

Laser Cutting Guide for Manufacturing

Charles L. Caristan



Society of
Manufacturing
Engineers



Association for
Forming & Fabricating
Technologies of SME

Dearborn, Michigan

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The Association for Forming & Fabricating Technologies of SME (AFFT/SME) focuses on the technologies and processes that efficiently make products from metal sheet, coil, plate, tube, or pipe stock. Typical industries served are automotive, off-highway, aerospace, defense, appliance, furniture, and consumer electronics products. Core processes include general pressworking—stamping, drawing, forming, bending, and shearing, for example—as well as the fabricating technologies of punching, cutting, sawing, welding, and others. Many AFFT/SME members are manufacturing, tool, or process engineers specializing in keeping production forming or fabricating technologies current for their companies; general stamping, fabricating, welding, and assembly managers responsible for overseeing plant operations; and owners, partners, proprietors, and other company officials of relevant job shops. AFFT/SME membership allows such people to more quickly identify innovations that can lower costs while increasing product quality and yield. The AFFT/SME community also fosters learning among members to better manage their businesses and interact with customers, suppliers, and industry partners.

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Preface and Acknowledgments

“Scientific truth is signaled by coherence and efficiency. Poetic truth is signaled by beauty.”

—Aimé Césaire

As I began this endeavor to write a book on laser cutting, I had no doubt that I was up to the task, as I am a firm believer of the lesson from Henry Ford: “whether you think that you can, or that you can’t, you are usually right.” Over the long course of completing this manuscript, I was reminded with humility that, in the words of the great philosopher Alain, also known as Emile Chartier, it is a difficult art to express in writing thoughts that you usually verbalize without needing to think about them. Thank God, I was supported and had been prepared by great family and friends. Among them, I am especially grateful to my wife Lisa for her judicious proofreading and our sons Adrien and Alex for their patience. My mother Marguerite and sister Helene shared their brilliance and wisdom. My Ph.D. advisers, Prof. Jean-Pierre Martin of CNRS Laboratory EM2C at Ecole Centrale de Paris and Prof. William Rich of the Ohio State University in Columbus, Ohio were my models for the thought process and inspired my passion for discovery.

I am deeply indebted to five experts for their informative reviews that helped make this book a reality: Dr. Richard Martukanitz, Head of the Laser Processing Division of the Applied Research

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To the readers, whether students, experts, or neophytes, may this book provide the information, tools, ideas, and motivation for which you are looking. In many instances I chose to maintain a high level of detail that may appear to some overwhelming and repetitive. I ask for your indulgence as many of those instances are motivated by my personal experiences. Metaphorically speaking, readers familiar with the 1974 book, *The Gulag Archipelago*, by Alexander Solzhenitsyn, can appreciate how for some, cutting bread in slanted slices rather than vertical slices, is a detail far more important than having bread at all.

In this guide, I have broken down scientific concepts into simplified explanations so they could be understood by all, without hopefully stripping out totally the science foundation behind the art of laser cutting of metals. Some of the assertions in this guide may have derived from hypotheses that do not necessarily describe

everyone's specific situation and circumstances. However, in the words written by Gaston Bachelard in 1938, "the goal of a hypothesis is not to be true or false; it is to help arrive at a true or false result." Translating this true scientific spirit into pragmatic manufacturing engineering, the relationship between hypothesis and result is inherent in the dichotomy of this book—"Part I—Laser Cutting Inputs" and "Part II—Laser Cutting Outputs." All efforts were made to jell these two parts with a cohesive combination of experience, expertise, and education. "Education is what remains after one has forgotten what one has learned in school," said Albert Einstein. After reading this book, my friends may argue that I forgot a lot. I hope that all others credit it with some contribution to the teaching of laser cutting processes, lasers, and optics.

In conclusion, I will risk another attempt at a long-loved poetry hobby with inclusion of these verses that I wrote in praise of the invention and teaching of lasers. They are inspired by a notorious poem by Victor Hugo. Far from rivaling Hugo's prowess, may you find it an entertaining mnemotechnic means of remembering the decimal digits of a famous real number so irrational, yet so useful to the wise . . . up to the 30th decimal place.

