

Contents

1	Introduction	1
1.1	Issue	3
1.2	Task and Objective of the Work	3
1.3	Structure of the Work	4
2	State of the Art in Research and Technology	7
2.1	Market and Development Situation of Vehicle Transmissions	7
2.2	Torsional Vibration Behavior of Internal Combustion Engines	8
2.3	Requirements and Structure of Vehicle Transmissions in Spur Gear Design	12
2.4	Work on Rattling Noise Behavior of Vehicle Transmissions	14
2.5	Measures to Minimize Rattle Noise from Vehicle Transmissions	18
2.6	Transmission Power Loss	19
3	Gear Rattling Noises from Vehicle Transmissions	21
3.1	Gear Rattling	22
3.2	Synchronizer Ring Rattling	24
3.3	Rattle Noise Analysis of Vehicle Transmissions	27
3.3.1	Test Bench Setup and Test Execution	28
3.3.2	Acoustic Properties of the Soundproof Cabin	33
4	Lubricants as Design Elements	37
4.1	Tasks and Requirement Profile of a Gear Lubricant	37
4.2	Chemical Composition of Gear Oils	38

4.2.1	Mineral Oil Based Base Oils	39
4.2.2	Polyether Oils	39
4.2.3	Synthetic Hydrocarbons	40
4.2.4	Carboxylic Acid Esters	40
4.2.5	Additives	41
4.3	Mechanical Properties of Gear Oils	43
4.3.1	Viscosity	43
4.3.2	Density	44
4.4	Selected Test Procedures for Testing Gear Oils	44
4.4.1	Contact Angle Measurement	44
4.4.2	Mini Traction Machine for Measuring the Coefficient of Friction	50
4.4.3	Flow Behavior under Shear Stress	54
5	Parameter Variation of Base Oils and Additives	57
5.1	Structure of the Manual Transmission for Front-Transverse Drive	57
5.2	Test Procedure	60
5.3	Rattle Noise Investigations	60
5.3.1	Standard Gear Oils, Adhesion Additive and Wetting Agent	60
5.3.2	Gear Oils Based on Polyalkylene Glycols	63
5.3.3	Base Oil Type Variation	65
5.3.4	Variation of VI Improvers	66
5.3.5	Different Concentrations of Dispersant PAMA	67
5.3.6	Various VI Improvers in High Concentration	69
5.3.7	Formulations with Ester Oils	71
5.3.8	Effect of Friction Modifier and Antifoam Agent	72
5.4	Measurement of the Drive-Side Torque Loss	74
5.5	Notes on formulating an optimized gear oil	76
6	Correlation between Oil and Geometric Parameters	77
6.1	Structure of the Single-Stage Test Gearbox	77
6.2	Test Procedure	85
6.3	Gear Rattle Experiments	88
6.3.1	Oil Level Variation	88
6.3.2	Variation of the Oil Sump Temperature	91
6.3.3	Contribution of Synchronizers	94
6.3.4	Influence of a Relative Speed Between Gear Shaft and Idler Gear	95

6.3.5	Influence of the Oil Type with Different Torsional Backlashes	100
6.3.6	Dependence between Axial and Torsional Backlash	103
6.4	Synchronizer Ring Rattling Experiments	106
6.4.1	Variation of Oil Sump Temperature	107
6.4.2	Influence of a Relative Speed between the Synchronizer Hub and Synchronizer Ring	110
6.4.3	Variation of the Clearance between Synchronizer Hub and Synchro-Ring	112
7	Mechanism of Gear Rattling Noise Generation	115
7.1	Rotational Path Deviation Without Torsional Vibration Excitation	115
7.2	Comparison of Straight and Helical Gears	117
7.3	Influence of Torsional Backlash with Helical Idler Gear in the Non-Shifted State	120
7.4	Variation of the Oil Type with Helical Gearing	122
7.5	Summary of the Mechanism of Rattling Noise Generation	128
8	Summary and Outlook	131
	Bibliography	135