

Contents

1	Introduction	1
1.1	Why Implement Condition Monitoring?	1
1.2	Three Maintenance Strategies	5
1.3	Some Preliminary Conclusions	10
1.4	Potential Benefits of CBM	10
1.5	Benefits Applied to Plant Economics.....	12
1.6	Types of Condition Monitoring Systems.....	13
1.7	Methods of Condition Monitoring.....	14
1.8	Failure Modes and Effects Analysis (FMEA)	15
1.9	Correcting the Fault – Fault Tree Analysis.....	19
1.10	Computer Simulation as a Fault Synthesis/Detecting Tool	21
2	Modelling and Computer Simulation as an Aid to Understanding Circuit Behaviour	29
2.1	Introduction	29
2.2	Steady-state Analysis of Components and Circuits.....	30
2.2.1	Pumps and Motors.....	30
2.2.2	Cylinders	35
2.2.3	Leakage Flow and Lift Characteristics of Slippers	35
2.2.4	Pressure Ripple in Positive Displacement Pumps and Motors	38
2.2.5	Flow Restrictors – Flow Rate and Flow Reaction Force....	39
2.2.6	Pressure Drop through Pipes	42
2.2.7	Pressure/Flow Characteristics of Directional Valves, Check Valves, Flow Control Valves, Pressure Relief Valves.....	42
2.2.8	A Circuit Calculation Example	44
2.3	Electrohydraulic Servovalves	32
2.3.1	Principles of Operation.....	32
2.3.2	Steady-state Performance Characteristics	39
2.3.3	Spool Underlap.....	42

2.3.4	Spool Valve Linearised Coefficients.....	44
2.3.5	Servovalve Dynamic Response	48
2.4	Steady-state Control of a Servovalve/Motor Drive	49
2.4.1	The Basic Circuit.....	49
2.4.2	Open-loop Behaviour with Losses	50
2.4.3	Closed-loop Behaviour with Losses.....	53
2.5	Steady-state Motion of a Servovalve/Linear Actuator Drive.....	56
2.5.1	The Basic Circuit.....	56
2.5.2	The Extending Case	56
2.5.3	The Retracting Case	57
2.6	Undamped Natural Frequency of Actuators, the Effect of Fluid Compressibility and Load Mass.....	57
2.7	Some General Observations on Line Pressures in Servovalve/ Actuator Control Systems in the Presence of Load Mass and Inertia.....	60
2.8	Linearisation Technique to Estimate the Dynamic Behaviour of Nonlinear Systems	61
2.9	Underlapped Servovalve Spools - the Effect on Steady-state Behaviour for Closed-loop Control Systems.....	63
2.10	Underlapped Servovalve Spools – the Effect on Dynamic Behaviour for Closed-loop Control Systems.....	66
2.11	Proportional Pressure Relief Valve Modelling Concepts	70
2.12	Long Lines.....	74
2.12.1	The Basic Equations.....	74
2.12.2	Application to a Servovalve/Single-line/Cylinder.....	76
2.12.3	Modelling Actuator Volume Effects	82
2.12.4	Frequency Response.....	83
2.12.5	Frequency Response with Actuator Included.....	84
2.12.6	Response and Stability of a Servovalve/Motor Speed Control System with Long Lines.....	88
2.13	Effective Bulk Modulus	94
2.14	Fluid Viscosity and Density	100
2.15	Solving the System Equations – Simulation Software	101
2.16	Transient Response and Stability of a Pressure Rate-controlled Two-stage Pressure Relief Valve	105
2.17	Data-based Dynamic Modelling of Components – Accumulator Charging Behaviour.....	112
2.18	Data-based Dynamic Modelling of Components – Time Series Analysis	117
2.19	Data-based Dynamic Modelling of Components – Long Lines ...	121
2.20	Data-based Dynamic Modelling of Components – Artificial Neural Networks (ANNs).....	126
2.20.1	Introduction	126
2.20.2	The Artificial Neuron – Forming the ANN	127