To Laserfacturers

*And I love a sound knowledge of lasers grown,
Via world teachers, engineers, artists, Internets!
Set on lit coherent wave, gleams of wisdom sown,
For all revealed, fix pi numeral alphabets.*

—Charles L. Caristan

Introduction

“Where there is much light, the shadows are deepest.”

—Johann W. Von Goethe

Judging by the fast rise of laser cutting’s popularity in the world market, it can no longer be considered a high-tech science reserved for a few specialists. Market data from the Laser Systems Product Group of the Association for Manufacturing Technology (AMT) shows that among all industrial laser applications, laser-cutting systems have solidly earned their rank as first, representing about 10% of the sale of all machine tools in North America. The quarterly growth index for laser-cutting systems parallels that of the U.S. machine-tool industry since at least 1999. Laser cutting of thick metal plates and thin sheet metal has become common practice equally popular in the small so-called “Mom and Pop” shops as on the plant floors of large fabricator companies. In fact, laser cutting has expanded beyond prototype application roles into outright volume production in all segments of sheet-metal fabrication in the automotive, aerospace, appliance, shipyard, and electronics industries.

To support the successful transition from laboratory development to the industrial manufacturing world, a practical reference manual is essential to offer guidance from a modern quality manufacturing perspective. This transition started less than 10 years

after the invention of lasers in the early 1960s and promises a bright future, particularly in the metal industry. A book on laser cutting targeted to this industry that addresses the manufacturing challenges is long due.

Rather than duplicating academic reviews on the subject, a manufacturing perspective is presented here to provide complementary practical information and guidance for successful establishment of a laser metal-cutting business. This guide is designed to deliver essentials for a roadmap to develop, implement, operate, maintain, and even benchmark a laser-cutting manufacturing enterprise. It distinguishes itself from other publishing efforts in that it remains focused in its unbiased practical presentation.

The scope of the book encompasses common metal cutting of flat parts, roll-formed parts, hydroformed parts, and 3-D shaped stampings. The intent is to present today's reality of the technical, engineering, and business challenges of laser cutting metals. Following the fishbone diagram of *Figure P-1*, it is organized to support the development, implementation, operation, and maintenance of laser-cutting activity. It is written in simple terms familiar to a shop-floor operator. The targeted audience for this practical guide also includes owners and their management teams; engineers from production, quality, service and maintenance teams; product engineers and industrial process engineers; and students in search of information on manufacturing with lasers.

“Part I—Laser Cutting Inputs” includes Chapters 1 through 8. Chapter 1, “Overview of Metal Laser-cutting Applications,” describes various laser-cutting applications in metal forming and fabrication. It also provides a perspective of special applications and, in particular, an alternative to traditional die blanking that high-speed laser cutting presents to the automotive industry. Chapter 2, “Market for Laser Cutting,” summarizes market surveys published by independent and government entities. It places laser cutting in a wider machine-tool industry business context. Technology trends follow with insight to the ever-evolving state of the art. Chapters 3 through 8 describe laser cutting's specific key process input variables (KPIVs) within each of the “6M” categories: material, machine, method, man, measurement, and Mother Nature.

