Подстрочный перевод для книги:

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Joe Martin
Craig Libuse

Tabletop Machining

a basic approach to making small parts on miniature machine tools

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`https://github.com/ponyatov/tabletop`

Настольные станки

основные приемы изготовления мелких деталей на миниатюрных станках

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Joe Martin

фотографии и иллюстрации Craig Libuse

- модели
- приемы и техники
- прототипы
- измерения
- наладка станков

... Это то, что каждый инженер должен знать о станках, механической обработке и производстве

Оглавление

Глава 1

A special note to engineers reading this book... Специальное примечание для инженеров, читающих эту книгу...

1.1 Machining for engineers and engineering for machinists Мехобработка для инженеров и инжиниринг для станочников

At first glance the subtitle on the cover of this book could be a bit deceiving. What does tabletop machining have do with engineering you may ask? Compare it to a book that has been written about the ocean. The seas could be described from the perspective of a young man who has just sailed around the world in a twenty-five foot sailboat or by a merchant seaman who has spent his career aboard a giant ocean liner. Each would have an entirely different view of what the ocean was all about. In a storm, the chap in the small boat would write about surviving broken masts and mountainous seas while the merchant seaman might write about seasick passengers.

I believe you would learn more about the ocean from the young man in the small boat, because in a sense he was more involved in his subject. He was not just on it, he was *in* it.

На первый взгляд подзаголовок на обложке этой книги может быть немного обманчив. Вы можете спросить, как настольная обработка связана с инжинирингом? Сравним с книгой, написанной об океане. Моря могли бы быть описаны с точки зрения молодого человека, который только что ходил по всему миру на парусной лодке длиной двадцать пять футов, или моряком торгового флота, который провёл свою карьеру на гигантском океанском лайнере. Каждый из них будет иметь совершенно разную точку зрения об океане. В шторм парень на небольшой лодке написал бы о выживании со сломанными мачтами и волнах размером в гору, в то время как моряк торгового флота мог бы написать о морской болезни пассажиров. Я думаю, что вы бы узнали об океане больше от молодого человека на небольшой лодке, потому что некоторым образом ему было сложнее в своём путешествии. Он был не просто в путешествии, он был *внутри* него.

1.2 Navigating the seas of machining
Навигация по морям механической обработки

The ocean in this case is the world of machining. The craftsman using tabletop machine tools is like the sailor in a small boat, while the professional machinist with his big CNC shop tools is like the world-traveling seaman. The process of producing complex, accurate parts cannot be described by looking in the window of a quarter million dollar CNC machine. It would be like a merchant seaman working in the engine room trying to describe a storm in the Atlantic Ocean by telling you how much extra fuel the ship used. The professional's view of the subject may be so cluttered with details that it is difficult to sort the things you really need to know to sail in rough seas or make good parts. It is the craftsman working with small tools, turning the cranks by hand, who will have the most to tell you about the real world of working with metal.

Океан в нашем случае — мир механической обработки. Мастер использующий настольные станки, как матрос на маленькой лодке, в то время как профессиональный станочник с его большим магазином инструментом на станке с ЧПУ, как моряк несколько раз совершивший кругосветку. Процесс производства сложных, точных деталей не может быть описан описан, глядя в окно ЧПУ станка за четверть миллиона долларов. Это было бы похоже на моряка торгового судна, работающего в машинном отделении, который пытается описать бурю в Атлантическом океане, рассказывая вам, сколько дополнительного топлива использовал корабль. Представления специалиста о предмете разговора может быть так наполнено тонкостями, что трудно отсортировать вещи, которые вам действительно нужно знать, чтобы плавать в бурных морях, или делать хорошие детали. Если этот мастер работает с мелкими инструментами, вытачивает шатуны вручную, у него больше возможностей рассказать вам о реальном мире работы с металлом.

