

Table of Contents

Chapter 1 Introduction to Mobile Hydraulics	1-1
Advantages of Hydraulic Power Transmission.....	1-1
Basic Components that are Used in Hydraulic Systems.....	1-2
A Simple Hydraulic System	1-2
Pumps.....	1-3
Accumulators	1-3
Valves	1-3
Hydraulic Cylinders	1-4
Motors.....	1-4
Components for Remote Control Systems.....	1-4
Typical Mobile Applications.....	1-5
Drill Rig - Description	1-5
Excavator - Description	1-6
Forwarder (Log Loader) Description.....	1-7
Wheel Loader Description	1-8
Reach Stacker Description.....	1-9
Cranes Description.....	1-10
Refuse Collecting Vehicle Description	1-11
Chapter 1 Exercise Hydraulic Transmission of Energy	1-12
Chapter 2 Basic Hydraulic Principles.....	2-1
Force	2-1
Changes in Motion	2-1
Resistance	2-1
Friction as Resistance	2-1
Energy	2-2
Law of Conservation of Energy	2-2
Energy changes form	2-2
Inertia as energy	2-2
States of Energy	2-2
Kinetic State of Energy	2-3
Potential State of Energy	2-3
Energy Changes State	2-3
Work	2-3
Power	2-4
Horsepower	2-4
Liquid Characteristics.....	2-4
Force Transmitted Through a Liquid.....	2-4
Pascal's Law.....	2-5
Pressure	2-5
Pressure Gauge	2-6
Bourdon Tube Pressure Gauge.....	2-6
Plunger Pressure Gauge.....	2-6
Hydraulic Transmission of Energy	2-7
Inefficiency	2-7
Pressure Differential and Pressure Drop.....	2-7
Hydraulic System Design to Avoid Heat Generation.....	2-8
Converting Hydraulic Pressure to Mechanical Force.....	2-8
Mechanical Force Multiplication.....	2-9
Positive Displacement Pumps.....	2-9
A Simple Hydraulic System.....	2-9
Operating Principles of a Simple Hydraulic System.....	2-10

Hydrodynamics versus Hydrostatics	2-11
Open Loop Systems	2-12
Closed Loop Systems.....	2-12
Summary	2-12
Chapter 2 Exercises.....	2-13
Exercise 1 - Basic Hydraulic Principles.....	2-13
Chapter 2 Exercises (cont'd.)	2-14
Exercise 2 - Basic Hydraulic Principles.....	2-14

Chapter 3 Mobile Hydraulic Pumps 3-1

Gear Pumps	3-1
What a Gear Pump Consists Of	3-1
How a Gear Pump Works	3-1
External Gear Pumps	3-2
History of the Gear Pump	3-2
The Dump Truck.....	3-2
The Pump/Valve.....	3-2
Two-Line Schematic	3-2
Two-Line Raise.....	3-3
Two-Line Lower	3-3
Two-Line Neutral.....	3-3
Three-Line Schematic.....	3-4
Three-Line Raise.....	3-4
Three-Line Lower	3-4
Three-Line Neutral.....	3-5
Gear Pump Rotation.....	3-5
Vane Pumps	3-5
What a Vane Pump Consists Of	3-5
How a Vane Pump Works	3-5
Balanced Vane Pump Design	3-6
Cartridge Assembly	3-6
Vane Loading	3-6
Tandem and Thru-drive Pumps	3-7
Internal Gear Pump	3-8
Piston Pumps	3-8
What a Piston Pump Consists Of	3-8
How a Piston Pump Works	3-9
Bent-axis Piston Pump	3-9
Radial Piston Pump	3-10
Variable Volume Pumps	3-10
Variable Volume from a Gear Pump	3-10
Regulating Hydraulic Power with Variable Volume Pumps	3-10
What a Variable Volume Vane Pump Consists Of	3-11
Case Drain	3-11
How a Variable Volume Vane Pump Works	3-11
How the Pressure Compensator of a Variable Volume Vane Pump Works	3-11
Vane Pump Dual Compensation	3-12
Variable Volume Axial Piston Pump	3-12
What a Variable Volume Axial Piston Pump Consists Of	3-12
How the Volume Adjustment of a Variable Volume Axial Piston Pump Works	3-13
How the Pressure Compensator of a Variable Volume Axial Piston Pump Works	3-13
Piston Pump Dual Compensation	3-15
Comparing Fixed and Pressure Compensated Variable Volume Operation	3-15
Overcenter Axial Piston Pumps	3-16
Load Sensing Theory of Operation	3-17

