functions
 - 11.4 Product Life Curve
 - 11.5 Distribution Functions
 - 11.6 The Mortality Model
 - 11.7 Weibull Plot and Failure Analysis
 - 11.8 Plotting on Weibull Probability Paper
 - 11.9 Non-linear Weibull Plot
 - 11.10 Reliability Quantification
 - 11.11 Reliability Predictions
 - 11.12 System Reliability Models
 - 11.13 Component Hazard Data
 - 11.14 A Deterministic Reliability Approach
 - 11.15 Maintaining System Reliability
 - 11.16 Designing for Reliability
 - 11.17 Specific Reliability Design Factors
- 12 System Design Methodology**
 - 12.1 System Design Process
 - 12.2 Functionality
 - 12.3 Performance
 - 12.4 Reliability
 - 12.5 Longevity
 - 12.6 Maintainability
 - 12.7 Quality
 - 12.8 Safety
 - 12.9 Logistics
 - 12.10 The Critical Design Steps
 - 12.11 Design Details