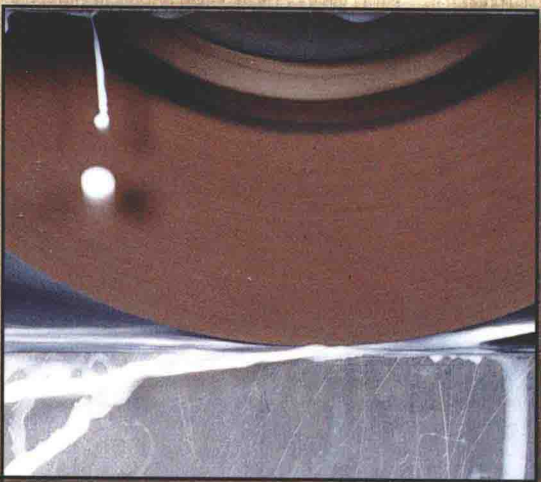
Edition 2

Principles of Modern Grinding Technology



W. Brian Rowe

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Second Edition

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Dedication

I dedicate this book to my wife Margaret Ruth
for her love and support throughout my work,
the mother of my children Ivor and Ella
and my constant companion.

Preface

Principles of Modern Grinding Technology explains in simple terms the principles that led to rapid improvements in modern grinding technology over recent decades. Removal rates and quality standards have increased a hundred-fold. Very fine tolerances are routine due to improved understanding of the process and the factors that need to be controlled.

Superb grinding machines now produce optical-quality finishes due to developments in process control and machine design. It is the same for extremely high removal rates. This book shows how best quality can be improved and costs can be brought down at the same time as output is increased.

The book is aimed at practitioners, engineers, researchers, students and teachers. The approach is direct, concise and authoritative. This edition introduces additional materials including data, photographs, updated references and design examples. There are additions in most chapters including abrasives, dressing, cooling, high-speed grinding, centreless grinding, materials, wear, temperatures and heat transfer. There are numerous worked examples. Progressing through each major element of a grinding system and then on to machine developments, the reader becomes aware of all aspects of operation and design. Trends are described demonstrating key features. Coverage includes abrasives and superabrasives, wheel design, dressing technology, machine accuracy and productivity, machine design, high-speed grinding technology, cost optimization, ultra-precision grinding, process control, vibration control, coolants and fluid delivery, thermal damage and grinding temperatures.

Advances in the field are supported with references to leading research. Analysis is presented in later chapters and appendices with new contributions to machine design, intelligent control, centreless grinding, fluid delivery, cost analysis and thermal analysis for prediction and control of grinding temperatures are provided. By selecting the right conditions, extremely high removal rates can be achieved accompanied by low temperatures. Techniques for measurement of grinding temperatures are also included.

This edition includes recent process developments and additional design examples.

- Trends in high precision and high-speed grinding are explored.
- Principles underlying improvements in machines and processes are explained.
- Numerical worked examples give scale to essential process parameters.
- Recent research findings and original contributions to knowledge are included.
- A number of ultra-precision grinding machine developments are included.

Acknowledgements

I wish to record sincere gratitude for the help and friendship provided by research students, research fellows, colleagues and visiting scholars with whom I had the privilege to work and whose valuable contributions made this volume possible. A number of these have achieved well-deserved distinction in academic and industrial spheres. The list, roughly in date order, includes D.L. Richards, J.I. Willmore, M.J. Edwards, P.A. Mason, J.P. O'Donoghue, K.J. Stout, S. Spraggett, D. Koshal, W.F. Bell, F.S. Chong, R. Gill, N. Barlow, R.N. Harrison, S.P. Johnson, T.W. Elliott, S. Yoshimoto, D. Ives, C. Goodall, G.K. Chang, J.A. Pettit, S. Kelly, D.R. Allanson, D.A. Thomas, K. Cheng, M. Jackson, M.N. Morgan, H.S. Qi, X. Chen, S. Black, N. Shepherd, Y. Chen, Y. Li, C. Statham, C.T. Schaeffer, X.Z. Lin, D. McCormack, S. Ebbrell, R. Cai, V. Gviniashvili, T. Jin, A.D. Batako, D. Cabrera, A.R. Jackson, V. Baines-Jones and Zhang Lei. I would especially like to mention Paul Wright who, through his invaluable contributions, helped me and many researchers succeed in their projects. Eventually he became manager of the laboratories within the School of Engineering at Liverpool John Moores University.

W. Brian Rowe

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About the Author

W. Brian Rowe is a research and consulting engineer, Emeritus Professor and previous Director of Advanced Manufacturing Technology and Tribology Research Laboratory (AMTTREL) at Liverpool John Moores University in the United Kingdom. A multiple recipient of prizes from The Institution of Mechanical Engineers (IMECHE), Dr Rowe has four decades of experience in academic and industrial positions concerned with machine tools, grinding processes and tribology. His accomplishments include over 250 published papers, several books, international visiting professorships and international consulting in industry.