Load Sensing (Flow Control) with a Variable Volume Pressure Compensated Axial Piston Pump.....	3-22
Low Pressure Standby.....	3-23
Operating Modes.....	3-24
Horsepower (Torque) Limiting Control	3-28
Determining Limiting Flow	3-29
Hydromechanical Control.....	3-30
Hydromechanical Horsepower Limiting Control	3-30
Horsepower (Torque) Limiting with Load Sensing (Flow Control)	3-32
Minimum Horsepower Full Flow Boundary	3-33
Horsepower, Flow and Pressure Curves	3-34
Setting a Horsepower Limiter Control	3-34
Utilizing the Horsepower Formula	3-34
Chapter 3 Exercises.....	3-36
Exercise 1 - Torque (Horsepower) Limiting.....	3-36
Chapter 3 Exercises (cont'd.).....	3-37
Exercise 2 - Load Sensing Exercise.....	3-37

Chapter 4 Hydraulic Motors and Hydrostatic Drives 4-1

Implement or Auxiliary Drive.....	4-1
Vane Motors	4-1
What a Vane Motor Consists Of	4-1
How a Vane Motor Works	4-1
Balanced Vane Motor Design	4-2
Cartridge Assembly	4-2
Extending a Motor's Vanes	4-2
Freewheeling of Pressure Loaded Vane Motors	4-3
Gear Motors	4-3
What an External Gear Motor Consists Of.....	4-3
How an External Gear Motor Works	4-3
Gerotor Motor (An Internal Gear)	4-4
Low Speed High Torque Motors.....	4-4
How a LSHT Motor Works.....	4-4
Two Speed Motor.....	4-4
Parallel Mode in a Two Speed Motor	4-5
Series Mode in a Two Speed Motor.....	4-5
Piston Motors	4-5
What an Axial Piston Motor Consists Of	4-5
How an Axial Piston Motor Works	4-6
Bent Axis Piston Motor.....	4-6
How a Bent Axis Piston Motor Works.....	4-6
Variable Displacement Axial Piston Motors	4-6
Variable Displacement Bent Axis Piston Motor	4-7
Hydraulic Motors in a Circuit	4-7
Preventing Motor Cavitation.....	4-9
Makeup Check Valves.....	4-9
Crossover Relief Valves	4-9
Hydrostatic Drives	4-9
Open Loop	4-9
Closed Loop.....	4-10
Hydrostatic Transmission	4-10
Integral and Split Hydrostatic Transmission.....	4-10
Parallel Hydrostatic Transmission	4-10
Series Hydrostatic Transmission.....	4-10

Constructing a Hydrostatic Transmission	4-11
Preventing Wheel Spin.....	4-11
Braking a Hydrostatic Transmission Drive.....	4-11
Hydrostatic Shunt Transmission	4-12
Wheel Motors.....	4-13
Variable Displacement Bent Axis Wheel Motor	4-13
Displacement Controls.....	4-13
Pressure Compensator Control	4-13
Pressure Compensator with Brake Defeat	4-14
Electrohydraulic Proportional Control.....	4-14
Fixed Displacement Motor Controls Used in a Hydrostatic Transmission.....	4-14
Braking Valve.....	4-14
Swing Drive Motors.....	4-15
Selection of a Motor.....	4-15
Side Load	4-15
Sizing for Vehicle Propulsion Systems	4-16
Tractive Effort (TE) Definition	4-16
Rolling Resistance Definition	4-16
Grade Resistance (GR) Definition	4-16
Acceleration Force (F) Definition.....	4-17
Drawbar Pull (DP) Definition	4-17
Motor Torque Defined.....	4-17
Slip Torque Definition.....	4-17
Rolling Radius	4-17
Hydraulic Motor Speed.....	4-17
Chapter 4 Exercises.....	4-18