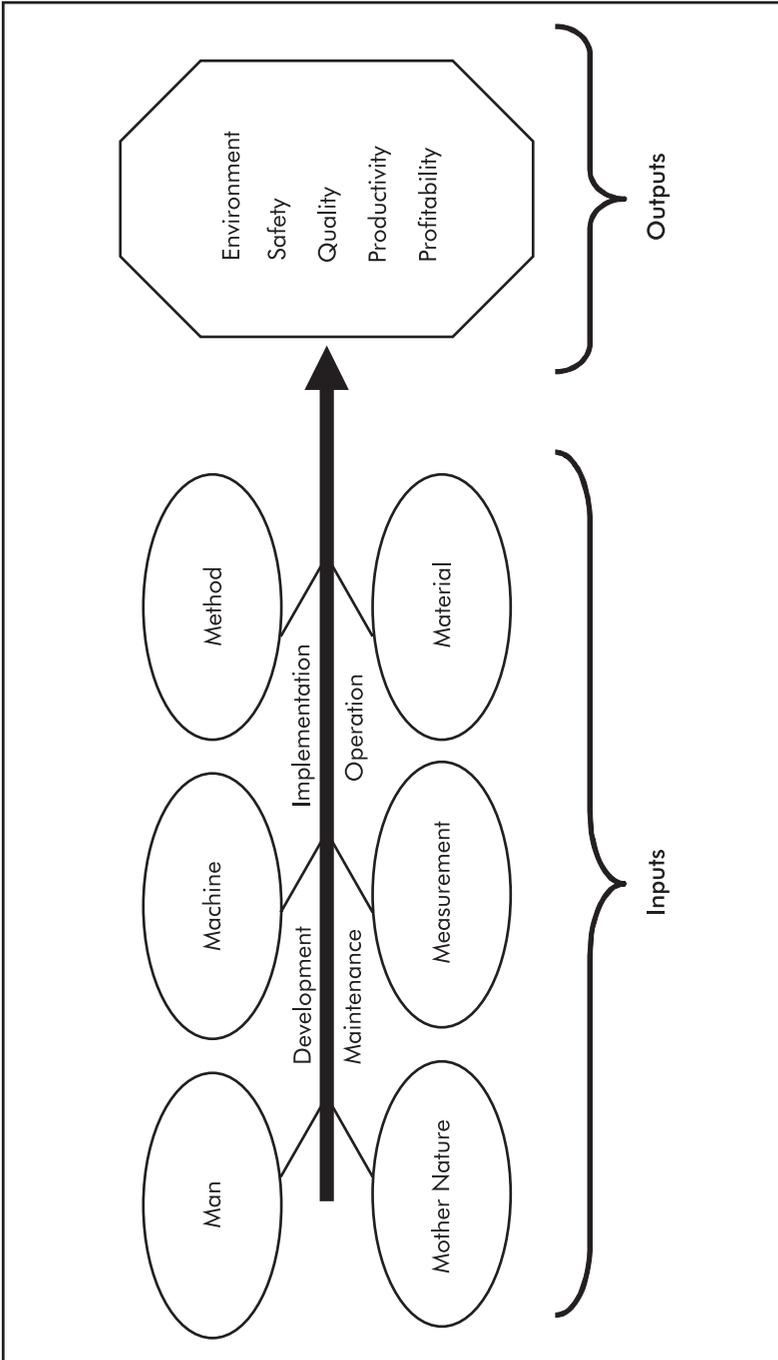


Figure P-1. This high-level Ishikawa fishbone diagram helps visualize influential inputs and key outputs for industrial laser cutting of metal sheets and plates.



“Part II—Laser Cutting Outputs” includes Chapters 9 through 13. It extensively details laser cutting’s specific key process output variables (KPOVs) for a laser operation. Each KPOV appears as a customer-driven, critical-to-quality specification and is categorized into one of five main areas: quality, productivity, profitability, environment, and safety. The influences of the KPIVs on the KPOVs are exposed. Chapter 13, “The Six-sigma Approach,” explains the methodology as it relates to the design, verification, and control phases in a continuous-improvement cycle. The chapter defines defects and opportunities for defects, and explains process mapping, measurement and analysis, and how to rank critical-to-quality (CTQ) specifications.

For more in-depth study, three appendices explain the customization of tools specific to laser cutting that can be helpful for design and implementation, troubleshooting, operation, and maintenance. Appendix A reviews the basics of lasers with a historical perspective. Appendix B develops beam-propagation tools practical for many realistic beam-delivery-system designs. Appendix C provides information on compressible gas dynamics for laser cutting.

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