

## ***TABLE OF CONTENTS***

|  |     |
|--|-----|
| <b><i>ACKNOWLEDGEMENTS</i></b> .....                     | I   |
| <b><i>FOREWORD</i></b> .....                             | III |
| <b><i>INTRODUCTION</i></b> .....                         | 1   |
| Brief history .....                                      | 2   |
| FIELDS OF APPLICATION OF OIL HYDRAULICS .....            | 3   |
| STANDARDS .....  | 4   |
| BASIC HYDRAULIC CIRCUIT .....                            | 5   |
| <b>Chapter 1 - <i>PRINCIPLES OF HYDRAULICS</i></b> ..... | 9   |
| UNITS OF MEASUREMENT .....                               | 9   |
| Mass per volume .....                                    | 10  |
| Speed .....  | 10  |
| Acceleration .....                                       | 10  |
| Gravity acceleration .....                               | 10  |
| Force .....  | 11  |
| Torque/Twisting moment .....                             | 11  |
| Work and Energy .....                                    | 11  |
| Power .....  | 11  |
| Frequency .....  | 12  |

|   |    |
|---|----|
| Rotation frequency .....                              | 12 |
| Heat .....  | 12 |
| Pressure .....  | 12 |
| British and US measurement units .....                | 13 |
| <br>  |    |
| ELEMENTS OF HYDROSTATICS .....                        | 14 |
| Pressure .....  | 14 |
| Pascal's Principle .....                              | 21 |
| Hydraulic press .....                                 | 23 |
| Compression of a perfect gas .....                    | 27 |
| <br>  |    |
| ELEMENTS OF HYDRODYNAMICS .....                       | 28 |
| Flow .....  | 28 |
| Forms of energy in a fluid .....                      | 29 |
| Bernoulli's Principle .....                           | 31 |
| Bernoulli's Principle in oil hydraulics .....         | 32 |
| Torricelli's Principle .....                          | 34 |
| Laminar and turbulent flow .....                      | 36 |
| Internal resistances .....                            | 37 |
| Widespread pressure drops .....                       | 38 |
| Localised pressure drops .....                        | 39 |
| Fluid hammer .....                                    | 40 |
| <br>  |    |
| <b>Chapter 2 - <i>HYDRAULIC FLUIDS</i></b> .....      | 41 |
| <br>  |    |
| PROPERTIES OF HYDRAULIC FLUIDS .....                  | 42 |
| Viscosity .....                                       | 42 |
| Viscosity Index .....                                 | 46 |
| Viscosity Grade standards .....                       | 47 |
| Influence of viscosity in oil hydraulic systems ..... | 49 |
| Compressibility .....                                 | 49 |
| Inclusion of air and vapours .....                    | 51 |
| Vapour tension .....                                  | 51 |
| Density .....   | 52 |
| Lubricant power .....                                 | 52 |
| Dilation .....  | 54 |
| Antifoaming properties .....                          | 54 |
| Demulsibility .....                                   | 54 |
| Fluid active life .....                               | 54 |

|   |           |
|---|-----------|
| Pour point and Cloud point .....  | 55        |
| Oxidation and rust formation .....  | 55        |
| Fire resistance .....   | 55        |
| <b>HYDRAULIC FLUIDS CLASSIFICATION .....</b>                                    | <b>56</b> |
| Mineral oil .....   | 57        |
| Water .....   | 58        |
| Mixtures with water .....   | 59        |
| Synthetic fluids .....  | 60        |
| Biodegradable vegetable-based oil .....   | 60        |
| Biodegradable synthetic-based oil .....   | 60        |
| Conclusions .....   | 60        |
| <br>  |           |
| <b>Chapter 3 - <i>OIL HYDRAULIC PUMPS – GENERAL</i> .....</b>                   | <b>63</b> |
| <br>  |           |
| <b>INTRODUCTORY REMARKS .....</b>   | <b>63</b> |
| Prime mover .....   | 65        |
| Intermittent operation .....  | 66        |
| Rotodynamic pumps .....   | 66        |
| <br>  |           |
| <b>DISPLACEMENT PUMPS OR VOLUMETRIC PUMPS - CONCEPTS AND<br/>FORMULAS .....</b> | <b>68</b> |
| Key concepts .....  | 69        |
| Working principle of displacement pumps .....                                   | 74        |
| Suction .....   | 76        |
| Compatible viscosity .....  | 79        |
| Cavitation .....  | 80        |
| Delivery .....  | 81        |
| Displacement .....  | 83        |
| Efficiency .....  | 83        |
| Power .....   | 85        |
| USA System .....  | 86        |
| Maximum pressure and flow .....   | 86        |
| Pre-filling .....   | 87        |
| <br>  |           |
| <b>ASSEMBLIES .....</b>   | <b>87</b> |
| Coaxial or multistage pumps .....   | 87        |
| Drive couplings .....   | 89        |
| Bell housings .....   | 91        |
| Vibration dampening .....   | 93        |