Chapter 5 Hydraulic Cylinders 5-1

Hydraulic Cylinder Types	5-1
Single-Acting Cylinder.....	5-2
Double-Acting, Single Rod Cylinder.....	5-2
Telescoping Cylinders.....	5-2
Special Types	5-2
Cylinder Designs.....	5-3
Cylinders for Mobile Applications.....	5-3
Design	5-3
Cylinder Parts	5-3
Mounting Styles.....	5-3
Mechanical Motions.....	5-4
Butt Contact Mounting	5-4
Movement in One Plane.....	5-4
Movement in Two Planes.....	5-5
Types of Cylinder Loads	5-5
Forces and Pressures Affecting a Cylinder	5-5
Pump Pressure in Phases/Regions 1-2-3	5-6
Cylinders Without Cushions	5-6
Hydraulic Shock	5-6
Cushions	5-7
How a Cushion Works	5-7
Cylinders with Cushions.....	5-7
Transverse Forces	5-8
Cylinder Rod Buckling	5-8
Initial Deflection	5-9
Static Loads for a Pushing Cylinder (Compression/Thrust Load).....	5-9
Cylinder Piston and Piston Areas	5-10
Rod Speed of an Extending, Double-Acting Cylinder.....	5-10

Discharge Flow from an Extending, Double-Acting Cylinder	5-10
Rod Speed in a Retracting, Double-Acting Cylinder.....	5-10
Discharge Flow from a Retracting, Double-Acting Cylinder	5-10
Pushing (Compression/Thrust) Force from an Extending Cylinder	5-11
Pulling (Tension) Force from a Retracting Cylinder	5-11
Double Rod Cylinder Circuit.....	5-11
Regeneration With a 2:1 Cylinder.....	5-12
Regeneration During Rod Extension	5-12
Cylinder Force During Regeneration	5-13
Sample Regenerative Circuits	5-13
Synchronizing Two Cylinders.....	5-13
Seals	5-14
Piston Rod Seal	5-14
U-sleeve (Lip Seal)	5-15
Slide Ring Seals	5-15
Scraper	5-15
Piston Seal.....	5-16
Piston Seal Leakage	5-16
Piston Seal Leakage Affects Rod Speed	5-17
Pressure Intensification Due to Piston Leakage	5-17
Checking for Piston Seal Leakage	5-18
Intensification at the Cylinder Rod End.....	5-19
Guide (Bearing) Rings/Wear Rings	5-21
Conditions for Useful Life.....	5-21
Integrated Cylinders.....	5-21
Cylinders for “Closed Loop” Systems.....	5-22
Selecting a Mobile Cylinder	5-23
Chapter 5 Exercises.....	5-24

Chapter 6 Pressure Control Valves 6-1

Direct Acting System Relief Valves.....	6-1
Valve Function	6-1
Valve Characteristic	6-2
Relief Valve Damping.....	6-2
Pressure Relief Valve Applications	6-3
Actuator Relief Valves	6-3
Relief Valves in a Circuit.....	6-3
Crossover Relief Valves.....	6-4
Pilot Operated Pressure Relief Valves	6-5
Design	6-5
Valve Function	6-5
Remotely Controlled, Pilot Operated Relief Valves	6-6
Pressure Reducing Valves	6-6
Sequence Valves.....	6-7
Inlet Compensators	6-7
The Unloading Valve in a Circuit	6-8
Control of Maximum Load Pressure.....	6-8
Pressure Reducing Compensator	6-9
Load Control Valves.....	6-10
Pilot Operated Check Valve	6-10
Counterbalance Valve	6-11
The Counterbalance Valve in a Circuit	6-11
Valve Function	6-12
Other pressure Control Valves	6-13
Accumulator Relief Valves	6-13
Valve Function	6-13

Reducing Energy Loss During Machine Idling	6-14
Unloading a Pilot Operated Relief Valve.....	6-14
Unloading a Fixed Displacement Pump in an Accumulator Circuit.....	6-15
Summary	6-15
Chapter 6 Exercise Pressure Control Valves.....	6-17

