Principles and Applications of Metal Rolling

This is a book written by a practitioner. It is somewhat different from a normal textbook involving machines and equipment in the field of Mechanical Engineering. Generally stress is given to the theories and principles involved and processes are explained in great detail. There is no doubt that these are essential for an engineer. But it is equally important for an engineer to know the basic design, working principle and operation of various machines/equipment used for conversion of raw materials into desired products. The introduction of laboratories, workshops and industrial tours help fill this void to some degree. Yet, engineering curriculum retains the deficiency.

Meant for undergraduate and graduate students, this book attempts to fill the void in the sub-field ‘Rolling Process’. It also intends serving as a reference book for practicing engineers. It begins with comprehensive coverage of rolling processes and the mechanics of rolling, which is the theoretical content of the subject. This is followed by a chapter on ‘rolling practices’ that highlights plant level procedures and practices employed by the rollers for producing desired products. The book concludes with the description, operation and design principles of various equipment, mechanisms and systems used inside a rolling plant.

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Principles and Applications of Metal Rolling

Siddhartha Ray
This book is dedicated to the memory of my mother

Sadhana Roy

She remains the main source of inspiration in my life.
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\( x, y, z \) \hspace{1cm} three rectangular coordinates

\( F \) \hspace{1cm} force

\( F_R \) \hspace{1cm} repulsive force

\( F_A \) \hspace{1cm} attractive force

\( r_o \) \hspace{1cm} inter-atomic distance

\( \tau_o \) \hspace{1cm} ultimate shear stress

\( G \) \hspace{1cm} modulus of rigidity

\( H_i \) \hspace{1cm} abbreviation of “High”, signifying number of rolls in a mill stand

\( h \) \hspace{1cm} thickness of stock/workpiece

\( h_i \) \hspace{1cm} input thickness

\( h_2, h_0 \) \hspace{1cm} output thickness after deformation through rolling

\( h_n \) \hspace{1cm} thickness at neutral axis

\( w, b \) \hspace{1cm} width of stock/workpiece

\( w_1, b_1 \) \hspace{1cm} Input width

\( w_2, b_2 \) \hspace{1cm} output width after deformation

\( w_m, b_m \) \hspace{1cm} mean width

\( A_1 \) \hspace{1cm} cross sectional area of stock/material at input

\( A_2 \) \hspace{1cm} cross sectional area of output after deformation

\( L_1 \) \hspace{1cm} length of stock/workpiece at input

\( L_2 \) \hspace{1cm} length of stock at output after deformation

\( \alpha \) \hspace{1cm} contact angle or angle of bite/contact

\( \Delta h_i (h_i - h_2), \delta \) \hspace{1cm} draught or reduction in height/thickness

\( E' \) \hspace{1cm} elongation factor

\( \Delta w, \Delta b_m, (b_2 - b_1) \) \hspace{1cm} spread

\( R, r \) \hspace{1cm} roll radius

\( D \) \hspace{1cm} roll diameter

\( l \) \hspace{1cm} projected length of arc of contact

\( \mu \) \hspace{1cm} coefficient of friction

\( N \) \hspace{1cm} neutral point

\( \alpha_n, \gamma \) \hspace{1cm} neutral point angle

\( v_1 \) \hspace{1cm} stock velocity at entry

\( v_2 \) \hspace{1cm} stock velocity at output

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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$h$</td>
<td>set roll gap</td>
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<tr>
<td>$\gamma$</td>
<td>Poisson ratio</td>
</tr>
<tr>
<td>$E$</td>
<td>Young's modulus</td>
</tr>
<tr>
<td>$\Delta f$</td>
<td>mill stretch</td>
</tr>
<tr>
<td>$R', r'$</td>
<td>Deformed roll radius</td>
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<tr>
<td>$h_m$</td>
<td>Mean thickness of stock/workpiece</td>
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<tr>
<td>$v_r, v_r'$</td>
<td>Roll surface velocity</td>
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<tr>
<td>$v_x$</td>
<td>Roll surface velocity in the direction 'x'</td>
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<tr>
<td>$\phi$</td>
<td>Angle subtended by a point on roll surface within roll bite</td>
</tr>
<tr>
<td>$\phi_x$</td>
<td>Angle subtended by a point on roll surface at a distance x from roll axis</td>
</tr>
<tr>
<td>$\sigma_x, \sigma_y, \sigma_z$</td>
<td>Normal stresses</td>
</tr>
<tr>
<td>$k, \tau_s$</td>
<td>Shear yield stress</td>
</tr>
<tr>
<td>$\tau_x$</td>
<td>Contact shear stress</td>
</tr>
<tr>
<td>$\sigma_1, \sigma_2, \sigma_3$</td>
<td>Principal normal stresses</td>
</tr>
<tr>
<td>$\tau_{xy}, \tau_{yx}, \tau_{zx}$</td>
<td>Shear stresses</td>
</tr>
<tr>
<td>$\tau_{1x}, \tau_{2x}, \tau_{3x}$</td>
<td>Principal shear stresses</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Yield stress</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Actual resistance to deformation (tensile yield stress)</td>
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<tr>
<td>$\sigma_t$</td>
<td>Ultimate strength</td>
</tr>
<tr>
<td>$\sigma_B$</td>
<td>Tensile stress due to back tension</td>
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<tr>
<td>$\eta$</td>
<td>Coefficient of viscosity</td>
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<tr>
<td>$F$</td>
<td>Horizontal projection of contact area</td>
</tr>
<tr>
<td>$\sigma_i$</td>
<td>Tensile yield stress of annealed metal</td>
</tr>
<tr>
<td>$T$</td>
<td>Absolute temperature</td>
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<tr>
<td>$s$</td>
<td>Specific heat of metal</td>
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<tr>
<td>$t$</td>
<td>Rolling temperature, $^\circ$C</td>
</tr>
<tr>
<td>$\Delta t$</td>
<td>Time interval, seconds</td>
</tr>
<tr>
<td>$A$</td>
<td>Energy required to deform metal</td>
</tr>
<tr>
<td>$W$</td>
<td>Weight of metal in kg</td>
</tr>
<tr>
<td>$u, \varepsilon$</td>
<td>Strain rate, sec$^{-1}$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Strain</td>
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<tr>
<td>$p$</td>
<td>Contact pressure between roll and stock</td>
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<tr>
<td>$a$</td>
<td>Length of lever arm</td>
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<td>$\lambda$</td>
<td>Lever arm coefficient</td>
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<td>$T$</td>
<td>Torque</td>
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<tr>
<td>$kw$</td>
<td>Kilo-watt</td>
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<tr>
<td>HP</td>
<td>Horse power</td>
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<tr>
<td>HAGC</td>
<td>Hydraulic automatic gauge control</td>
</tr>
<tr>
<td>EDC</td>
<td>Edge drop control</td>
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</table>
Preface