|  |     |
|--|-----|
| <b>Chapter 4 - <i>OIL HYDRAULIC PUMPS</i></b> .....  | 95  |
| FIXED DISPLACEMENT PUMPS .....   | 95  |
| Manual lever pumps .....   | 95  |
| External gear pumps .....  | 99  |
| Gerotor pumps .....  | 108 |
| Internal gear pumps .....  | 110 |
| Lobe pumps .....   | 112 |
| Screw pumps .....  | 113 |
| <br>   |     |
| FIXED AND VARIABLE DISPLACEMENT PUMPS .....  | 115 |
| Fixed displacement vane pumps .....  | 115 |
| Variable displacement vane pumps .....   | 124 |
| Piston pumps – Preliminary remarks .....   | 129 |
| Radial piston pumps - Fixed displacement .....   | 131 |
| Radial piston pumps - Variable displacement .....  | 135 |
| Axial piston pumps - Fixed displacement .....  | 135 |
| Axial piston pumps - Variable displacement .....   | 142 |
| Displacement adjustment circuits .....   | 146 |
| Integrated motor pump .....  | 148 |
| <br>   |     |
| <b>Chapter 5 - <i>OIL HYDRAULIC PUMPS – CONTROLS AND FURTHER<br/>IN-DEPTH ANALYSIS</i></b> ..... | 151 |
| <br>   |     |
| DISPLACEMENT ADJUSTMENT .....  | 152 |
| Constant power regulator .....   | 153 |
| Flow stop controller .....   | 154 |
| Other controllers related to flow management .....   | 155 |
| Pressure limiting compensator .....  | 156 |
| Load Sensing pressure limiting compensator .....   | 159 |
| Torque or power summation .....  | 161 |
| Proportional electrohydraulic controls .....   | 164 |
| <br>   |     |
| IN-DEPTH ANALYSES .....  | 166 |
| What pump? .....   | 166 |
| Notes on fixed displacement pumps .....  | 168 |
| Double fixed displacement pumps for high and low flows .....                                     | 172 |
| Three or more fixed displacement coaxial pumps .....   | 174 |
| Multiple pressure circuit .....  | 175 |
| Notes on controls for variable displacement pumps .....  | 176 |

