SCHULER

Metal Forming Handbook

Springer-Verlag Berlin Heidelberg GmbH

SCHULER

METAL FORMING HANDBOOK

Springer

SCHULER GmbH
Bahnhofstr. 41
73033 Göppingen
Germany

Consulting editor: Professor Taylan Altan
Director, Engineering Research Center for Net Shape Manufacturing
The Ohio State University, USA

Library of Congress Cataloging-in-Publication Data

Handbuch der Umformtechnik. English
Metal forming handbook / Schuler GmbH.
Includes bibliographical references and index.
ISBN 978-3-642-63763-6 ISBN 978-3-642-58857-0 (eBook)
DOI 10.1007/978-3-642-58857-0
1. Metal-work. I. Schuler GmbH. II. Title.
TS205.H33413 1998
671--dc21 98-22434

ISBN 978-3-642-63763-6

Originally published by Springer-Verlag Berlin Heidelberg New York in 1998
Softcover reprint of the hardcover 1st edition 1998

Cover design by MEDIO, Berlin
Layout design and data conversion by K.-D. Grotz, MEDIO, Berlin

SPIN: 10712900 3020/ 62/ 5 4 3 2 1 – Printed on acid-free paper.

Preface

Following the long tradition of the Schuler Company, the Metal Forming Handbook presents the scientific fundamentals of metal forming technology in a way which is both compact and easily understood. Thus, this book makes the theory and practice of this field accessible to teaching and practical implementation.

The first Schuler "Metal Forming Handbook" was published in 1930. The last edition of 1966, already revised four times, was translated into a number of languages, and met with resounding approval around the globe.

Over the last 30 years, the field of forming technology has been radically changed by a number of innovations. New forming techniques and extended product design possibilities have been developed and introduced. This Metal Forming Handbook has been fundamentally revised to take account of these technological changes. It is both a textbook and a reference work whose initial chapters are concerned to provide a survey of the fundamental processes of forming technology and press design. The book then goes on to provide an in-depth study of the major fields of sheet metal forming, cutting, hydroforming and solid forming. A large number of relevant calculations offers state of the art solutions in the field of metal forming technology. In presenting technical explanations, particular emphasis was placed on easily understandable graphic visualization. All illustrations and diagrams were compiled using a standardized system of functionally oriented color codes with a view to aiding the reader's understanding.

It is sincerely hoped that this Handbook helps not only disseminate specialized knowledge but also provides an impetus for dialogue between the fields of production engineering, production line construction, teaching and research.

This Handbook is the product of dedicated commitment and the wide range of specialized knowledge contributed by many employees of the SCHULER Group in close cooperation with Prof. Dr.-Ing. H. Hoffmann and Dipl.-Ing. M. Kasparbauer of the *utg*, Institute for Metal Forming and Casting at the Technical University of Munich. In close cooperation with the SCHULER team, they have created a solid foundation for the practical and scientific competence presented in this Handbook. We wish to offer our sincere thanks and appreciation to all those involved.