Organization of this book is somewhat different from a normal textbook involving machines and equipment, in the field of mechanical engineering. Generally, stress is given to the theories and principles involved and the processes are explained to a great detail. There is no doubt that these are essential for an engineer. But it is equally important for an engineer to know the basic design, working principles and operations of the various machines and equipment which are used in the practical field for conversion of the raw materials into desired products. Baring the subject of ‘Machine Tools’, in most other fields of manufacturing processes, available textbooks seem to be rather miserly in thorough discussions on the description, design, working principles of various machines and systems involved and practices followed in actual operation.

An attempt has been made to bridge this gap by introducing laboratory exercises and workshops along with industry visits, in the engineering curricula. More often than not these prove to be inadequate. It is next to impossible that an equipment or machine like a turbine, an extrusion press or a rolling mill can be installed in an academic institution. By observing the operation of a machine or system during a visit to an industrial plant, definitely a lot can be learned about the manufacturing process, but seldom can it give an idea about the working principles of the various mechanisms, their design details or about the intricacies of operational practices.

While teaching ‘Manufacturing Technology’ to MTech students at the National Institute of Technical Teachers’ Training and Research (NITTTR), Kolkata, I observed this shortcoming in my students and cherished the desire to bridge the gap as soon as possible. With 30 years’ experience in the industry in design, development and commissioning to operation plant and machinery (out of which more than half the period was in the field of Rolling Mills), I decided to write this book titled Principles and Applications of Metal Rolling.

This book is intended to cover undergraduate and postgraduate engineering curricula for ‘Rolling Technology’ in India and in other countries. It is also meant to be a reference book for practicing engineers working in the field of rolling mills. The first two chapters cover the rolling process and mechanics of rolling
comprehensively, which is the theoretical content of the process of rolling. The third chapter on 'Rolling Practices' highlights plant level procedures and practices employed by the rollers for producing desired products. The whole of the fourth chapter on 'Rolling Equipment and Systems' is devoted to the description, operation and design principles of various equipment, mechanisms and systems used in a rolling plant.

In preparing the book, help has been taken from some specialized books written and edited by experts and from the literature of equipment manufacturers. Acknowledgement and references to such books and literature have been made at appropriate places.

Suggestions and comments on the organization and contents of the book are welcome and may kindly be sent to the publisher or the author.
While writing this book I have received help, suggestions and encouragement from many of my ex-colleagues, friends and well wishers, which I gratefully acknowledge.

At the very outset I would like to express my appreciation to my MTech students of Manufacturing Technology course offered by the National Institute of Technical Teachers’ Training and Research (NITTTR), Kolkata. While teaching and discussing the subject of Rolling Technology with them, I got impetus to write the present book. I am indeed thankful to them.

During the writing of this book I have drawn upon the knowledge and experience I received while working with M/s Davy Ashmore India Ltd., in close contact with their collaborators in the UK – Davy Lowey Ltd. and Loewy Robertson Engineering Company of the UK, and later with M/s Tata Construction and Projects Limited. I would like to acknowledge my deep sense of gratitude to the following persons, who gave me the opportunity to work in the field of design and operation of Rolling Mills and also gave me all possible help and cooperation during the writing of this book: Late P. Sen, Ex.-M. D. of Davy Ashmore India Ltd. and my ex-colleagues P. K. Bera and A. K. Mitra. I am particularly indebted to S. Bhattacharya from the same organization, who advised me while writing the topic on Mill Electrics.

I am also grateful to friends from the Davy Group of companies in the UK, namely: T. Shiemeld, T. Smith, A. F. Uff, D. Fretwell and others who helped me with information and material on the subject as and when I needed them. I am thankful to S. Majumdar, Ex President of Hindalco and colleagues at NITTTR, Kolkata and Heritage Institute of Technology, Kolkata for advising and encouraging me during the preparation of the book.

My thanks are also due to T. K. Dutta, an ex-colleague of Davy Ashmore, who joined later M/s. SMS Demag, India, for giving me valuable suggestions on Roll Lubrication and Cooling System.

I am thankful to Kingshuk Ghosh, the DTP operator of my department at NITTTR, who untiringly finished the entire manuscript, working beyond his working hours. My thanks go to G. Patra for preparing some of the diagrams using CAD.
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I am grateful to my wife Dipali Ray and other family members for their constant encouragement and sacrifices during the preparation of the book.

Finally, my thanks are to the Cambridge University Press for readily accepting to publish the book.