List of Abbreviations

ACO	Adaptive control optimization
AE	Acoustic emission
ANSI	American National Standards Institution
BN	Barkhausen Noise
CBN	Cubic boron nitride
CIRP	International Academy of Production Engineering Research
CNC	Computer numerical control
CVD	Chemical vapour deposited
CW	Control wheel
ED	Electrical discharge
EDD	Electrical discharge dressing
ELID	Electrolytic in-process dressing
EP	Electroplated
FEPA	Federation of European Producers of Abrasives
FWM	Fluid wheel model of fluid convection
GW	Grinding wheel
HEDG	High-efficiency deep grinding
HEG	High-efficiency grinding
HSS	High speed steel
ID	Impregnated diamond
ISO	International Standards Organization
JIS	Japanese Industrial Standards
LFM	Laminar flow model of fluid convection
MQL	Minimum quantity lubrication
MRR	Material removal rate
PCD	Poly-crystalline diamond
PLCs	Programmable logic controls
PVD	Physical vapour deposition
RMS	Root mean square
SD	Single-point diamond
SEM	Scanning electron microscope
SG	Seeded gel (alumina composite abrasive) – trade name
SI	ISO international system (e.g. units)
SiC	Silicon carbide
UFM	Useful flow model
VHN	Vickers Hardness Number
WP	Workpiece

Notation for Grinding Parameters

Note: Symbols within a special context are explained in the relevant text.

a	Depth of cut or hydrostatic bearing land width
a_d	Dressing depth of cut
a_e	Effective (real) depth of cut in grinding
a_p	Programmed (set) depth of cut in grinding
b, b_r, b_w	Width of grinding wheel contact with work
b_{cu}	Width of uncut chip
b_d	Dressing tool contact width
b_r	Radial width of cut
c	Machine damping
c, c_p	Specific heat capacity
c_d, c_v, c_a	Discharge, velocity and area coefficients in nozzle flow
d	Diameter in pipe flow
d_c	Control wheel diameter in centreless grinding
d_e	Effective grinding wheel diameter
d_g	Mean abrasive grain diameter
d_s	Actual grinding wheel diameter
d_w	Workpiece diameter
e	Error
e_c, u	Specific grinding energy (energy per unit volume removed)
e_{ch}	Specific energy carried in chips
erf( )	Error function given in math tables
f	Frequency in cycles per second (Hz)
f	Interface friction factor = τ/k
f	Grain force
h	Thin film or chip thickness
h, h_f	Convection factor and work-fluid convection factor
h_{cu}	Uncut chip thickness
h_{eq}	Equivalent chip thickness
h_g	Convection factor into a grain
h_w	Work height in centreless grinding
h_{wg}	Convection factor into the workpiece at a grain contact
j	Complex number operator
k	Shear flow stress
k	Thermal conductivity
k_w, k_g	Thermal conductivity of work material and abrasive grain
l_c	Contact length
l_f	Contact length due to force and deflection of grinding wheel and workpiece
l_g	Geometric contact length due to depth of cut

n	Number of grinding passes
n	Junction growth factor
n_d	Number of dressing passes
n_s	Grinding wheel rotational speed
n_w	Work rotational speed
p	Instantaneous power
p_p	Fluid pumping pressure
q	Speed ratio = v_s/v_w
q	Flux value = heat per unit area in unit time
q_d	Dressing roll speed ratio = v_d/v_s
q_{flash}	Flux into the workpiece at a flash contact
r_{cu}	Uncut chip width/chip thickness ratio = b_{cu}/h_{cu}
r_o	Average effective grain contact radius
s	Laplace operator in vibration theory
t	Time
t_d	Dressing time
t_p	Point/flash contact time of grain and workpiece
t_s	Grinding cycle time
t_s	Grain contact time within contact length
t_t	Total cycle time including grinding and dressing
u_i	Input to a control system
u_o	Output from a control system
v	Mean velocity in pipe flow
v_d	Dressing roll speed
v_f	Work feed rate
v_{fd}	Dressing feed rate
v_j	Jet velocity
v_s	Wheel speed
v_w	Work speed
x	Deflection
x, y, z	Position coordinates
A	Geometric stability parameter in centreless grinding
A	Wear flat area on grinding wheel as fraction or percentage
A_c	Apparent area of grinding contact zone = $l_c \cdot b$
A_{cu}	Cross-section area of uncut chip
Al_2O_3	Aluminium oxide, alumina
B	Lateral grain spacing
C	Number of active abrasive grains per unit area = cutting edge density
C	C-factors giving temperature for particular grinding conditions
C_t	Total cost per part
D	Diameter as in journal diameter
E	Young modulus of elasticity
F_a, F'_a	Axial force and specific value per unit width
F_n, F'_n	Normal force and specific value per unit width
F_t, F'_t	Tangential force and specific value per unit width
G	*G*-ratio
H	Feedback function in a control system
H_a	Depth of cut function in vibrations

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