Goeppingen, March 1998

Schuler GmbH
Board of Management

Contributors

Adam, K., Dipl.-Ing. (FH), SMG Süddeutsche Maschinenbau GmbH & Co
Bareis, A., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Birzer, F., Prof. Dipl.-Ing., Feintool AG
Blasig, N., Dipl.-Ing. (FH), Schleicher Automation GmbH & Co
Brandstetter, R., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Breuer, W., Dipl.-Ing., Schuler Pressen GmbH & Co
Frontzek, H., Dr.-Ing., Schuler GmbH
Hoffmann, H., Prof. Dr.-Ing., Lehrstuhl für Umformtechnik und Gießereiwesen, Technische Universität München
Jarosch, B., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Käsmacher, H., SMG Engineering für Industrieanlagen GmbH
Kasparbauer, M., Dipl.-Ing., Lehrstuhl für Umformtechnik und Gießereiwesen, Technische Universität München
Kellenbenz, R., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Kiefer, A., Dipl.-Ing. (BA), GMG Automation GmbH & Co
Klein, P., Gräbener Pressensysteme GmbH & Co. KG
Klemm, P., Dr.-Ing., Schuler Pressen GmbH & Co
Knauß, V., Dipl.-Ing. (FH), Schuler Werkzeuge GmbH & Co
Kohler, H., Dipl.-Ing., Schuler Guß GmbH & Co
Körner, E., Dr.-Ing., Schuler Pressen GmbH & Co
Kutscher, H.-W., Dipl.-Ing. (FH), Gräbener Pressensysteme GmbH & Co. KG
Leitloff, F.-U., Dr.-Ing., Schäfer Hydroforming GmbH & Co
Merkle, D., Schuler Pressen GmbH & Co
Osen, W., Dr.- Ing., SMG Süddeutsche Maschinenbau GmbH & Co
Pfeifle, P., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Reitmeier, C., Dipl.-Ing., Schäfer Hydroforming GmbH & Co
Remppis, M., Ing. grad., Schuler Pressen GmbH & Co
Rosenauer, K., Dipl.-Ing. (FH), Schuler Werkzeuge GmbH & Co

Schäfer, A.W., Schäfer Hydroforming GmbH & Co
Schmid, W., Dipl.-Ing. (FH), Schuler Werkzeuge GmbH & Co
Schmitt, K. P., Schuler Pressen GmbH & Co
Schneider, F., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Simon, H., Dr.-Ing., Schuler Werkzeuge GmbH & Co
Steinmetz, M., Dipl.-Wirt.-Ing., SMG Engineering für Industrieanlagen GmbH
Strommer, K., Dipl.-Ing. (FH), Schuler Pressen GmbH & Co
Vogel, N., Dipl.-Ing., Schleicher Automation GmbH & Co
Wegener, K., Dr.-Ing., Schuler Pressen GmbH & Co

Contents

Index of formula symbols XV

1 Introduction 1

2 Basic principles of metal forming 5

2.1 Methods of forming and cutting technology 5
2.1.1 Summary 5
2.1.2 Forming 6
2.1.3 Dividing 19
2.1.4 Combinations of processes in manufacturing 22

2.2 Basic terms 25
2.2.1 Flow condition and flow curve 25
2.2.2 Deformation and material flow 26
2.2.3 Force and work 28
2.2.4 Formability 30
2.2.5 Units of measurement 31

Bibliography 32

3 Fundamentals of press design 33

3.1 Press types and press construction 33
3.1.1 Press frame 34
3.1.2 Slide drive 37
3.1.3 Drive systems for deep drawing presses 41
3.1.4 Draw cushions 44

3.2 Mechanical presses 49
3.2.1 Determination of characteristic data 49
3.2.2 Types of drive system 54
3.2.3 Drive motor and flywheel 60
3.2.4 Clutch and brake 61
3.2.5 Longitudinal and transverse shaft drive 63
3.2.6 Gear drives 65
3.2.7 Press crown assembly 66
3.2.8 Slide and blank holder 66
3.2.9 Pneumatic system 70
3.2.10 Hydraulic system 71
3.2.11 Lubrication 72

3.3 Hydraulic presses 73
3.3.1 Drive system 73
3.3.2 Hydraulic oil 77
3.3.3 Parallelism of the slide 80
3.3.4 Stroke limitation and damping 82
3.3.5 Slide locking 83

3.4 Changing dies 86
3.4.1 Die handling 86
3.4.2 Die clamping devices 91

3.5 Press control systems 94
3.5.1 Functions of the control system 94
3.5.2 Electrical components of presses 94
3.5.3 Operating and visualization system 95
3.5.4 Structure of electrical control systems 97
3.5.5 Functional structure of the control system 99
3.5.6 Major electronic control components 99
3.5.7 Architecture and hardware configuration 101
3.5.8 Architecture of the PLC software 101
3.5.9 Future outlook 102

3.6 Press safety and certification 106
3.6.1 Accident prevention 106
3.6.2 Legislation 107
3.6.3 European safety requirements 107
3.6.4 CE marking 111