---

|   |     |
|---|-----|
| Remarks on pressure compensators .....                      | 177 |
| Combining controls .....                                    | 179 |
| Factors related to pump duration .....                      | 180 |
| <br>  |     |
| <b>Chapter 6 - <i>LINEAR AND ROTARY ACTUATORS</i></b> ..... | 183 |
| <br>  |     |
| PRINCIPLES .....  | 183 |
| Operating principle .....                                   | 184 |
| Dimensioning .....  | 186 |
| <br>  |     |
| SINGLE-ACTING CYLINDERS .....                               | 189 |
| Ram cylinder .....  | 189 |
| Extending or retracting cylinders .....                     | 191 |
| Spring return cylinders .....                               | 191 |
| Telescopic cylinder .....                                   | 193 |
| <br>  |     |
| DOUBLE-ACTING CYLINDERS .....                               | 195 |
| Differential cylinder .....                                 | 195 |
| Double rod cylinder .....                                   | 197 |
| Tandem cylinder .....                                       | 199 |
| Multi-position linear actuators .....                       | 200 |
| <br>  |     |
| PARTS OF A CYLINDER .....                                   | 201 |
| Materials and assembly .....                                | 202 |
| Rod cartridge .....   | 203 |
| Air bleed .....   | 204 |
| Cushion .....   | 206 |
| Piston .....  | 208 |
| <br>  |     |
| ADDITIONAL COMPONENTS .....                                 | 209 |
| Stroke limiting stop tube .....                             | 209 |
| Stroke limiting stop valve .....                            | 210 |
| Pilot-controlled check cartridge valve .....                | 211 |
| Cylinders fastening .....                                   | 212 |
| Hydraulic fittings .....                                    | 213 |
| <br>  |     |
| CHOOSING THE ROD .....                                      | 214 |
| Combined bending and compressive stress .....               | 215 |
| Rod dimensioning .....                                      | 215 |

|  |            |
|--|------------|
| POSITION DETECTION .....                             | 217        |
| Electromechanical limit switches .....               | 218        |
| Magnetic Reed sensors .....                          | 219        |
| Proximity switches .....                             | 220        |
| Virtual or actual detection .....                    | 221        |
| Servocylinder .....                                  | 221        |
| <br>   |            |
| ISO STANDARDS FOR CYLINDERS .....                    | 223        |
| The ISO 6020 standard .....                          | 223        |
| The ISO 6022 standard .....                          | 224        |
| <br>   |            |
| SPECIAL ACTUATORS .....                              | 225        |
| Pressure intensifier .....                           | 225        |
| Decelerators .....                                   | 227        |
| Collection devices .....                             | 228        |
| <br>   |            |
| ROTARY ACTUATORS .....                               | 228        |
| Simple vane .....                                    | 228        |
| Double vane .....                                    | 229        |
| Rack cylinder .....                                  | 230        |
| Torque actuator .....                                | 230        |
| <br>   |            |
| <b>Chapter 7 - OIL HYDRAULIC MOTORS .....</b>        | <b>233</b> |
| <br>   |            |
| BASICS .....   | 233        |
| Operating principle .....                            | 233        |
| Dimensioning .....                                   | 234        |
| General features .....                               | 235        |
| <br>   |            |
| HIGH-SPEED LOW-TORQUE MOTORS .....                   | 236        |
| External gear motors .....                           | 236        |
| Direct drive Gerotor motors .....                    | 238        |
| Vane motors .....                                    | 239        |
| In-line piston motors .....                          | 240        |
| Bent axis piston motors .....                        | 242        |
| Axial piston motors with variable displacement ..... | 242        |
| <br>   |            |
| ORBITAL MOTORS .....                                 | 244        |
| Operation .....                                      | 244        |

|  |     |
|--|-----|
| Roller .....   | 246 |
| Features .....   | 247 |
| Shapes and applications .....                          | 248 |
| <br>   |     |
| LOW-SPEED HIGH-TORQUE MOTORS .....                     | 250 |
| Cam-type radial piston motor .....                     | 250 |
| Crankshaft radial piston motors .....                  | 251 |
| Fluid column radial piston motors .....                | 254 |
| Radial piston motors with dual displacement .....      | 256 |
| <br>   |     |
| PUMP – MOTOR COMBINATIONS .....                        | 257 |
| <br>   |     |
| <b>Chapter 8 - <i>DIRECTIONAL VALVES</i></b> .....     | 261 |
| <br>   |     |
| DEFINITION OF DIRECTIONAL VALVES .....                 | 261 |
| Spool .....  | 262 |
| Ports .....  | 262 |
| Positions .....  | 263 |
| Control system .....                                   | 263 |
| Reset system .....                                     | 263 |
| Size .....   | 263 |
| <br>   |     |
| DISTRIBUTION .....                                     | 264 |
| Rotary distributor .....                               | 264 |
| Seat valve .....                                       | 265 |
| Slide valve .....                                      | 266 |
| <br>   |     |
| PATHS AND POSITIONS IN VALVES .....                    | 269 |
| Notes for drawings .....                               | 270 |
| Directional valve 2/2 .....                            | 270 |
| Three-way directional valves .....                     | 271 |
| Four-way directional valves .....                      | 271 |
| Valves with a larger number of ways or positions ..... | 272 |
| Central position .....                                 | 272 |
| Transitory position .....                              | 273 |
| Spool lap condition .....                              | 275 |
| <br>   |     |
| VALVE CONTROL .....                                    | 276 |
| Manual operation .....                                 | 277 |