1.3 Looking ot engineering from the craftsman's perspective Инжиниринг с точки зрения мастера

With the aid of computers, parts can easily be drawn that can't be built. CAD programs allow a designer to put a perfect .0001" radius on the inside comer of a pocket cut in tool steel. Hopefully after reading this book you will not ask a toolmaker to do it, but if you do, you'll at least know it is going to cost a great deal of money to try. Working with metal is far more difficult than one would imagine. A false impression is gained by looking at the beautiful yet inexpensive machined parts that we deal with daily. They have been produced in very large quantities, and that five-dollar part you may consider a "rip-off could easily cost five hundred dollars if you had to manufacture just one. New engineers will often think a toolmaker is a failure when the seemingly simple part they design ends up costing a thousand dollars to make. Most engineers will eventually have to deal with the craftsman who turn their ideas into reality, and in reading this book I would hope you come away with a new perspective of what is really involved in producing a machined part or a product. An alternate subtitle for the book might have been "Things they should have taught you in engineering school but didn't". This book might be considered your textbook for a course called "Reality 101".

Используя компьютер, очень легко смоделировать детали, которые не могут быть изготовлены. САПР программы позволяют проектировщику поставить идеальный радиус с точностью 0,0001 мм на внутреннем ребре кармана, отфрезерованного в инструментальной стали. Надеюсь после прочтения этой книги вы не будете просить инструментальщика сделать такой элемент, но если вы это сделаете, вы по крайней мере будете знать, что это будет стоить много много денег, даже только чтобы попробовать это сделать. Работа с металлом является гораздо более трудной, чем можно себе представить. Это ложное впечатление сложилось, глядя на красивые, но все же недорогие детали, сделанные на станках, с которыми мы имеем дело ежедневно. Они были сделаны серийно в очень больших количествах, и цена в 5 долларов за деталь, которую вы можете почитать надувательством, легко может взлететь до 500 долларов, если вам нужно сделать одну такую деталь. Начинающие инженеры часто думают что для инструментальщик плох, когда казалось бы простая деталь в итоге оказывается с ценой в тысячи долларов. Большинству инженеров в конечном итоге придется иметь дело с мастером, который может превратить их идеи в реальность, и вы читаете эту книгу, я надеюсь, чтобы сформировать новую точку зрения на то, что на самом деле происходит при обработки детали или продукта. Альтернативным названием для книги могло бы быть "Вещи, которым вас должны были научить в ВУЗе". Эта книга может считаться вашим учебником по курсу с названием "Реальность 101".

1.4 Seeing production from the point of view of both the engineer and machinist Производство с точки зрения инженера и станочника

My perspective on machining could be considered unique because, in order to survive, I have had to deal with every aspect of product design from engineering to prototyping to tooling to manufacturing to sales. In this book I have tried to pass along the logic I used to solve the associated problems. Understanding how a craftsman thinks and works is an essential part of getting projects done. Unless you are willing to build your designs yourself, you are going to have to learn how to deal with the craftsman who will actually build them. The more you know about their methods, personalities and unique problems, the better your chances are for success. Smooth sailing.

Мой взгляд на мехобработку можно считать уникальным потому что, для того чтобы выжить на рынке, я имел дело с каждым аспектом дизайна продукта от проектирования и прототипирования до производства и продаж. В этой книге я попытался объяснить логику моих решений, связанных с этим проблемами. Понимание того, как мастер думает и работает, является неотъемлемой частью получения готовых проектов. Если вы не готовы изготавливать свои проекты самостоятельно, вы все равно сможете узнать, как общаться с мастером, который будет на самом деле их делать. Чем больше вы знаете о его методах, личных и уникальных особенностях, тем выше ваши шансы на успех. Счастливого плавания.

— Joe Martin
— Джо Мартин

Глава 2

About the Author

Joe Martin worked in the construction trades after graduating from high school, but his real love was always building and flying radio controlled model airplanes. When he decided to turn his hobby into a business and start his own company making components for the radio control industry, he had to learn about machining and toolmaking on his own. He simply couldn't afford to hire anyone else to set up the tools and make the molds. He has designed and taken to market numerous products and owned several companies over the years. He began his association with Sherline Products as an importer of Australian-built lathes in the early 1970's. Since then, Joe's company has grown to become the sole manufacturer and worldwide distributor of Sherline machine tools.

Joe was one of the founders of the sport of Formula One model aircraft competition as well as one of its early champions. His competitive nature seems to find its way into whatever form of fun he pursues. He has been a winner in sports from model airplane competition to ocean sailboat racing and, most recently, automobile racing.

Never one to be a spectator in life, he has tried and mastered many skills. In this book, he passes on to you some of his hard-won knowledge about machining. His down-to-earth style is not highly polished. In fact, if you could say that life has put a finish on him, it would probably be described as ground or honed... very accurate but not slick. I think his heartfelt love of good tools and miniature machining will be apparent to all who read this book. Working with him these past 25 years is certainly an experience 1 would not have wanted to miss.

