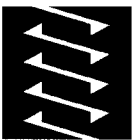


MAHLE GmbH (Ed.)

# Cylinder components

Properties, applications, materials

With 119 figures and 24 tables



**VIEWEG+**  
**TEUBNER**

# Contents

<b>1</b>	<b>Piston rings</b>	<b>1</b>
1.1	Purpose and function of piston rings	1
1.2	Principles of operation	3
1.3	Forces and stresses	4
1.3.1	Forces and temperatures on piston rings	4
1.4	Types of piston rings	7
1.4.1	Rectangular ring	9
1.4.2	Rectangular ring with taper-faced running face	9
1.4.3	Piston ring with top internal bevel or internal step	10
1.4.4	Piston ring with bottom internal bevel or internal step	10
1.4.5	Keystone ring	11
1.4.6	L-shaped piston ring	11
1.4.7	First piston ring with barrel-shaped surface	11
1.4.8	Napier ring with taper-faced running face	12
1.4.9	Ring gap configuration	12
1.4.10	Slotted oil control ring	13
1.4.11	Spring-loaded oil control ring	13
1.4.11.1	Coil spring loaded ring	13
1.4.11.2	Spring-supported oil control ring (expander ring)	15
1.4.12	U-flex-ring	15
1.5	Design details	16
1.5.1	Analysis and simulation	16
1.5.1.1	Numerical analysis	16
1.5.1.2	Stress analysis	16
1.5.1.3	Dynamic analysis	17
1.5.1.4	Conformability	17
1.5.1.5	Specific surface pressure	17
1.5.1.6	Ovality	18
1.5.1.7	Design guidelines	18
1.6	Materials, coatings, and surface treatment	18
1.6.1	Materials	18
1.6.1.1	Cast iron	18
1.6.1.2	Steel	19
1.6.2	Coatings and surface treatments	20
1.6.2.1	Gray cast iron as a base material	20
1.6.2.2	Martensitic nodular cast iron as a base material	21
1.6.2.3	Carbon and stainless steels	22
1.6.2.4	Running face and face coatings	23
1.6.2.5	Nitriding of running faces	24
1.6.2.6	Surface protection	25

<b>2</b>	<b>Piston pins and piston pin circlips</b> .....	27
2.1	Function of the piston pin .....	27
2.2	Requirements .....	28
2.2.1	General .....	28
2.2.2	Strength .....	28
2.2.3	Deformation .....	31
2.2.4	Lubrication, oil supply .....	32
2.2.5	Wear .....	33
2.2.6	Weight .....	33
2.3	Types of piston pins .....	33
2.4	Design .....	35
2.4.1	Dimensioning .....	35
2.4.2	Analysis .....	37
2.4.3	Finite element analysis .....	38
2.4.4	Dimensional and form tolerances, standard .....	40
2.5	Piston pin materials .....	42
2.6	Component testing .....	45
2.6.1	Piston pin test bench .....	45
2.7	Piston pin circlips .....	46
<b>3</b>	<b>Bearings</b> .....	49
3.1	Product range .....	49
3.1.1	Applications .....	49
3.1.2	Types and terminology .....	49
3.2	Design guidelines .....	52
3.2.1	Properties .....	52
3.2.2	Load capacity .....	52
3.2.3	Wear resistance .....	54
3.2.4	Seizure resistance .....	55
3.3	Bearing geometry .....	55
3.3.1	Bearing diameter and width .....	55
3.3.2	Oil grooves and holes .....	56
3.3.3	Bearing clearance .....	56
3.3.4	Bearing and bushing fit .....	57
3.3.4.1	Eccentricity .....	57
3.4	Numerical simulation .....	58
3.4.1	Hydrodynamic lubrication (LOCUS) .....	58
3.4.2	Elasto-hydrodynamic lubrication (EHL) .....	59
3.4.3	Axial bearing simulation (ABAS) .....	60
3.4.4	Overlaps (PRESSFIT) .....	60
3.5	Bearing materials .....	61
3.5.1	Composition and properties of bearing materials .....	62
3.6	Market requirements and technology trends .....	67

<b>4</b>	<b>Connecting rod</b> .....	<b>69</b>
4.1	Introduction .....	69
4.2	Stresses .....	72
4.3	Requirements .....	73
4.3.1	Mass of the connecting rod .....	73
4.4	Crank end .....	74
4.4.1	Cracking (fracture splitting) .....	74
4.4.2	Angle split of the crank end .....	75
4.5	Connecting rod shank .....	76
4.6	Small end .....	76
4.6.1	Pin bearing in the small end .....	76
4.6.2	Geometry of the connecting rod small end .....	77
4.6.3	Bushing-less pin bearing in the small end .....	78
4.7	FE analysis of the connecting rod .....	79
4.7.1	Modeling .....	79
4.7.2	Stresses from assembly .....	80
4.7.2.1	Bolt force .....	80
4.7.2.2	Bushings, bearings, and shrink fit .....	81
4.7.3	Stresses from engine operation .....	81
4.7.3.1	Gas pressure .....	82
4.7.3.2	Inertia force .....	84
4.8	Component testing of the connecting rod .....	86
4.9	Steel grades for forged connecting rods .....	90
4.10	Connecting rod bolted joint .....	91
4.10.1	Requirements for connecting rod bolted joint .....	91
4.10.2	Design and analysis of connecting rod bolted joint .....	91
4.10.3	Shape of the connecting rod bolts .....	92
<b>5</b>	<b>Crankcase and cylinder liners</b> .....	<b>95</b>
5.1	Introduction .....	95
5.1.1	Forces and stresses .....	95
5.1.2	Development goals .....	96
5.2	Types of crankcases .....	96
5.2.1	Methods for reducing noise emissions .....	97
5.2.2	Main bearing seats .....	98
5.2.3	Cooling .....	99
5.3	Crankcase materials .....	100
5.3.1	Cast iron .....	100
5.3.2	Aluminum alloys and material properties .....	100
5.3.2.1	Effects of the casting process on the material properties of aluminum alloys .....	104
5.3.2.2	Effects of heat treatment on the properties of cast aluminum alloys .....	105
5.3.3	Magnesium .....	106
5.3.4	Material trends .....	106

5.3.5	Effects of the casting process on the design of the crankcase .....	106
5.3.5.1	Sand casting .....	106
5.3.5.2	COSCAST™ method .....	107
5.3.5.3	Molding sand—"green sand" .....	107
5.3.5.4	CPS method .....	107
5.3.5.5	Full-mold casting method (lost foam method) .....	108
5.3.5.6	Permanent mold casting .....	108
5.3.5.7	Gravity die casting .....	108
5.3.5.8	Low-pressure die casting .....	108
5.3.5.9	Pressure die casting .....	109
5.3.5.10	Squeeze casting .....	109
5.3.5.11	Semi-solid method.....	109
5.4	Cylinder liners and cylinder surfaces .....	109
5.4.1	Requirements for the cylinder surface .....	109
5.4.2	Cylinder surfaces in aluminum crankcases .....	110
5.4.3	Types of cylinder liners .....	111
5.4.4	Materials for cylinder liners .....	116
5.4.5	Treatment of cylinder surfaces of liners .....	118
5.5	Light-alloy cylinders .....	119
5.5.1	Types of light-alloy cylinders for small engines .....	119
5.5.2	Air-cooled cylinders .....	120
5.5.3	Channel shapes and charge exchange in two-stroke engines .....	121
5.5.4	Cylinders for four-stroke engines .....	124
5.5.5	Bore coatings for light-alloy cylinders .....	124
<b>Glossary</b>	.....	<b>127</b>
<b>Index</b>	.....	<b>129</b>