Chapter 7 Flow Control Valves..... 7-1

Orifice	7-2
Orifice Size Affects Flow.....	7-2
Fixed Orifice	7-2
Variable Orifice	7-2
Gate Valve.....	7-2
Globe Valve.....	7-2
Needle Valve	7-3
Needle Valves in a Circuit.....	7-3
Pressure Differential Affects Flow.....	7-3
Relief Valve Setting Increased	7-4
Work Load Pressure Increased.....	7-4
Throttling Check Valve	7-5
Pressure Compensated Flow Control Valves	7-5
Nonadjustable Constant Flow Valves	7-5
Function	7-5
Adjustable Pressure Compensated Flow Control Valves.....	7-5
Function	7-6
Three-way, Pressure-Compensated Flow Control Valves in a Circuit.....	7-6
Workload Pressure and Relief Valve Setting Increased	7-6
Other Flow Control Applications.....	7-7
Meter-in Circuits.....	7-7
Meter-out Circuit.....	7-8
Lowering Brake Valve	7-8
Flow Control via Fflow Notches on the Spool of a Directional Control Valve	7-9
Summary.....	7-9
Chapter 7 Exercise Flow Control Valves	7-10

Chapter 8 Directional Control Valves 8-1

Check Valves.....	8-2
Cartridge Valves.....	8-2
Seat/poppet Valves.....	8-3
Spool Valves	8-3
Valve Inlet.....	8-4
Common Load-Hold Check Valve.....	8-4
Bypass Valve/Main Relief Valve.....	8-5
Emergency Stop Function.....	8-6
Unloading Signal Orifice	8-6
Load Sensing Signal Connector.....	8-7
Copy Function.....	8-7
Valve Outlet	8-7
Series Connections.....	8-7
Counterpressure/Backpressure Valve.....	8-8
Internal Pilot Pressure Supply.....	8-8
Valve Section	8-9
Load Holding Check Valve.....	8-10
Check Valve Gauge Port	8-11
Check Valve Restrictor/Orifice	8-11
Lift/Feed Brake	8-11
Pressure Reducing Valve.....	8-12

Port Relief and Anti-Cavitation Valves	8-12
Additional Actuator Port Accessories	8-13
Pressure Compensator	8-14
Load-Sensing Signal System	8-14
Spools	8-15
Spool Nomenclature.....	8-15
Spool Center Position	8-16
Pressure Compensation	8-16
Spool Leakage.....	8-17
Spool Overlap	8-17
Spool Configuration.....	8-18
Spool Type D	8-19
Spool Type Dm	8-19
Spool Type Da.....	8-19
Spool Type Db	8-20
Spool Type S.....	8-20
Spool Type M.....	8-20
Spool Type F.....	8-20
Spool Type R.....	8-20
Spool Type DQ.....	8-20
Spool Nomenclature.....	8-20
Spool Selection	8-20
Spool Actuators.....	8-21
Mechanical Actuators.....	8-22
Manual Actuators	8-22
Pilot Operated Spools	8-23
Pneumatic Pilot Control	8-23
Hydraulic Pilot Control	8-23
Solenoid Operated, On-Off Control	8-24
Electrohydraulic, Proportional Pilot Control	8-24
Electrohydraulic Directional Flow Control Valves.....	8-25
Proportional vs. Servo	8-26
Response	8-26
Spool center Condition	8-26
Hysteresis, Repeatability, Tthreshold	8-27
Filtration Requirements	8-27
Proportional Valve Construction	8-27
How a Direct Operated Proportional Solenoid Directional Valve Works	8-28
How a Pilot Operated Proportional Solenoid Controlled Directional Valve Works	8-28
A Pressure Differential Proportional Directional Valve (Torque Motor Pilot)	8-29
1st Stage Pilot Valve Consists Of	8-29
2nd Stage or Main Stage Consists Of	8-29
How the Pilot Valve Works	8-29
How the Main Valve Works	8-30
Force Feedback	8-30
What a Mobile Servo Valve Consists Of	8-30
Types of First Stages	8-31
Types of 2nd Stage Spool Designs	8-31
Line-On-Line Condition	8-31
Underlapped Condition	8-31
Overlapped Condition	8-31
How a Servo Valve Works	8-32
Support Electronics for Electrohydraulic Systems	8-32
Overload Protection Device.....	8-34
Parallel and Series Circuits	
Multiple-Spool Circuits	8-34
Parallel or Series Circuits	8-34