— Craig Libuse

Joe at speed in a 1974 vintage IndyCar at Phoenix International Raceway.

Глава 3

Dedication

Carl Hammons — 1936–1997

Carl Hammons, my friend and business partner for thirty years, died September 11, 1997 as I was writing this book. We shared thousands of lunches and coffee breaks over the years we worked together, and much of the knowledge I have passed on in this book came from Carl. Carl and 1 shared the rare distinction of having been partners not just once, but twice. We both played different roles in putting together the product line, and without him it just isn't going to be as much fun.

When we joined forces for the second time, we had an agreement that eliminated any need to financially justify the purchase of a new piece of equipment. We would buy machines that interested us and find a job for them later. The laser engraver was a perfect example of this, but now we couldn't get along without it. It may seem contrary to smart business practice, but that's the way we did it. I have no regrets, for we were always the happiest when we were confronted with a new set of technical problems. Therefore, I dedicate this book to Carl Hammons; my business partner, my friend.

I should also credit the English teachers in the Cranston, Rhode Island school system for forcing a not-so-willing student enrolled in the "boys general class"to learn enough about our language to dare to take on the task of expressing difficult concepts in simple words. I graduated in 1953. You, the reader, will be the ultimate judge of their (and my) success in this undertaking.

— Joe Martin

The photo composition above is a joint effort. The photo of Cart was taken by his wife Barbara. The photo of Swan Lake, Montana, a favorite spot of Carl's, was taken by friend Wayne Armstrong. The two images were composed in PhotoShop by artist Elaine Collins

Глава 4

Modeling Miniature Machine Tools

You will probably not be surprised to find that people who are interested in miniature machine tools often find it fun to make miniature models of full-size tools. This page shows beautiful examples of a lathe and a mill from two expert craftsmen.

Barry Jordan built a 2"diameter rotary table and then needed a machine to use it on. The result was this 1/5 scale Bridgeport® mill. The project was started in 1997 and completed just in time for Bridgeport's 60th anniversary in 1998. What started as a model turned into a real machine in miniature, capable of actually cutting small parts in mild steel.

The parts are all machined from aluminum and billet cast iron. No castings were used. The polished pulley cover is made from Dural. More of Barry Jordan's miniature tools can be seen on page 246.

This small but fully functional 1/6 scale Hardinge lathe was modeled by Wilhelm Huxhold of Ontario, Canada. A lifelong machinist, he shows his love for machine tools by modeling them in miniature. Unlike Barry Jordan's

Bridgeport, this project took many years to complete. More of Mr. Huxhold's work can be seen on pages 22 and 217. A profile of his career is presented on page 330.

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Joe Martin

Design, typesetting, illustration and photography by Craig Libuse

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To order additional copies of this book call:
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or write to: Joe Martin. 3235 Executive Ridge, Vista. California 92081

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4.1 Machining is not a "paint-by-numbers" process

If you are looking for a book that will give you complete, step-by-step instructions on how to build your particular machining project, this is not it. In fact, that book probably does not exist. What this book will give you is all the basic knowledge you need to start machining metal. Your imagination plus the information in this book will allow you to make just about anything. The many photos showing what others have done are here to spark your imagination. None of the projects shown in the photos in this book came with detailed instructions. Most came with none at all. They are, for the most part, not beginner projects. I'd suggest you start with a relatively simple project and apply what you learn from this book. As your skill and experience increase, you'll be ready to tackle anything you see here. Read the parts about tools and materials. Read the parts about speeds and feed rates. Study the photos of setups carefully. Everything you need is right there, but you have to use some brainpower to apply it to your projects. The level of satisfaction you achieve will be directly related to the amount of effort you are willing to put forth.

The book is now in its fourth printing, and some have commented that it doesn't contain enough project plans. I have avoided adding a lot of "how to"plans in order to concentrate on the general skills, craftsmanship and techniques needed to create a good part. These will never be found in a set of plans. For those looking to take what they've learned here and apply it to a specific project, there are many sources of kits and plans on Sherline's web site at `www.sherline.com`. Several magazines like *The Home Shop Machinist* and *Machinist's Workshop* offer new plans in every issue.

