

Contents

1	Introduction	1
1.1	Motivation	1
1.2	Aim of this Work	3
2	Fundamentals	4
2.1	State of Science	4
2.1.1	Newton 's Law of Viscosity	4
2.1.2	Molecular Theory of the Viscosity of Low-Density Gases and Liquids	5
2.2	State of the Art	9
2.2.1	Viscometer	9
	Oscillating Body Viscometer	10
	Vibrating Wire and Torsional Crystal Viscometer	11
	Capillary Viscometer	13
	Falling Sphere Viscometer	14
	Falling Cylinder Viscometer	15
2.2.2	Cylinder Shapes in Laminar and Turbulent Flow	23
2.2.3	Continuous Position Measurement in High Pressure	26
2.2.4	Adjoint Solving	30
2.3	Summary of State of the Art & Conclusion for New Development	31
3	Impact Analysis	33
3.1	Analytical Solution for a Falling Body Viscometer	33
3.2	Measurement Error and Accuracy Analysis	39
3.2.1	Flow Regime	41
3.2.2	Eccentricity	41
3.2.3	Tilting	43
3.2.4	End Correction Factor	44

3.2.5	Surface and Dimensions	47
3.3	Potential for Further Development	48
4	Development Process	49
4.1	Requirements	51
4.1.1	Geometry Deviations	52
4.1.2	Acceleration and Tube Length	54
4.2	Application Oriented Material Selection	57
4.2.1	Tube Manufacturing	60
4.3	Falling Body Design	64
4.3.1	Adjoint Solving	64
4.3.2	Selection and Manufacturing	72
4.4	Novel Measurement Principle	75
4.4.1	Resetting	76
4.4.2	Development of an Integrated Electromagnetic Stroke Measurement and Actuation System	77
4.4.3	Achievable Accuracy	80
4.5	Pressure Vessel	82
4.6	Final Design	87
5	Investigative Measurements	89
5.1	Statistical Measurement Planning	89
5.2	Calibration and Proof of Concept of Position Measurement Device	92
5.3	Preliminary Testing	93
5.4	Investigation of Analytical and Experimental Deviation	98
5.4.1	Temperature Influence	98
5.4.2	Shear Rate Dependent Viscosity	101
5.4.3	Eccentricity	103
6	Results	107
6.1	Sinker Behaviour	107
6.2	Measurement Series	114
7	Conclusion and Outlook	122
	Bibliography	124