Parallel–Parallel Circuits	8-34
Series–parallel circuits	8-35
Series-Series Circuit.....	8-36
Comparing Standard Mobile Hydraulic Systems	8-36
CF Constant Flow System	8-37
Operating Characteristics.....	8-38
Applications	8-39
CP Constant Pressure System	8-39
CPU Constant Pressure, Unloaded System.....	8-40
Operating Characteristics.....	8-40
Applications	8-40
LS Load Sensing System	8-41
Operating Characteristics	8-42
Applications	8-42
Power Loss.....	8-43
CF Constant Flow System	8-43
CP Constant Pressure Systems.....	8-43
LS Load Sensing Systems.....	8-43
Chapter 8 Exercise	8-44

Chapter 9 Remote Controls in Mobile Hydraulic Systems 9-1

Introduction.....	9-1
Characteristics of Direct Control	9-1
Characteristics of Remote Control.....	9-2
Different Means of Remote Control	9-2
Spool Actuators.....	9-2
Open Spool Actuators	9-2
Closed Spool Actuators.....	9-3
Pilot Pressure	9-3
Hydraulic Remote Control.....	9-3
Proportional Hydraulic Lever Unit	9-3
Function	9-4
Pneumatic Remote Control.....	9-4
Electropneumatic ON/OFF Control.....	9-4
Proportional Pneumatic Lever Unit	9-4
Electrohydraulic Remote Control	9-5
Direct Control by Coordinate-lever Units (Joysticks)	9-5
Indirect Control by Coordinate-lever Units (Joysticks).....	9-5
Dual Mode Operation	9-6
Single ModeOperation	9-6
Contactless Levers	9-6
Cab Design Eergonomics.....	9-7
Facts About Ergonomics	9-7
Current Feedback Amplifiers	9-8
Start and Final Current.....	9-8
Hysteresis.....	9-9
Ramps	9-9
Proportional Solenoids.....	9-9
Communication.....	9-9
Analog/Analogue Transmission.....	9-9
Digital Transmission.....	9-10
Communication Buses	9-11
Machine Concept.....	9-11
Functions.....	9-11
Sensors	9-11
Modular Design	9-11

Master Control Unit	9-12
Interactive Display	9-12
Expansion Units	9-12
Communication with the System	9-12
Typical Functions - Engine Control	9-13
Transmission Control	9-13
Temperature Control	9-13
Crane Control	9-13
Chapter 9 Exercise Petroleum base hydraulic fluids	10-1

Chapter 10 Fluids - Introduction..... 10-1

Lubrication	10-1
Friction	10-1
Fluid film	10-2
Lubricity	10-2
Viscosity affects a system	10-2
Liquid molecules	10-3
Viscosity	10-3
Viscosity affected by temperature	10-3
Centistoke	10-3
Saybolt universal second	10-3
Viscosity affected by pressure	10-4
Viscosity affects heat generation	10-4
Viscosity affects lubricity.....	10-4
Viscosity affects hydrodynamic lubrication	10-4
Viscosity affects clearance flow	10-5
Viscosity index	10-6
Oil operating range	10-6
Pour point.....	10-7
Oil problems and additives	10-7
High pressure lubrication.....	10-7
Antiwear additives	10-8
Check for high pressure lubrication	10-8
Oil oxidation	10-8
Check for oxidized oil.....	10-10
Water in hydraulic oil.....	10-10
Check for water in hydraulic oil	10-10
Rusting and corrosion	10-10
Rust and oxidation inhibitors	10-11
Foaming	10-11
Anti-foam additives	10-11
Check for foaming	10-11
Dirt in the oil.....	10-12
Check for dirt in the oil.....	10-12
Hydraulic oil maintenance considerations	10-12
Cleaning wire mesh filter elements.....	10-13
Fire resistant hydraulic fluids.....	10-14
Fire resistance determined	10-14
Flash point.....	10-15
Fire point.....	10-15
Auto ignition temperature	10-15
Types of fire resistant fluid.....	10-15
Water base fluid.....	10-15
Water-oil emulsion.....	10-15
Soluble oil fluid.....	10-15
Invert emulsion	10-16
Viscosity of water-oil emulsions.....	10-16