3.6.5 Measures to be undertaken by the user 115
3.6.6 Safety requirements in the USA 117

3.7 Casting components for presses 120

Bibliography 122

4 Sheet metal forming and blanking 123
4.1 Principles of die manufacture 123
4.1.1 Classification of dies 123
4.1.2 Die development 128
4.1.3 Die materials 142
4.1.4 Casting of dies 142
4.1.5 Try-out equipment 148
4.1.6 Transfer simulators 154

4.2 Deep drawing and stretch drawing 156
4.2.1 Forming process 156
4.2.2 Materials for sheet metal forming 174
4.2.3 Friction, wear and lubrication during sheet metal forming 179
4.2.4 Hydro-mechanical deep drawing 185
4.2.5 Active hydro-mechanical drawing 188

4.3 Coil lines 194

4.4 Sheet metal forming lines 198
4.4.1 Universal presses 198
4.4.2 Production lines for the manufacture of flat radiator plates 208
4.4.3 Lines for side member manufacture 210
4.4.4 Destackers and blank turnover stations 217
4.4.5 Press lines 222
4.4.6 Transfer presses for small and medium sized parts 229
4.4.7 Large-panel tri-axis transfer presses 234
4.4.8 Crossbar transfer presses 243
4.4.9 Presses for plastics 250
4.4.10 Stacking units for finished parts 252
4.4.11 Control systems for large-panel transfer presses . . 254

4.5 Blanking processes 268

4.6 Shearing lines 284
4.6.1 Slitting lines 284
4.6.2 Blanking lines 286
4.6.3 High-speed blanking lines 291
4.6.4 Lines for the production of electric motor laminations 296
4.6.5 Production and processing of tailored blanks 310
4.6.6 Perforating presses 314
4.6.7 Control systems for blanking presses 320

4.7 Fine blanking 330
4.7.1 Fine blanking process 330
4.7.2 Fine blanking materials, forces, quality characteristics and part variety 338
4.7.3 Fine blanking tools 351
4.7.4 Fine blanking presses and lines 359

4.8 Bending 366
4.8.1 Bending process 366
4.8.2 Roll forming and variety of sections 373
4.8.3 Roller straightening 383

4.9 Organization of stamping plants 389
4.9.1 Design 389
4.9.2 Layout 391
4.9.3 Quality assurance through quality control 398

Bibliography 403

5 Hydroforming 405

5.1 General 405

5.2 Process technology and example applications 405
5.2.1 Process technology 405
5.2.2 Types of hydroformed components 408
5.2.3 Fields of application 410

5.3 Component development 413
5.3.1 User-oriented project management 413
5.3.2 Feasibility studies 414
5.3.3 Component design 416

5.4 Die engineering 420
5.4.1 Die layout 420
5.4.2 Lubricants 422

5.5 Materials and preforms for producing hydroformed components 423
5.5.1 Materials and heat treatment 423
5.5.2 Preforms and preparation 424

5.6 Presses for hydroforming 426

5.7 General considerations 429
5.7.1 Production technology issues 429
5.7.2 Technical and economic considerations 431

Bibliography 432

6 Solid forming (Forging) 433

6.1 General 433

6.2 Benefits of solid forming 441
6.2.1 Economic aspects 441
6.2.2 Workpiece properties 443

6.3 Materials, billet production and surface treatment . . . 450
6.3.1 Materials 450
6.3.2 Billet or slug preparation 454
6.3.3 Surface treatment 459

6.4 Formed part and process plan 464
6.4.1 The formed part 464
6.4.2 Process plan 467

6.5 Force and work requirement 469
6.5.1 Forward rod extrusion 469
6.5.2 Forward tube extrusion 474

6.5.3 Backward cup extrusion and centering 474
6.5.4 Reducing (open die forward extrusion)..... 475
6.5.5 Ironing 476
6.5.6 Upsetting 476
6.5.7 Lateral extrusion 477

6.6 Part transfer 478
6.6.1 Loading station 479
6.6.2 Transfer study 481

6.7 Die design 485
6.7.1 Die holders 488
6.7.2 Die and punch design 491
6.7.3 Die and punch materials 496
6.7.4 Die closing systems (multiple-action dies) 502

