Contents

1 General Introduction .................................................. 1
   1.1 Introduction of the Cold Rolling Precision Forming Technology .................................. 1
   1.2 Present Situation of Shaft Part Manufacturing Technology .... 3
       1.2.1 Cutting of the Spline Shafts .............................. 4
       1.2.2 Plastic Forming of Spline Shafts ..................... 6
       1.2.3 Manufacturing Methods of Thread Components ..... 13
   1.3 Research Progress on the Cold Rolling Precision Forming Technology of Shaft Parts .......... 16
       1.3.1 The State of the Art on the Manufacturing of Spline Shafts ......................... 16
       1.3.2 Theoretical Researches on the Cold Rolling Forming of Spline Shafts ................. 19
       1.3.3 Surface Modification of the Cold Rolling Forming Spline Shafts .................... 20
       1.3.4 Development Status on Cold Rolling Forming of Threads ................................ 21
   1.4 Development Trends on Cold Rolling Precision Forming Technology of Shaft Parts ............ 23
   References ..................................................................... 25

2 Principle and Mechanical Analysis on the Cold Rolling Precision Forming of Spline ................................ 29
   2.1 Principle and Process on the Cold Rolling Precision Forming of Spline Shafts ................ 29
   2.2 Mechanical Analysis ................................................. 31
   2.3 Analysis on the Cold Rolling Forming Process of the Spline Tooth ......................... 32
       2.3.1 Indexing and Biting Conditions ............................. 32
2.3.2 Rotating Conditions ....................................... 32
2.3.3 Geometrical Indexing Conditions .............................. 35
2.4 Double-Flank Non-backlash Meshing .............................. 37
  2.4.1 Contact Area in the Forming Process ........................ 37
  2.4.2 Position of the Contact Points ............................... 40
2.5 Sliding of the Contact Point ...................................... 44
  2.5.1 Sliding Motion of the Contact Point
       on the Active Tooth Flank .................................. 44
  2.5.2 Sliding Motion of the Contact Point
       on the Driven Tooth Flank .................................. 46
  2.5.3 Metal Flow on the Tooth Surface of the Workpiece ....... 47
2.6 Mechanical Analysis on the Cold Rolling Precision
  2.6.1 Basic Assumption of the Stress Analysis ...................... 48
  2.6.2 Fundamental Plastic Forming Theory of Stress
       Analysis .................................................. 50
  2.6.3 Slip-Line Field and Stress Analysis in the Initial
       Rolling Stage ............................................ 55
  2.6.4 Slip-Line Field and Stress Analysis in the Stable
       Rolling Stage ............................................ 57
2.7 Average Pressure on the Contact Surface During
       the Forming Process ......................................... 60
References ...................................................................... 63

3 Process Parameters in the Cold Rolling Forming of Spline .... 65
  3.1 Contact Area in the Cold Rolling Forming of Spline Shafts ...
      3.1.1 Calculation Model ......................................... 66
      3.1.2 Tooth Profile Equation of the Roller and the
             Workpiece in the Forming Process ...................... 67
      3.1.3 Contact Boundary Conditions .............................. 73
      3.1.4 Calculation of the Contact Area ......................... 74
      3.1.5 Main Algorithm of the Subroutine ....................... 76
  3.2 Rolling Force and Rolling Moment ............................... 85
      3.2.1 Theoretical Calculation of the Rolling Force
             and Rolling Moment ...................................... 85
      3.2.2 Analysis of the Rolling Force and Rolling
             Moment in the Forming Process ......................... 87
  3.3 Calculation of the Cold Rolling Workpiece Billet Diameter ...
      3.3.1 Theoretical Calculation Formulas ......................... 91
      3.3.2 Cross-Sectional Area of a Single Tooth Above
             the Dedendum Circle ................................... 91
      3.3.3 Radius of the Dedendum Transition Arc .................. 94
4 Numerical Simulation on the Cold Rolling Forming of Spline ............................................... 97
   4.1 Establishment of the Finite Element Model and Boundary Conditions .............................. 97
   4.1.1 Finite Element Model .................................. 97
   4.1.2 Simulation Parameters and Constrain Conditions .................................................. 98
   4.2 Numerical Simulation of the Cold Rolling Forming Process .................................. 98
   4.2.1 Plastic Deformation Zone .................................. 98
   4.2.2 Bulge at the End of the Shafts .................................. 99
   4.2.3 Stress and Strain Fields .................................. 101
   4.3 Comparison Between the Theoretical Analysis and Numerical Simulation Results ....................... 104
   4.3.1 Unit Pressure on the Contact Area .................................. 104
   4.3.2 Rolling Force in the Rolling Forming Process .................................. 108