Problems with an invert emulsion.....	10-17
Phase separation.....	10-17
Check for phase separation.....	10-17
Bacteria formation.....	10-17
Check for bacteria formation.....	10-17
Water glycol.....	10-17
Comparing invert emulsion with water glycol.....	10-18
Problems with water base fluids.....	10-18
Lubricity of water base fluids.....	10-18
Water evaporation.....	10-18
Synthetic fire resistant fluid.....	10-19
Comparing water base with synthetic fire resistant fluid.....	10-19
Problems with fire resistant fluids.....	10-20
Compatibility with fire resistant fluids.....	10-20
Foaming and air retention with fire resistant fluids.....	10-20
Dirt retention with fire resistant fluids.....	10-21
Maintenance considerations.....	10-21
Biodegradable Hydraulic Fluids.....	10-21
Vegetable Based Oils.....	10-22
Ester Based Fluids.....	10-23
Polyglycol Fluids (Polyalkylenglykols).....	10-25
Mixtures.....	10-25
Associated Costs.....	10-25
Water as a Hydraulic Fluid.....	10-26
Dissolved Air.....	10-26
Liquid Vapor Pressure.....	10-27
Viscosity.....	10-27
Water Properties.....	10-27
Conclusion.....	10-28
References.....	10-28
Chapter 10 exercises.....	10-28

Chapter 11 Hydraulic Filters 11-1

Dirt Interferes with Hydraulic Fluid.....	11-1
Dirt Is Pollution.....	11-2
Contamination Types and Sources.....	11-2
Water Contamination.....	11-2
Prevention.....	11-4
Absorption.....	11-4
Centrifugation.....	11-4
Vacuum Dehydration.....	11-4
The Micrometre Scale.....	11-4
Limit of Visibility.....	11-4
Determination of Fluid Cleanliness.....	11-4
Particle Counting.....	11-5
Component Cleanliness Level Requirements.....	11-5
Filter Elements.....	11-6
Depth Type Elements.....	11-6
Pore Size in Depth Type Elements.....	11-6
Nominal Rating.....	11-7
Filter Media Types and Ratings.....	11-7
The Multipass Test.....	11-7
β ratio.....	11-7
Surface Type Elements.....	11-8
Pore Size in Surface Type Elements.....	11-8
Absolute Rating.....	11-8

Filter ratings in Practice	11-9
Sources of Dirt	11-9
Dirt Built into a System	11-9
Dirt Generated Within a System	11-9
Dirt Added to a System	11-10
Type of Filtration by Flow	11-10
Proportional Flow Filtration	11-10
Full flow Filtration	11-11
Type of Filtration by Position in a System	11-11
Sump Strainer	11-11
Suction Filter	11-11
Pressure Filter	11-12
Return Line Filter	11-12
Filter Bypass Valve	11-12
What a Bypass Valve Consists Of	11-12
How a Bypass Valve Works	11-12
Filter Indicator	11-13
What a Filter Indicator Consists Of	11-13
How a Filter Indicator Works	11-13
Filters Must be Maintained	11-13
Chapter 11 Exercise Filters	11-14