|  |     |
|--|-----|
| Mechanical operation .....   | 279 |
| Pneumatic operation .....  | 280 |
| Hydraulic operation .....  | 282 |
| <br>   |     |
| SOLENOID VALVES .....  | 282 |
| On/off solenoid .....  | 283 |
| Directly operated solenoid valves .....  | 285 |
| Two-stage (indirectly operated) solenoid valves .....                                | 289 |
| Servo-controlling valves with by-pass centre .....                                   | 291 |
| Standard voltage and current requirement .....                                       | 293 |
| Insulation class .....   | 293 |
| Insertion .....  | 293 |
| Continuous rating .....  | 294 |
| IP Protection Degree .....   | 294 |
| Special structures .....   | 295 |
| <br>   |     |
| DISTINGUISHING TRAITS .....  | 295 |
| Flow/pressure characteristics .....  | 295 |
| Pressure drop .....  | 297 |
| Sizes .....  | 297 |
| Mounting surface .....   | 298 |
| Anomalies .....  | 299 |
| Stack valves or sandwich valves .....  | 299 |
| <br>   |     |
| <b>Chapter 9 - <i>COMPLEMENTARY DIRECTIONAL VALVES,<br/>REMOTE CONTROL</i></b> ..... | 303 |
| <br>   |     |
| NON-RETURN VALVES .....  | 303 |
| Ball or poppet check valve .....   | 303 |
| Spring-loaded ball or poppet check valve .....                                       | 305 |
| Right angle check valve .....  | 305 |
| Restriction check valve .....  | 306 |
| Pilot-to-close operated check valve .....  | 306 |
| Pilot-operated check valve with decompression poppet .....                           | 308 |
| Pilot-to-open operated check valve .....   | 309 |
| Cross-piloted check valve .....  | 310 |
| Automatic shut-off valve .....   | 311 |
| Non-return valve with electric control .....   | 312 |



---

|   |     |
|---|-----|
| OTHER VALVES .....  | 313 |
| Shuttle valve .....   | 313 |
| Deceleration valve .....  | 313 |
| Actuator deceleration .....   | 314 |
| Prefill valve .....   | 317 |
| <br>  |     |
| REMOTE CONTROL .....  | 321 |
| Mechanical remote control .....   | 322 |
| Electrical remote control .....   | 323 |
| Pneumatic remote control .....  | 325 |
| Hydraulic remote control .....  | 326 |
| Radio control .....   | 330 |
| <br>  |     |
| <b>Chapter 10 - <i>PRESSURE CONTROL AND ADJUSTMENT VALVES</i></b> ..... | 331 |
| <br>  |     |
| RELIEF VALVES .....   | 331 |
| Direct-acting relief valve .....  | 332 |
| Spring-loaded piston valve .....  | 335 |
| Pilot-operated relief valve .....                                       | 336 |
| Vent connection .....   | 338 |
| Remote control .....  | 339 |
| Pressure selection .....  | 340 |
| Unloading relief valve .....  | 341 |
| <br>  |     |
| PRESSURE REDUCING VALVES .....  | 342 |
| Direct-acting pressure reducing valve .....                             | 344 |
| Pilot-operated pressure reducing valve .....                            | 345 |
| <br>  |     |
| PRESSURE CONTROL VALVES .....   | 348 |
| Sequence valve .....  | 349 |
| Back pressure valve .....   | 352 |
| Unloading valve for high/low pressure double pump .....                 | 353 |
| Brake valve .....   | 354 |
| <br>  |     |
| COUNTERBALANCE OR OVERCENTRE VALVES .....                               | 355 |
| Counterbalance valve .....  | 356 |
| Motor counterbalance valves .....                                       | 358 |