References .................................................................... 109

5 Metal Flow Rules and Forming Quality of Cold Rolling Forming Spline Shaft ..................................... 111
   5.1 Metal Flow Rules of the Tooth in Cold Rolling Precision Forming of Spline Shafts .................. 111
   5.1.1 Workpiece Billet and the Forming Parameters .................................. 111
   5.1.2 Metal Flow Analysis of the Tooth Profile .................................. 112
   5.2 Precision of the Spline Cold Rolling Forming Process .................................. 114
   5.3 Surface Quality of the Cold Rolling Forming Spline Shaft Parts .................................. 116
   5.3.1 Surface Roughness of the Formed Components .................................. 116
   5.3.2 Tooth Surface Hardness of the Cold Rolling Forming Components .................................. 117
   5.3.3 Microstructure of the Cold Rolling Forming Spline Tooth .................................. 119
   5.3.4 Tooth Surface Strengthening Mechanism of the Cold Rolling Precision Forming Spline Shaft .................................. 121
   5.4 Forming Error and Defects of the Cold Rolling Forming Spline .................................. 122
   5.4.1 Formation and Control of the Accumulated Pitch Error .................................. 122
   5.4.2 Defect Analysis of the Cold Rolling Forming Spline Shaft .................................. 127
5.5 Quality Control Methods of Cold Rolling Forming
   Spline Shafts ........................................ 130
   5.5.1 Design of the Cold Rolling Billet ................. 130
   5.5.2 Setting of the Roller and Adjustment
       of the Tooth Positions .......................... 132
   5.5.3 Reasonable Selection of the Process Parameters ..... 133
References .................................................. 135

6 Mechanism and Process Analysis on the Cold Rolling
   Forming of Threads .................................... 137
   6.1 Principle of the Thread Cold Rolling Forming Process .. 137
       6.1.1 Two-Wheel Rolling of Threads .................. 138
       6.1.2 Three-Wheel Rolling of Threads ............... 139
   6.2 Diameter Conditions of Three-Wheel Rolling Threads ... 140
   6.3 Cold Rolling Forming Process of Threads .............. 141
   6.4 Relative Movement Between the Workpiece
       and the Rolling Wheel ................................ 144
       6.4.1 Axial Motion Relationship ..................... 144
       6.4.2 Rotational Motion Relationship Between the
             Workpiece and the Rolling Wheel ............... 146
       6.4.3 Relative Sliding Between the Rolling Wheel
             and the Workpiece ................................ 148
Reference ................................................................ 150

7 Process Parameters in the Cold Rolling Forming of Threads .... 151
   7.1 Thread Billets Before Cold Rolling Forming .......... 151
       7.1.1 Commonly Used Calculation Formulas
             of the Workpiece Billet Diameter ............... 151
       7.1.2 Solution of the Billet Diameter of the Cold
             Rolling Forming Thread .......................... 153
       7.1.3 Chamfer of the Billet ............................ 156
       7.1.4 Material of the Rolling Billet .................. 157
   7.2 Parameters in the Cold Rolling Forming Process of Threads .. 160
       7.2.1 Rolling Force ................................ 160
       7.2.2 Selection of the Rolling Speed .................. 170
       7.2.3 Selection of the Feed Rate in Thread Rolling .... 171
   7.3 Cold Rolling Forming of Hollow Thin-Walled Thread
       Components ............................................ 173
       7.3.1 Cold Rolling Forming of Hollow Threads ........ 173
       7.3.2 Wall Thickness of the Cold Rolling Hollow
             Thread Components ................................ 174
References .................................................. 185
8 Numerical Simulation of the Thread Cold Rolling Forming Process