Chapter 12 Fluid Conductors 12-1

Introduction.....	12-1
Leakage Must be Eliminated in Hydraulic Systems.....	12-1
Reasons for Leakage.....	12-1
System Design: Component Selection-Fitting Style	12-1
37° Flare (for Metric or Inch Tubing).....	12-1
Flareless (for Inch Tubing).....	12-2
Multiple Bite Flareless (for Metric Tubing).....	12-2
Face Seal with O-ring (for Metric or Inch Tubing)	12-2
Pipe Thread Port Connections	12-2
Straight Thread with O-ring (Inch and Metric Threads)	12-2
Four-bolt Split Flange	12-3
Component Selection - Tube Type	12-3
Component Interchangeability	12-3
System Design - Routing	12-3
Avoid Excessive Strain	12-3
Use Proper Clamping	12-3
Allow for Movement Under Load	12-4
Component Quality - Fitting Quality	12-4
Tubing Quality	12-4
Mating Ports Quality	12-5
Installation – Tube Bends	12-5
Tube Cutting	12-5
Tube Flaring	12-5
Under- and Overflaring	12-5
Flareless Preset	12-6
Improper Flareless Preset	12-6
Face Seal Brazing	12-6
Improper Brazing	12-6
Assembly of Tube to 37° Flare Fitting –	12-6
The Torque Method	12-6
Assembly of Mixed Platings on 37° Flare Fittings	12-7
Assembly of Tube to 37° Flared Fitting -	12-7
The ‘Flats From Finger Tight’ Method	12-7

Flats From Finger Tight (FFFT) table	12-8
Torque and FFFT Methods Compared	12-8
Assembly of a Flareless Fitting	12-8
Assembly of a Face Seal Fitting	12-8
Assembly of a Pipe Thread Fitting to a Port	12-8
Assembly of a Straight Thread Fitting to a Port	12-8
Assembly of an Adjustable Straight Thread Fitting	12-9
Pinched O-rings	12-9
Assembly of a 4-bolt Split Flange Fitting	12-9
4-bolt Split Flange Torque	12-9
Troubleshooting Fitting Failures	12-9
Abuse Failures	12-9
Recommendations for a Leak-Free System	12-10
Quick Couplings	12-10
Single Shut-off.....	12-10
Double Shut-off.....	12-10
Straight-thru	12-11
Coupling Materials.....	12-11
Steel, Carbon Alloy.....	12-11
Brass.....	12-11
Stainless Steel	12-11
Coupling Seal Material	12-11
Fluorocarbon Rubber (FPM)	12-11
Nitrile or Buna N (nbr)	12-11
Ethylene Propylene Rubber (EPM)	12-11
Chloroprene Rubber (CR).....	12-11
Coupling Selection.....	12-11
System Pressure and Pressure Surges	12-11
Flow Requirements	12-12
System Media and Temperature.....	12-12
Environmental and Functional Considerations	12-12
Hose Selection Considerations	12-12
Ambient Temperatures	12-12
Bend Radius.....	12-12
Burst Pressure	12-12
Chemical Resistance	12-12
Electrical Conductivity	12-12
Line Size	12-13
Operating (Working) Pressure	12-13
Operating Temperatures.....	12-13
Pressure Surges	12-13
Hose Guards.....	12-13
Hose Application Considerations.....	12-14
Pressure Effects.....	12-14
Swivel Adapters	12-14
Hose Failure.....	12-14
Vacuum Requirements	12-15
Hose Installation Guidelines.....	12-15
Basic Hose Construction.....	12-16
Hose Construction Summary	12-17
Hose Fitting Types	12-18

Chapter 13 Steering Hydraulic Systems and Accumulators..... 13-1

Steering Pump - Gear.....	13-1
Built-in Relief and Flow Divider	13-1
(Return to Inlet).....	13-1