|   |         |
|---|---------|
| <b>Chapter 11 - <i>FLOW CONTROL VALVES</i></b> .....                  | 359     |
| RESTRICTOR VALVES .....   | 359     |
| Restrictors .....   | 361     |
| Adjustable two-way restrictor valves .....                            | 361     |
| Throttle check valve .....  | 362     |
| SPEED CONTROL WITH RESTRICTORS .....                                  | 364     |
| Meter-In .....  | 364     |
| Meter-Out .....   | 366     |
| Bleed-Off .....   | 368     |
| COMPENSATED FLOW CONTROL VALVES .....                                 | 370     |
| Restrictor-type pressure compensated flow control valve .....         | 371     |
| Pressure and temperature compensated two-way flow control valve ..... | 372     |
| By-pass type flow control valve with relief port to reservoir .....   | 373     |
| Electrical control of flow control valves .....                       | 376     |
| SYNCHRONISATION OF TWO OR MORE ACTUATORS .....                        | 377     |
| Simple synchronisation circuits .....                                 | 378     |
| Flow division .....   | 379     |
| Spool flow dividers .....   | 381     |
| Gear flow dividers .....  | 382     |
| Phase correction valves for flow dividers .....                       | 384     |
| <br><b>Chapter 12 - <i>CARTRIDGE VALVES</i></b> .....                 | <br>385 |
| MANIFOLD .....  | 385     |
| Assembly .....  | 385     |
| Mono-block structure .....  | 388     |
| Operational issues .....  | 389     |
| Insertion cavities .....  | 390     |
| SCREW-IN CARTRIDGE VALVES .....                                       | 391     |
| Cavities .....  | 392     |
| Cavities preparation .....  | 393     |
| Auxiliary directional seal valves .....                               | 394     |
| Spool directional valves with hydraulic control .....                 | 397     |
| Shuttle valve for closed circuits .....                               | 398     |

|   |     |
|---|-----|
| Solenoid seal valves .....                    | 400 |
| Solenoid spool valves .....                   | 404 |
| Relief and pressure control valves .....      | 409 |
| Counterbalance or overcentre valves .....     | 414 |
| Double-acting counterbalance valves .....     | 415 |
| Pressure-reducing valves .....                | 418 |
| Flow control .....                            | 420 |
| Other screw-in cartridges .....               | 423 |
| <br>  |     |
| SLIP-IN CARTRIDGE VALVES .....                | 424 |
| Size .....                                    | 425 |
| Cavities and slip-in .....                    | 425 |
| Cartridge .....                               | 426 |
| Directional control .....                     | 428 |
| Pressure control .....                        | 431 |
| Flow control .....                            | 432 |
| <br>  |     |
| <b>Chapter 13 - FLUID CONTAMINATION</b> ..... | 435 |
| <br>  |     |
| CONTAMINATION AND RELATED EFFECTS .....       | 436 |
| Sources of contamination .....                | 436 |
| Genesis and nature of the contaminant .....   | 436 |
| Effects on the system .....                   | 438 |
| Particle size definition .....                | 439 |
| Critical tolerance .....                      | 440 |
| Typical failures .....                        | 441 |
| <br>  |     |
| ANALYTICAL METHODOLOGIES .....                | 443 |
| International fluid analysis standards .....  | 443 |
| Testing powders .....                         | 444 |
| Contamination level codification .....        | 446 |
| Particle counting .....                       | 448 |
| Laser diode optical sensors .....             | 449 |
| <br>  |     |
| FILTRATION TECHNIQUE .....                    | 451 |
| Multi-pass test .....                         | 452 |
| Key features of filters .....                 | 453 |
| Filter selection criteria .....               | 454 |
| Filter element .....                          | 456 |