8.1 Basic Procedure and Assumptions

8.1.1 Numerical Simulation Procedure of the Thread Cold Rolling Process

8.1.2 Simplification of the Model

8.2 Simulation of the Cold Rolling Forming Process of a M10 × 1.5 Solid Thread

8.2.1 Load and Moment of the Die (Rolling Wheel)

8.2.2 Stress State Analysis of the Workpiece

8.3 Numerical Simulation on the Cold Rolling Forming of Hollow Threads

8.3.1 Analysis of the Rolling Force

8.3.2 Velocity Field

8.3.3 Stress State of the Workpiece

8.3.4 Analysis of the Strain State

8.4 Failure Analysis of the Thread Components

8.4.1 Variation of the Effective Stress in the Workpiece

8.4.2 Repairing Action of the Three Rolling Wheels on the Instability of the Hollow Thread

References

9 Metal Flow and Parameter Optimization of Thread Cold Rolling Forming Process

9.1 Cold Rolling Forming of Threads with Three-Wheel Rolling Machine

9.1.1 Material of the Billet and the Forming Machine

9.1.2 Factors Influencing the Cold Rolling Forming Process of Threads

9.1.3 Influence of the Hollow Thread Wall Thickness on the Forming of Threads

9.2 Metal Flow Rules in the Cold Rolling Forming Process of Threads

9.3 Hardness Distribution of the Cold Rolling Forming and Cutting Threads

9.4 Optimization of the Rolling Parameters

9.4.1 Determination of the Orthogonal Factors, Levels, and Index of the Thread Cold Rolling Forming Parameters

9.4.2 Hardening Degree Under Different Forming Conditions

9.5 Determination of the Optimized Rolling Parameters

References
10 Cold Rolling Precision Forming Equipments .......................... 227
10.1 Summary ........................................... 227
10.2 Design of the Cold Rolling Forming Machine
and the Rolling Wheel ........................................ 230
10.2.1 Structure and Parameters of the Equipment ............. 230
10.2.2 Design of the Synchronous Spindle Damping
Absorption ................................................................ 231
10.2.3 Modeling and Simulation of the Hydraulic System ... 233
10.2.4 Design of the Rolling Wheel .............................. 241
10.3 Measuring System of the Mechanical Parameters ............ 243
10.3.1 Measurement Method of the Spindle Torque .......... 243
10.3.2 Measuring of the Radial Feeding Force of the Slider .................................................. 245
10.3.3 The Data Acquisition System ............................ 246
10.4 Determination of the Process Parameters ...................... 247
10.4.1 Rotation Speed of the Rolling Wheel ................. 247
10.4.2 Feed Rate of the Rolling Wheel ....................... 248
10.4.3 Control of the Spindle Positions ....................... 249
10.5 Mechanical Parameters in the Cold Rolling Precision Forming Process ........................................ 250
10.5.1 Dynamic Load of the Forming Process .............. 250
10.5.2 Influence of the Process Parameters
on the Maximum Forming Force .............................. 252
10.5.3 Comparison Between the Theoretical Calculation
and Experimental Results ...................................... 255
10.6 Brief Introduction of the Cold Rolling Precision Forming Equipments ........................................ 256
10.6.1 Cold Rolling Forming Equipments of Kinefac Corporation (Kinefac) in the USA .................. 256
10.6.2 Cold Rolling Equipments of Profiroll Corporation in Germany ......................................... 263
10.6.3 Cold Rolling Forming Equipments of Qingdao Shengjian Machinery Factory ............................... 272
References .................................................... 276
Cold Rolling Precision Forming of Shaft Parts
Theory and Technologies
Song, J.; Liu, Z.; Li, Y.
2017, XVII, 276 p. 179 illus., 85 illus. in color.,
Hardcover
ISBN: 978-3-662-54046-6