Built In Relief and Flow Divider	13-2
(Return to Tank)	13-2
Built In Relief and Flow Divider	13-2
(Return to Inlet and Secondary Flow to Inlet)	13-2
Priority Flow Divider	13-2
Flow Divider Performance	13-2
What a Built In Relief Valve Consists Of	13-3
“Two Line” Power Steering Pump Circuit	13-3
“Three Line” Power Steering Pump Circuit	13-4
Steering circuits	13-4
Rotor Set Operation in the Metering Element	13-4
Steering Valve Operation Neutral Position	13-5
Steering Valve Operation Right Turn	13-5
Manual Steering Operation - No System Pressure	13-5
Open Center, Non-reversing System	13-5
Open Center, Reversing System	13-6
Open Center, Power Beyond Steering System	13-6
Open Center, Demand System	13-6
Closed Center, Non-reversing Steering System	13-7
Closed Center System with Steering Priority Valve	13-7
Open Center, Demand System	13-7
Closed Center, Load Sense Steering System	13-7
Accumulator in the Steering System	13-8
Piston Type Accumulator	13-8
Bladder Type Accumulator	13-8
Accumulators in a Circuit	13-8
Developing Flow	13-8
Precharge Pressure	13-9
Precharge Affects Shock Absorber Operation	13-9
Losing Gas Precharge Pressure	13-9
Checking Gas Precharge	13-9
Chapter 13 exercise Steering systems	13-11

Chapter 14 Reservoirs and Coolers..... 14-1

Hydraulic Reservoirs	14-1
What a Hydraulic Reservoir Consists Of	14-1
How a Reservoir Works	14-1
Coolers	14-2
Air Cooler	14-2
Water Cooler	14-2
Coolers in a Circuit	14-2
Mechanical Forces on the Reservoir	14-3
Filler/Breather Cap	14-3
Additional Reservoir Accessories	14-4
Integral Reservoirs	14-4
Chapter 14 Exercise Reservoirs and Coolers	14-5

Chapter 15 What is a Power Take-Off? 15-1

PTO Operation	15-3
Specifying a PTO	15-4
Installation and Conversion of PTO's	15-6
Installing a Sidemount PTO	15-8
Installation of Countershaft PTO's	15-10
PTO Driveshaft	15-11
PTO Conversion	15-11
PTO Troubleshooting	15-12

Glossary of Power Take-Off Terms	15-16
Chapter 15 Exercise What is a Power Take-off?.....	15-18

Appendix B - Applications..... App. B-1

Application - Excavator	App. B-1
Function description.....	App. B-1
Application - Forestry.....	App. B-3
Full-tree harvesting	App. B-3
Cut-to-length harvesting	App. B-4
Application - Mining.....	App. B-6
Construction work.....	App. B-6
Main functions	App. B-6
Function description.....	App. B-7
Application - Refuse collecting vehicle.....	App. B-8
Rear end loader	App. B-8
Compaction	App. B-8
Discharging	App. B-9
Hydraulic system	App. B-9
Control system	App. B-9
Hydraulic functions.....	App. B-9
Hopper door function.....	App. B-10
Ejecting function.....	App. B-10
Sweeping function	App. B-11
Packing function	App. B-11
Application - Truck Crane	App. B-12
Functions	App. B-12
Crane.....	App. B-12
Swing	App. B-12
Main boom.....	App. B-13
Second boom.....	App. B-13
Telescope.....	App. B-13
Winch	App. B-13
Support legs	App. B-13
Special functions.....	App. B-13
Emergency stop.....	App. B-13
Counterbalance valve	App. B-13
Leakage grooves	App. B-13
Speed reduction.....	App. B-13
Overload protection	App. B-13
Shock valve	App. B-14
Directional control valve selection and installation.....	App. B-14
Application Wheel loader	App. B-15
Compact loaders.....	App. B-15
Midsized loaders	App. B-15
Large loaders.....	App. B-16
Boom function	App. B-16
Boom suspension	App. B-17
Bucket	App. B-17
Auxiliary functions	App. B-17
Valve control system	App. B-17
Steering	App. B-17
Hydrodynamic transmission.....	App. B-17
Hydrostatic transmission.....	App. B-17

Appendix C Hydraulic Fluid Filter Selection..... App. C-1

Lubrication and Wear.....	App. C-1
---------------------------	----------

Effects of Particle Generated Wear and Interference	App. C-1
Economic Consequences of Downtime	App. C-2
Filter Selection Considerations	App. C-3
Pump Protection	App. C-3
High Pressure Components	App. C-4
Other Options	App. C-5
Fluid Compatibility	App. C-6
Media and Element Construction.....	App. C-6
Pressure Rating	App. C-7
Filter Assembly Selection Procedures	App. C-7
Chapter Summary	App. C-9