2.20.3	Training ANNs – The Basic Weight Change Equation for a Single Neuron	130
2.20.4	Some Practical Issues.....	132
2.20.5	Modelling a Long Line in a Pressure Control System.....	132
2.21	Data-based Dynamic Modelling of Components – the Group Method of Data Handling (GMDH)	136
2.21.1	Introduction.....	136
2.21.2	An Introductory Example – a Servovalve/Motor Drive	136
2.21.3	Application to a Practical Circuit – a Multivariable Problem	139
2.21.4	Circuit Simulation Using Interconnected Artificial Networks	142
2.22	Intelligent Control, Improving Closed-loop Performance	150
3	Condition Monitoring Methods.....	173
3.1	Methods Based Around Steady-state Flow Loss Metering.....	173
3.1.1	Visual Leak Detection, the Simplest Approach.....	173
3.1.2	Flow Meter Types	174
3.1.3	Vane Pump Wear Monitoring	175
3.1.4	Assessing the External Leakage from a Pressure- compensated Axial Piston Pump.....	177
3.1.5	Detection of Cylinder Piston Seal Wear for a Servovalve/ Cylinder Drive	179
3.1.6	Assessing Motor Leakage Characteristics by Coupling to a Servovalve	181
3.2	Cylinder Seal Leakage Identification Within a Vehicle Active Suspension Actuator Using Dynamic Data	182
3.3	Fluid Borne (FBN), Structural Borne (SBN) and Air Borne (ABN) noise.....	187
3.3.1	Introduction.....	187
3.3.2	Application to Pumps, FBN and SBN Spectrum Analysis.....	189
3.3.3	Fault Data Trending	193
3.3.4	Acoustic Emission Sensor Application and Comparison for Pump Wear and Cavitation Detection, SBN and FBN	195
3.3.5	Spectrum Analysis to Detect Piston Seal Wear within a Cylinder, SBN	199
3.3.6	Frequency Spectrum Archetypes and Fault Correlation FBN Analysis of a Cylinder Pressure Control System with Leakage	201
3.3.7	Component Impedance, FBN Analysis	203
3.3.8	Use of Impedance for Fault Diagnosis of a Pressure Relief Valve Using Frequency Response	206

3.3.9	SBN due to Repetitive Fault Phenomena	208
3.3.10	ABN Concepts	212
3.4	Time Encoded Signal Processing, TESP Analysis	215
3.4.1	Introduction	215
3.4.2	Example. Pump Torque Data Analysis	217
3.4.3	Example. Application to 28 Servovalves on the Work Roll Bending Control System of a Seven-stand Hot Steel Strip Mill	221
3.4.4	Combined TESP/ANN Approach to Leakage and Servovalve Fault Detection in a Pressure Control System.....	226
3.5	Further Applications of Artificial Neural Networks.....	231
3.5.1	Leakages Within a Position Control System	231
3.5.2	Weight Changes and the Use of Transmission Line Dynamics to Aid Fault Detection.....	233
3.5.3	Linear Prediction Coding and Cepstrum (LPC) Features Extraction and ANN Classification.....	236
3.5.4	Condition Monitoring of a Bent Axis Pump	240
3.6	Fluid and Wear Debris Analysis.....	242
3.6.1	Consideration of the Fluid.....	242
3.6.2	Wear and Particle Contamination.....	247
3.6.3	Particle Size Classification, ISO4406, Automatic Particle Counters	251
3.6.4	Wear Debris Analysis.....	255
3.7	Temperature Sensing	258
3.8	Data Acquisition.....	259
3.8.1	Hand-held Equipment	259
3.8.2	Distributed Sensing, Wireless Communication.....	260
3.8.3	Data Acquisition Cards for System Development.....	262
3.8.4	Application to a Hot Steel Strip Finishing Mill.....	264
3.9	Expert Systems and Knowledge-based Reasoning.....	266
3.9.1	What is an Expert System?.....	266
3.9.2	Generating a Knowledge Base	268
3.9.3	The Inferencing Process	270
3.9.4	Supporting Software.....	271
3.9.5	Knowledge Elicitation	272
3.9.6	Working Examples.....	274
3.10	Object-oriented Expert Systems Approach for Multiple Subsystems, and its Application to a Hot Steel Strip Rolling Mill	293

4 Common Faults and Breakdowns that can occur in a Hydraulic Circuit	303
4.1 Pumps and Motors	303
4.2 Directional Valves	308
4.3 Servovalves	311
4.4 Check Valves	312
4.5 Pressure Limiters	312
4.6 Flow Regulators	313
4.7 Anti-shock Valves	314
4.8 Actuating Cylinders	314
4.9 Filters	315
4.10 Tanks	315
4.11 Couplings	317
4.12 Piping	317
4.13 Accumulators	318
4.14 Oil Cooler	318
4.15 Miscellaneous	319
4.16 Some Typical Component Failures, Pumps and Motors	320
Further Reading.....	335
Author Biography.....	355
Index	357