4.2 Thanks to those who helped

Joe Martin and Craig Libuse would like to thank all of those who took the time to read this book word for word and sent in suggestions for corrections in the previous printings. Our thanks go to Marc Cimolino, Jim Clark, Glenn Ferguson Jr., Mort Goldberg, Alan Koski and especially Huntly Millar for their extremely diligent, voluntary efforts. Among other things, this book addresses the issue of quality and the quest for perfection,

so we have made every attempt to eliminate any typographical errors. We welcome your input in a continuing effort to improve the quality of this book. Though rarely achieved, perfection is a goal always worth pursuing.

Часть I

Safety rules for power tools

A patternmaker's interview for employment

One of the best patternmakers I ever knew apprenticed in the trade for many years with his father. When he went to work for U.S. Steel in their pattern shop, the foreman who was interviewing him for the job asked him to hold out his hands. When the foreman could see that the applicant still had all ten fingers, he was hired. The foreman could see from his work that the patternmaker was a good craftsman, but he figured that if he had been working in the trade that long and still had all his fingers he must be a good, safe worker too, and that was just as important.

Spinning tools that are powerful enough and sharp enough to remove metal can also remove just about anything else that gets in their way. Though less dangerous than their larger full size shop counterparts, small power tools can still cause serious injury to those who don't show them the proper respect. Even hand tools used improperly can cause injury. Talking about safety is not nearly as fun as talking about the beautiful miniature machining projects in this book, but working safely is part of the skill of a good craftsman.

Working safely is simply a series of habits that you develop. Once they become habits, it takes no longer and is no less enjoyable to work that way than to work with unsafe habits. Injuries definitely take the fun out of working with tools, and fun is what miniature machining is all about. Please read these rules and apply them until they become habits so that you can enjoy your hobby to the fullest.

1. KNOW YOUR POWER TOOL — Read the owner's manual carefully. Learn the tool's application and limitations as well as the specific potential hazards peculiar to this tool.

2. GROUND ALL TOOLS — If a tool is equipped with a three-prong plug, it should be plugged into a three-hole receptacle. If an adapter is used to accommodate a two-prong receptacle, the adapter wire must be attached to a KNOWN GROUND. Never remove the third prong. (See drawing on next page.)

3. KEEP GUARDS IN PLACE — and in working order.

4. REMOVE ADJUSTING KEYS AND WRENCHES — Form a habit of checking to see that keys and adjusting wrenches are removed from the tool before turning on your machine.

5. KEEP WORK AREA CLEAN — Cluttered areas and benches invite accidents.
6. AVOID DANGEROUS ENVIRONMENT — Do not use power tools in damp or wet locations. Keep your work area well illuminated.
7. KEEP CHILDREN AWAY — All visitors should be kept a safe distance from the work area.
8. MAKE WORKSHOP KID PROOF — with padlocks, master switches or by removing starter keys.
9. DO NOT FORCE TOOL — Do not force a tool or attachment to do a job for which it was not designed. Use the proper tool for the job.
10. WEAR PROPER APPAREL — Avoid loose clothing. neckties, gloves or jewelry that could become caught in moving parts. Wear protective head gear to keep long hair styles away from moving parts.
11. USE SAFETYGLASSES — Also use a face or dust mask if cutting operation is dusty.
12. SECURE WORK — Use clamps or a vise to hold work when practicable. It is safer than using your hand and frees both hands to operate the tool.
13. DO NOT OVERREACH — Keep your proper footing and balance at all times.
14. MAINTAIN TOOLS IN TOP CONDITION — Keep tools sharp and clean for best and safest performance. Follow instructions for lubrication and changing accessories.
15. DISCONNECT TOOLS — Unplug the tool before servicing and when changing accessories such as blades, bits or cutters.
16. AVOID ACCIDENTAL STARTING — Make sure the switch is "OFF"before plugging in power cord.

17. USE RECOMMENDED ACCESSORIES – Consult the owner's manual. Use of improper accessories may be hazardous.

18. TURN SPINDLE BY HAND BEFORE SWITCHING ON MOTOR — This ensures that the workpiece or chuck jaws will not hit the lathe bed, saddle or crosslide. and also ensures that they clear the cutting tool.