|  |     |
|--|-----|
| By-pass valve .....                          | 459 |
| Clogging gauge .....                         | 460 |
| Magnetic separation .....                    | 461 |
| Duplex .....                                 | 462 |
| Spin-on .....                                | 462 |
| Self-cleaning filters .....                  | 463 |
| Water removal .....                          | 464 |
| <br>   |     |
| FILTER PLACEMENT .....                       | 465 |
| Suction filters .....                        | 466 |
| Low-Medium-High pressure filters .....       | 468 |
| Return filters .....                         | 469 |
| Filter plugs .....                           | 471 |
| Breathers .....                              | 472 |
| Off-line filtration .....                    | 473 |
| <br>   |     |
| <b>Chapter 14 - ACCUMULATORS</b> .....       | 477 |
| <br>   |     |
| ACCUMULATORS FOR CASUAL USE .....            | 479 |
| Weight loaded accumulators .....             | 479 |
| Spring loaded accumulators .....             | 480 |
| Nitrogen-fluid accumulators .....            | 481 |
| <br>   |     |
| GAS-LOADED ACCUMULATORS WITH SEPARATOR ..... | 481 |
| Why nitrogen? .....                          | 481 |
| Piston accumulators .....                    | 482 |
| Bladder accumulators .....                   | 485 |
| Anti-extrusion valve .....                   | 487 |
| Banks of accumulators .....                  | 488 |
| Diaphragm accumulators .....                 | 490 |
| <br>   |     |
| USES .....                                   | 491 |
| Energy accumulation .....                    | 492 |
| Pulsation dampening .....                    | 494 |
| Fluid hammer absorption .....                | 495 |
| Spring action .....                          | 495 |
| Suspension for vehicles .....                | 496 |
| Fail-safe devices .....                      | 497 |

---

|   |            |
|---|------------|
| Transfer function .....   | 498        |
| Banks of accumulators and additional gas cylinders .....  | 499        |
| <b>DIMENSIONING .....</b>   | <b>500</b> |
| Pressures .....   | 501        |
| Physical correlations .....   | 502        |
| Isothermal transformation .....   | 503        |
| Adiabatic transformation .....  | 503        |
| Mixed transformation .....  | 504        |
| Temperature ranges .....  | 504        |
| Correction coefficient for high pressures .....   | 505        |
| Quick selection tables .....  | 506        |
| <b>ACCESSORIES, INSTALLATION, MAINTENANCE .....</b>   | <b>510</b> |
| Anti-pulsation baffle .....   | 510        |
| Gas pressure relief valve .....   | 510        |
| Safety manifold on the hydraulic fluid side .....   | 511        |
| Rings and shelves .....   | 512        |
| Pre-charge and control apparatus .....  | 513        |
| Bladder replacement .....   | 514        |
| <br>  |            |
| <b>Chapter 15 - <i>MEASUREMENT INSTRUMENTS, TRANSDUCERS<br/>AND PRESSURE SWITCHES</i> .....</b> | <b>517</b> |
| <br>  |            |
| <b>PRESSURE GAUGES .....</b>  | <b>519</b> |
| Piston pressure gauges .....  | 519        |
| Bourdon spring pressure gauges .....  | 520        |
| Diaphragm pressure gauges .....   | 522        |
| Digital pressure gauges .....   | 523        |
| Pressure gauges featuring electrical contacts .....   | 524        |
| Accessories and recommendations .....   | 525        |
| <br>  |            |
| <b>FLOW METERS .....</b>  | <b>528</b> |
| Flow gauges .....   | 528        |
| Flow meters with float .....  | 529        |
| Meters with magnetic ring .....   | 530        |
| Volumetric meters with oval wheels .....  | 531        |
| Turbine meters .....  | 532        |
| Flow switches .....   | 533        |