6.8 Presses used for solid forming 505
6.8.1 Choice of press 505
6.8.2 Mechanical presses 507
6.8.3 Hydraulic presses 514
6.8.4 Supplementary equipment 517
6.8.5 Special features of hot and warm forming lines .. 520
6.8.6 Sizing and coining presses 522
6.8.7 Minting and coin blanking lines 526

Bibliography 541

Index 543

Index of formula symbols

α	rib angle, bending angle, clearance angle, die opening angle, corner angle for blanking	° ° ° °
α_1	required bending angle	°
α_2	desired bending angle	°
β	draw ratio, corner angle when bending	 °
β_{tot}	total draw ratio	
β_{max}	maximum draw ratio	
ε	elongation, starting measurement	
ε_A	relative cross section change	%
η	efficiency	
η_A	degree of utilization of the sheet metal, utilization force	
η_F	forming efficiency factor	
μ	coefficient of friction	
$\dot{V}$	volumetric flow	1/s
σ	stress	N/mm^2
σ_m	mean stress	N/mm^2
σ_{max}	largest stress	N/mm^2
σ_{md}	mean comparative stress	N/mm^2
σ_{min}	smallest stress	N/mm^2
σ_N	normal contact stress	N/mm^2
σ_r	radial stress	N/mm^2

σ_t	tangential stress	N/mm^2
σ_v	comparative stress, effective stress	N/mm^2
σ_z	critical buckling stress	N/mm^2
σ_1	greatest principle stress	N/mm^2
σ_2	mean principle stress	N/mm^2
σ_3	smallest principle stress	N/mm^2
τ_R	frictional shear stress	N/mm^2
φ	degree of deformation, strain, logarithmic/true strain	
$\dot{\varphi}$	strain rate, deformation rate, deformation speed	
φ_B	fracture strain	
φ_g	principle deformation	
$\varphi_1, \varphi_2, \varphi_3$	deformation in main directions	
A	surface	mm^2
a	blanking plate measurement, rim width, leg length during bending, slot width	mm mm
A_0	initial surface, surface of blank cross section	mm^2
a_1	blanking punch dimension	mm
A_1	surface of blank cross section, end surface	mm^2
A_5, A_{80}	ultimate elongation	%
A_G	ejector surface, surface area under pressure by the ejector	mm^2
a_R	space between the rows	mm
A_S	sheared surface	mm^2
A_{St}	cross section of the punch, surface area of hole punch	mm^2 mm^2
A_Z	blank surface, area of the blank	mm^2
b	web width, leg length during bending, strip width, section width	mm mm
B	deflection	mm
b_A	shell-shaped tear width	mm
b_E	die roll width	mm
b_S	strip width	mm
c	material coefficient	
D	blank diameter, plate diameter, mandrel diameter	mm mm

d	inner diameter, hole diameter, (perforating) punch diameter	mm mm
d'	inside diameter of bottom die	mm
d_0	blank diameter, initial billet diameter	mm
d_1	diameter of the draw punch in the first drawing operation, punch diameter, end diameter	mm mm
d_2	upper cup diameter, outside diameter	mm
d_3	outside flange diameter	mm
e	off-center position of force application	mm
E	elasticity module	N/mm^2
F	force	kN
f_1, f_2, f_3	offset factors	
F_A	ejection force	kN
F_B	blank holder force	kN
F_b	bending force	kN
F_G	counterforce	kN
F_{Ga}	ejection force	kN
F_{Ges}	total machine force	kN
F_N	normal force	kN
F_{N0}	rated press force, nominal load	kN
F_R	radial tension force, friction force, vee-ring force	kN
F_{Ra}	stripping force	kN
F_{Re}	reaction force	kN
F_S	blanking force for punch with flat ground work surface, shearing force	kN kN
F_{ST}	slide force	kN
F_t	tangential compression force	kN
F_U	pressing force, forming force, maximum drawing force	kN kN
g	gravitational acceleration	m/s^2
h	forming path, drawing stroke, distance, height, punch displacement; lubrication gap	mm mm µm
H	plate thickness	mm
h_0	initial billet height, height of blank	mm