19. CHECK THAT ALL HOLDING, LOCKING AND DRIVING DEVICES ARE TIGHTENED — At the same time, be careful not to overtighten these adjustments. They should be just tight enough to do the job. Overtightening may damage threads or warp parts, thereby reducing accuracy and effectiveness.

20. WHEN WORKING THROUGH THE SPINDLE, DO NOT LET LONG, THIN STOCK PROTRUDE FROM THE BACK END OF THE SPINDLE SHAFT — The end of unsupported stock turned at high RPM can suddenly bend and whip around.

21. It is not recommended that the lathe be used for grinding. The fine dust that results from the grinding operation is extremely hard on bearings and other moving parts of your tool. For the same reason, if the lathe or any other precision tool is kept near an operating grinder, it should be kept covered when not in use.

22. WEAR YOUR SAFETY GLASSES — Foresight is better than NO SIGHT! The operation of any power tool can result in foreign objects being thrown into the eyes, which can result in severe eye damage. Always wear safety glasses or eye shields before commencing power tool operation. We recommend a Wide Vision Safety Mask for use over spectacles or standard safety glasses.

4.3 ELECTRICAL CONNECTIONS

The power cord used is equipped with a 3-prong grounding plug which should be connected only to a properly grounded receptacle for your safety. Should an electrical failure occur in the motor, the grounded plug and receptacle will protect the user from electrical shock. If a properly grounded receptacle is not available, use a grounding adapter to adapt the 3-prong plug to a properly grounded receptacle by attaching the grounding lead from the adapter to the receptacle cover screw.

NOTE: Electrical circuits designed into the speed control of the Sherline lathe or mill read incoming current and automatically adapt to supply the correct 90 volts DC to the motor. As long as you have a properly wired, grounded connector cord for your source, the machine will operate on any current from 100 to 240 volts AC and 50 or 60 Hz. without a transformer [1]. This should include just about any country in the world. Prior to 1994, an AC/DC motor was used. Use the AC/DC motor ONLY with the power source for which it was intended. It will not automatically adapt to any other current and using it with an improper power source will bum out the motor or speed control.

GROUNDING TYPE 3-PRONG PLUG
PROPERLY GROUNDED TYPE OUTLET
USE PROPERLY GROUNDED RECEPTACLE AS SHOWN
PLUG ADAPTER
GROUND WIRE

Proper grounding of electrical connections.

[1] The first DC units built in early 1994 did not include the circuits to adapt to other currents. The capability to include that feature was not available to Sherline at that time. As soon as it was, it was included. If you think you may have an early DC model, remove the plastic speed control housing and look. for a label on the aluminum speed control frame. If it has a small metallic label on top of the frame that lists input voltage as 120 VAC, DO NOT ATTEMPT TO CONVERT THIS UNIT TO OTHER CURRENTS. Models that can be used with any current have a paper label on the end of the speed control frame which lists the model number as KBLC-240DS.

Older AC/DC motors available from Grainger

Sherline's supply of older AC/DC motors is slowly being depleted. A very large run must be custom ordered to get more, and this is not economically feasible. However, the Grainger catalog stocks a 1/5 horsepower motor identical to the one used on early Sherline tools. The catalog number is 2M139. They have locations in every state and can be found in the Yellow Pages under "Electric Motors". Their web address is `www.grainger.com`. Your other option would be to upgrade your motor and speed control to the newer, more powerful DC version.

"Common sense is instinct, and enough of it is genius."
— Josh Billings

Часть II

FOREWORD

4.4 What is "tabletop machining"?

Tabletop machining is about operating miniature machine tools. These are machines that can be picked up and set on a small bench or, if need be, a kitchen table, and used to build precise metal parts. They are inexpensive compared to their full-size shop equivalents, but are just as versatile and accurate as long as the size of the part is appropriate for the machine. The "Unimat"was the first miniature lathe mass produced and well known. Thousands of Unimats were sold, and today many are still in use. It had a wide variety of accessories manufactured for it and a price that was affordable. A number of other miniature machine tools have been manufactured since the Unimat, and the company I own, Sherline Products Inc., has become today's leader for this class of machine. I believe the fact 1 am both a hobbyist and toolmaker gave me more insight into what our customers needed when it comes to both accessories and instructions.