|  |                |
|--|----------------|
| FLUID LEVEL .....  | 534            |
| Optical minimum and maximum level gauges .....   | 534            |
| Optical level gauges .....   | 535            |
| Level switches with side float .....   | 537            |
| Level switches with vertical float .....   | 538            |
| Level sensors .....  | 539            |
| <br>TEMPERATURE MEASUREMENT AND CONTROL .....  | <br>539        |
| Thermometers .....   | 539            |
| Thermostats .....  | 541            |
| <br>PRESSURE SWITCHES AND PRESSURE TRANSDUCERS .....                                   | <br>542        |
| Single threshold pressure switches .....   | 543            |
| Pressure switches with two or more thresholds .....                                    | 544            |
| Construction options .....   | 544            |
| Pressure transducers .....   | 546            |
| <br><b>Chapter 16 - <i>POWER UNITS, HEAT EXCHANGERS, NOISE, OSCILLATIONS</i></b> ..... | <br><b>549</b> |
| <br>HYDRAULIC POWER UNITS .....  | <br>549        |
| Standard design power units .....  | 550            |
| The exception of self-propelled machines .....   | 553            |
| Mini-units .....   | 553            |
| <br>TANKS .....  | <br>554        |
| Standard structure .....   | 555            |
| Forced de-aeration .....   | 556            |
| Notes on piping .....  | 556            |
| Accessories .....  | 557            |
| Volume .....   | 558            |
| Contaminant purification .....   | 559            |
| Pressurisation .....   | 560            |
| Tank positioning in self-propelled machines .....                                      | 561            |
| Electrical preheating .....  | 561            |
| <br>HEAT EXCHANGERS .....  | <br>562        |
| Heat induced by pressure drops .....   | 562            |
| General information on heat exchangers .....   | 563            |

|   |     |
|---|-----|
| Types and specific uses .....   | 564 |
| Dimensioning .....  | 565 |
| Water-Oil shell and tube exchangers .....   | 568 |
| Water-Oil plate exchangers .....  | 571 |
| Air-Oil exchangers .....  | 572 |
| External (out-plant) heat exchangers .....  | 576 |
| Installation and maintenance .....  | 576 |
| <br>  |     |
| NOISE .....   | 577 |
| Definition and calculation .....  | 578 |
| Noise in oil hydraulic systems .....  | 579 |
| Power units .....   | 580 |
| Valves .....  | 584 |
| <br>  |     |
| HYDRAULIC OSCILLATION .....   | 586 |
| <br>  |     |
| <b>Chapter 17 - <i>GENERAL INFORMATION ON CLOSED AND OPEN CIRCUITS,<br/>REGENERATION, LOAD SENSING, EC DIRECTIVES</i></b> ..... | 591 |
| <br>  |     |
| OPEN CIRCUITS .....   | 591 |
| Series and parallel-connected actuators .....   | 591 |
| Other automations for actuators .....   | 594 |
| Diagram layout method .....   | 595 |
| Motors in open circuits .....   | 600 |
| <br>  |     |
| CLOSED CIRCUITS .....   | 603 |
| Closed circuits for linear actuators .....  | 603 |
| Closed circuits for hydraulic motors .....  | 604 |
| Variable speed drive units .....  | 608 |
| <br>  |     |
| REGENERATION CIRCUITS .....   | 611 |
| Dimensioning .....  | 612 |
| Directional valves for regeneration circuits .....  | 613 |
| Regeneration circuits with slow/fast automatic progression .....  | 614 |
| <br>  |     |
| LOAD SENSING .....  | 616 |
| General .....   | 616 |
| LS distributors .....   | 618 |