h_1	final height of a body after compression	mm
h_1'	intermediate height, height of the truncated cone	mm
h_2	cup height	mm
h_E	die roll height	mm
h_G	flash height	mm
h_R, H_R	height of vee-ring	mm
h_{S1}	smooth cut section in case of fracture	%
h_{S2}	minimal smooth cut section in case of shell-shaped fracture	%
i	side cutter scrap	mm
k	correction factor	
$k_{2\alpha}$	correction coefficient (angle)	
k_f	flow stress	N/mm^2
k_{f0}	flow stress at the start of the forming process	N/mm^2
k_{f1}	flow stress towards the end of the forming process	N/mm^2
k_{fm}	mean stability factor	N/mm^2
k_h	correction coefficient (height)	
k_R	springback factor	
k_S	shearing resistance, shearing strength, relative blanking force	N/mm^2 N/mm^2
k_w	deformation resistance	N/mm^2
k_{wm}	mean deformation resistance	N/mm^2
l	rib length	mm
L	strip length, mandrel length	mm
l_a	rim length	mm
l_e	web length, strip length	mm
l_R	length of vee-ring	mm
l_S	length of sheared contour cut	mm
m	mass, module of a gear	kg
M_x	eccentric moment of load around the x axis	kNm
M_y	eccentric moment of load around the y axis	kNm
P	performance, drive power	W, kW
p	pressure	N/mm^2
p_B	specific blank holder pressure	N/mm^2

p_G	average compressive stress on the counterpunch	N/mm^2
p_i	internal pressure	N/mm^2
p_j	compressive stress at the wall of the bottom die	N/mm^2
p_m	mean (hydraustatic) pressure	N/mm^2
p_{St}	average compressive stress on the punch, average forming pressure	N/mm^2 N/mm^2
q_G	specific counterforce, counterpressure	N/mm^2
r	radius	mm
R	corner radius	mm
r_a	external radius of an inside contour	mm
R_a	external radius of an outside contour	mm
R_{eL}	lower yield strength	N/mm^2
$R_{p0,2}$	compression limit	N/mm^2
r_i	inside bending radius, internal radius of an inside contour	mm mm
R_i	internal radius of an outside contour	mm
r_{i1}	inside radius at the die	mm
r_{i2}	inside radius at the workpiece	mm
R_m	tensile strength of the material	N/mm^2
R_t	surface roughness	µm
R_w	roller radius	mm
R_z	surface roughness	µm
s	sheet metal thickness, wall thickness, blank thickness	mm mm
s_R	position of the center of force (x_s- und y_s: coordinates of the force), center of gravity	mm
t	pitch	mm
t_w	roller pitch	mm
u	blanking clearance	mm
U	speed/stroking speed, cut contour circumferences, punch perimeter	1/min mm
v	counterbalance value during bending, compensation factor	mm mm
V	feed step, volume	mm mm^3

V_0	starting volume, overall volume, part volume	mm^3
V_1	intermediate volume, compensation value	mm^3
V_1'	intermediate volume, compensation value	mm^3
V_2	intermediate volume, compensation value	mm^3
V_d	volume displaced during deformation	mm^3
W	deformation/forming work	Nm, kNm J, kJ
w	die width	mm
W_b	bending work	Nm
W_d	drawing work on double-action presses, draw energy of a double-action press	Nm, kNm Nm, kNm
W_e	drawing work on single-action presses, draw energy of a single-action press	Nm, kNm Nm, kNm
w_{id}	referenced deformation work, specific forming work	Nmm/mm^3
W_N	nominal work for continuous stroking	Nm, kNm
W_S	blanking work, blanking energy, shearing work	Nm, kNm
x	correction factor	
x_s	location of the resulting blanking force in the x direction	mm
y_s	location of the resulting blanking force in the y direction	mm
z	no. of teeth of a gear, no. of workpieces	
z_w	roller feed value	mm