The original Unimat lathe was the first miniature machine tool to achieve international popularity. It came in a professional looking wood box and offered a versatile design and many accessories at a reasonable price. Its two-rail bed design made it too flexible for jobs requiring a high degree of accuracy, but it introduced many people to the fun of machining in miniature.

4.5 Beating the system

For me there has always been something special about projects that have been built on these small machines. The machinist who works with miniature machine tools will have beaten the system by not spending thousands of dollars on tools. These craftsmen build beautiful projects for enjoyment, not wages. These are special people who may suddenly have an urge to accurately build that model they have dreamed of for years. The machinists who are successful will realize there is a learning curve involved in accomplishing this. This book is about shortening that learning curve and giving you a new sense of what craftsmanship is all about.

4.6 Not just the “how”, but also the “why”

The tables and charts can be found in *Machinery’s Handbook*, and I don’t plan to duplicate them in this book. Library shelves are full of books of this nature. The information in this book won’t be found in charts and graphs. I’m going to attempt to give you the information to actually start making "parts". Instructions that tell you "how"to do a job too often skip the most basic information, and that is "why"you would want to do a job this way or that way. I believe the customers who purchase miniature machines are intelligent enough to find the specific information they need at a library. These customers just don’t happen to know much about machining. However, I also believe this book contains enough general rules to get a job done. Get started on a project as soon as you have your tools set up and working. Read a little, machine a little. Never cut metal without a plan that includes dimensions. "Making chips"without a plan can develop terrible work habits. This trade has few choices when it comes to parts fitting together. To work in unison they must be accurate, and your first task should be to make parts "to size".

4.7 How to read this book

A book like this doesn’t need to be read from front to back like a novel. You will probably skip around reading first the sections that interest you the most. Therefore, this book may seem at times to be redundant. I have attempted to make each chapter relatively complete in and of itself, and some rules apply to more than one machining operation. Some of the more important ones may be repeated wherever they apply. To keep you interested and make the book more fun. we have included many pictures of actual projects and the people who made them. The examples of what has actually been done using tabletop machine tools speak more eloquently about their capabilities than anything I could say.

4.8 Why Sherline tools are used in the examples

I must say up front that Sherline tools will be used in the examples throughout this book. It is not my intention to use this book as a tool to sell Sherline tools, but rather to use these tools to demonstrate the techniques I am discussing. The reason should be obvious; that is, they are what I have available and what I know the most about. The principles involved in using these tools are pretty much typical of all machine tools, even larger full size shop tools, so what you learn through these examples should be able to be applied to whatever brand of tools you are using. Also, we have sold many thousands of these tools over the past twenty-five years, so the knowledge specific to Sherline tools will be of additional benefit to those of you who are using them as you work with this book. In addition, I hope the information I've included about how this tool line was developed and how our business is run might inspire some of you to follow your dreams and start a business of your own, whether it is in the area of machining or in any area that interests you.

Craig Libuse is seen at the drawing board with author Joe Martin. Craig has been doing all of Sherline's illustrations, instruction sheets, magazine advertisements and catalogs since shortly after Joe started the company in the mid-1970's. He ran his own graphic design studio for 22 years doing Sherline's work on contract before coming on board full time as Marketing Director in 1995.

According to builder Edward J. Young of Mobile, Alabama, this model Stuart 10H steam engine runs "smooth as silk" when powered by compressed air. The inset photo shows the plexiglass cover he made to replace the plate over the valve so its action can be viewed as the engine runs.

Глава 5

INTRODUCTION

5.1 The essence of “craftsmanship”

I wrote the introduction to this book last. That’s because when I started writing, I didn’t quite know where I was headed. I knew that over the years I had written many instructions for our products which contained enough knowledge and advice to be valuable. I also figured I could start writing answers to questions that had been asked of me over the years. I could fill the remainder of the book with pictures and charts and end up with a book that wouldn’t be any different or better than what was already out there. For me, therefore, the most important part was to try and instill in a potential machinist the value of good craftsmanship. Great craftsmen not only get the job done, they add a certain "look" to parts they build. It is almost a signature. I have seen the same part made by two different craftsmen using the same drawing. They were both highly skilled toolmakers. Both parts met the specifications perfectly, yet I could easily tell who built each part. Machining should be considered a form of art.

5.2 Some pretty good advice

Professional photographer, Tim Schroeder of Michigan built these five identical Stirling hot air engines to polish his skill as a new machinist. By making each part five times, he was able to get in more machining time with each setup and learn more in a shorter period... a pretty good way to learn.

