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# METAL FORMING HANDBOOK



Springer

**SCHULER GmbH**  
**Bahnhofstr. 41**  
**73033 Göppingen**  
**Germany**

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Cataloging-in-Publication Data applied for

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

**Metal forming handbook** / Schuler. – Berlin ; Heidelberg ; New York ; Barcelona ;  
Budapest ; Hong Kong ; London ; Milan ; Paris ; Santa Clara ; Singapore ; Tokyo :  
Springer, 1998

Dt. Ausg. u. d. T.: Handbuch der Umformtechnik  
ISBN 3-540-61185-1

ISBN 3-540-61185-1 Springer-Verlag Berlin Heidelberg New York

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Printed in Germany

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Cover design by MEDIO, Berlin  
Layout design and data conversion by MEDIO, Berlin  
Printing and binding by Konrad Triltsch Druck- und Verlagsanstalt, Würzburg  
SPIN: 10514857 3020/ 62/ 5 4 3 2 1 0 – Printed on acid-free paper.

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## 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

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# Index of formula symbols

$\alpha$	rib angle, bending angle, clearance angle, die opening angle, corner angle for blanking	◦
$\alpha_1$	required bending angle	◦
$\alpha_2$	desired bending angle	◦
$\beta$	draw ratio, corner angle when bending	◦
$\beta_{\text{tot}}$	total draw ratio	
$\beta_{\text{max}}$	maximum draw ratio	
$\varepsilon$	elongation, starting measurement	
$\varepsilon_A$	relative cross section change	%
$\eta$	efficiency	
$\eta_A$	degree of utilization of the sheet metal, utilization force	
$\eta_F$	forming efficiency factor	
$\mu$	coefficient of friction	
$V$	volumetric flow	1/s
$\sigma$	stress	N/mm <sup>2</sup>
$\sigma_m$	mean stress	N/mm <sup>2</sup>
$\sigma_{\text{max}}$	largest stress	N/mm <sup>2</sup>
$\sigma_{\text{md}}$	mean comparative stress	N/mm <sup>2</sup>
$\sigma_{\text{min}}$	smallest stress	N/mm <sup>2</sup>
$\sigma_N$	normal contact stress	N/mm <sup>2</sup>
$\sigma_r$	radial stress	N/mm <sup>2</sup>

$\sigma_t$	tangential stress	N/mm <sup>2</sup>
$\sigma_v$	comparative stress, effective stress	N/mm <sup>2</sup>
$\sigma_z$	critical buckling stress	N/mm <sup>2</sup>
$\sigma_1$	greatest principle stress	N/mm <sup>2</sup>
$\sigma_2$	mean principle stress	N/mm <sup>2</sup>
$\sigma_3$	smallest principle stress	N/mm <sup>2</sup>
$\tau_R$	frictional shear stress	N/mm <sup>2</sup>
$\varphi$	degree of deformation, strain, logarithmic/true strain	
$\dot{\varphi}$	strain rate, deformation rate, deformation speed	
$\varphi_B$	fracture strain	
$\varphi_g$	principle deformation	
$\varphi_1, \varphi_2, \varphi_3$	deformation in main directions	
A	surface	mm <sup>2</sup>
a	blanking plate measurement, rim width, leg length during bending, slot width	mm mm
A <sub>0</sub>	initial surface, surface of blank cross section	mm <sup>2</sup>
a <sub>1</sub>	blanking punch dimension	mm
A <sub>1</sub>	surface of blank cross section, end surface	mm <sup>2</sup>
A <sub>5</sub> , A <sub>80</sub>	ultimate elongation	%
A <sub>G</sub>	ejector surface, surface area under pressure by the ejector	mm <sup>2</sup>
a <sub>R</sub>	space between the rows	mm
A <sub>S</sub>	sheared surface	mm <sup>2</sup>
A <sub>St</sub>	cross section of the punch, surface area of hole punch	mm <sup>2</sup> mm <sup>2</sup>
A <sub>Z</sub>	blank surface, area of the blank	mm <sup>2</sup>
b	web width, leg length during bending, strip width, section width	mm mm
B	deflection	mm
b <sub>A</sub>	shell-shaped tear width	mm
b <sub>E</sub>	die roll width	mm
b <sub>S</sub>	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 <sup>2</sup>
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
$F_C$	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 <sup>2</sup>
h	forming path, drawing stroke, distance, height, punch displacement; lubrication gap	mm mm $\mu\text{m}$
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 <sup>2</sup>
$k_{f0}$	flow stress at the start of the forming process	N/mm <sup>2</sup>
$k_{f1}$	flow stress towards the end of the forming process	N/mm <sup>2</sup>
$k_{fm}$	mean stability factor	N/mm <sup>2</sup>
$k_h$	correction coefficient (height)	
$k_R$	springback factor	
$k_S$	shearing resistance, shearing strength, relative blanking force	N/mm <sup>2</sup> N/mm <sup>2</sup>
$k_w$	deformation resistance	N/mm <sup>2</sup>
$k_{wm}$	mean deformation resistance	N/mm <sup>2</sup>
$l$	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 <sup>2</sup>
$p_B$	specific blank holder pressure	N/mm <sup>2</sup>

$P_G$	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	$\mu m$
$R_w$	roller radius	mm
$R_z$	surface roughness	$\mu m$
$s$	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	$\text{mm}^3$
$V_1$	intermediate volume, compensation value	$\text{mm}^3$
$V_1'$	intermediate volume, compensation value	$\text{mm}^3$
$V_2$	intermediate volume, compensation value	$\text{mm}^3$
$V_d$	volume displaced during deformation	$\text{mm}^3$
$W$	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	$\text{Nmm/mm}^3$
$W_N$	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