|   |            |
|---|------------|
| EUROPEAN DIRECTIVES ON OIL HYDRAULICS .....                     | 623        |
| Machinery Directive (98/37/EC) – PED (97/23/EC) .....           | 624        |
| EMC Directive (2004/108/EC) and LV Directive (2006/95/EC) ..... | 624        |
| ATEX Directive (94/9/EC) .....                                  | 625        |
| <br>  |            |
| <b>Chapter 18 - <i>SEALS, TUBES, CONNECTORS</i></b> .....       | <b>627</b> |
| <br>  |            |
| SEALS .....   | 628        |
| Physical specifications .....                                   | 629        |
| Materials .....   | 630        |
| Seal shapes and seats .....                                     | 631        |
| Assembly .....  | 642        |
| <br>  |            |
| TUBES .....   | 643        |
| Dimensioning .....  | 644        |
| Rigid pipes .....   | 644        |
| Hoses .....   | 646        |
| <br>  |            |
| CONNECTORS .....  | 650        |
| Connectors for pipes .....                                      | 652        |
| Connectors for hoses .....                                      | 654        |
| Swivel joints .....   | 657        |
| Rotary joints .....   | 657        |
| Quick release couplings .....                                   | 658        |
| <br>  |            |
| <b>Chapter 19 - <i>PROPORTIONAL ELECTROHYDRAULICS</i></b> ..... | <b>667</b> |
| <br>  |            |
| ELECTROPROPORTIONAL TECHNIQUE .....                             | 668        |
| General information on directional and control valves .....     | 668        |
| Open loop, closed loop and feedback .....                       | 669        |
| Examples of application .....                                   | 672        |
| The Electrical Control Unit (ECU) .....                         | 673        |
| Derivative and integral control signal .....                    | 679        |
| Notes on loops .....  | 681        |
| Notes on overall gain .....                                     | 682        |
| Indirect feedback .....   | 684        |
| Complex systems management .....                                | 686        |



|  |            |
|--|------------|
| Fieldbus .....   | 688        |
| Adjustment, start, fail-safe potentiometer .....                     | 689        |
| <b>FEEDBACK TRANSDUCERS .....</b>                                    | <b>690</b> |
| Linear potentiometer .....   | 690        |
| Linear Variable Differential Transformer (LVDT) .....                | 691        |
| Magnetostrictive .....   | 692        |
| Rotary Variable Differential Transformer (RVDT) .....                | 693        |
| Encoder .....  | 693        |
| Tachogenerator .....   | 694        |
| <b>PROPORTIONAL SOLENOID VALVES .....</b>                            | <b>694</b> |
| Proportional solenoid .....  | 694        |
| Pressure limitation .....  | 696        |
| Pressure reduction .....   | 701        |
| Flow control .....   | 703        |
| Spool valves for direction and flow control .....                    | 705        |
| Cartridge versions .....   | 710        |
| <b>SERVO-VALVES .....</b>  | <b>711</b> |
| General data on servo-valves .....                                   | 713        |
| Single-stage mechanical servo-valves .....                           | 715        |
| Servo-valves with tracking bush .....                                | 716        |
| Flapper/nozzle .....   | 718        |
| Jet/pipe .....   | 720        |
| <b>Chapter 20 - <i>MOVEMENT OF SELF-PROPELLED MACHINES</i> .....</b> | <b>723</b> |
| <b>HYDROSTATIC TRANSMISSION .....</b>                                | <b>723</b> |
| General assembling types .....                                       | 727        |
| Open circuit transmission .....                                      | 732        |
| Closed circuit hydrostatic transmission .....                        | 735        |
| Some examples of hydrostatic closed circuit transmission .....       | 743        |
| General dimensioning of hydrostatic transmission .....               | 748        |
| Power split .....  | 749        |
| <b>ACCESSORY DEVICES .....</b>                                       | <b>754</b> |
| Clutches .....   | 754        |

|   |     |
|---|-----|
| Power shift .....   | 756 |
| Brakes .....  | 757 |
| STEERING .....  | 758 |
| Power steering .....                                      | 758 |
| Hydraulic power steering .....                            | 760 |
| <br>  |     |
| <b>Appendix - <i>MAIN OIL HYDRAULIC SYMBOLS</i></b> ..... | 771 |
| <br>  |     |
| <b><i>BIBLIOGRAPHY</i></b> .....                          | 781 |
| <br>  |     |
| <b><i>TECHNICAL REFERENCE DOCUMENTS</i></b> .....         | 783 |
| <br>  |     |
| <b><i>TABLE OF CONTENTS</i></b> .....                     | 787 |