On the wall of my Uncle's shop when I was a boy was a sign which I still remember. I'm not sure who said it. but I think it expresses what I'm trying to say pretty well. It said:

"A man who works with his hands is a laborer.

A man who works with his hands and his brain is a craftsman.

A man who works with his hands, his brain and his heart is an artist."

When I was building model aircraft, my friends and I had an interesting way of judging the quality of a model. We would set the model aircraft on the ground and start backing away from it until it looked good. A three-foot model would be considered superb and a fifty-foot model was one that was pretty crude. There were also models that wouldn't look good no matter what the distance was or the viewing angle. In those cases, the failure was in the design, and the best craftsman in the world can't make a bad design look good.

5.3 The best design is usually not your first design

The home machinist usually has more control over a design he is working with than a professional does. Don't use the first idea that comes into your head without proving to yourself that it's the *best* way. When a product has been designed properly, no one would even consider building it in a different way.

It is the way it is supposed to look because it's obvious. Unfortunately, these are the designs that are the hardest to come up with. They are also the designs you will get the least credit for even though they are your best. The assumption is that the obvious solution is also the easy solution, but this is usually not the case. The home craftsman also doesn't have to work within the constraints of commercial products where costs limit your choices. For us, time is not money, it's fun!

This is what craftsmanship is all about. Too few citizens really appreciate what good craftsmen do, Because their work doesn't fail it is taken for granted. A good craftsman can tell at a glance when someone's work is better than his, and he can start improving his work to be Number One, It is almost a form of competition between craftsmen where time and quality are considered at the same lime. Do you think Michaelangelo would be considered a great artist if he had only carved one statue and painted one picture? He produced so much good work in his lifetime that he set a standard that is still sought after today. One good part doesn't make you a craftsman. You are judged on the body of your work.

Author Joe Martin is shown with some of the miniature machine tools produced by Sherline Products. The small size of miniature machine tools makes them easy to use and not too intimidating for new machinists.

I not only wanted my writings to be useful to the hobbyist/machinist who builds parts for pleasure. but also to those future craftsman who want to build parts that have that "look". Please realize the parts being referred to in this book are not production parts. Machinists who produce these kinds of parts have the training and skill to make automatic machines build good parts. The only thing an automatic machine will manufacture automatically is scrap. It stilt takes that craftsman's touch to make machines run perfectly. The parts being discussed in this book will be parts built one at a time... "one off. These parts are usually part of another assembly that would be considered the final product.

5.4 You don't become a machinist by buying a machine

You should strive from the beginning to make better and more accurate parts than you think you need. Work to closer tolerances than the job demands. Be on the lookout for ways to make a job easier or better. I hope you will enjoy the process of creating accurate parts from raw metal. Buying a machine won't make you a machinist, but using it along with the skill and knowledge you acquire along the way eventually will.

5.5 What new machinists like most and least

If you are new to machining, you may find it to be either one of the most rewarding skills one can learn or the most frustrating thing you have ever attempted. What makes machining fun for some is the complexity and challenge. The same thing will drive others up the wall. One person may be overjoyed because he can now make parts that were not available for purchase. Another may wonder why he just spent all day making a part that is similar to one he could have purchased for two dollars. (The difference, of course, is that it is not the same as the two dollar part — it is *exactly* the part needed.)

Jewel-like projects like this miniature marine winch are a showcase for the kind of craftsmanship machinists strive for. Being able to display your work on a desk or coffee table or even carry it with you in your pocket is an advantage of working on small projects.

5.6 There are no shortcuts

Machining is a slow process because parts are made one at a time. The interesting thing is, a skilled machinist may take almost as long to make the same part as a novice. Shortcuts usually end in failure. Unlike some other trades, mistakes cannot be covered up. There are no erasers, white-out or "putting-on tools"for machinists. You simply start over. Do a lot of thinking before you start cutting. To expand a little on an old rule: "*Think three times, measure twice and cut once!*"

5.7 Anticipation of a tool's limitations is the crafts man's strength

The skill in machining isn't just "moving the dials". It is a combination of engineering and craftsmanship. A file is just as useful a tool to a machinist as a multi-thousand dollar machine tool. Tools "deflect" or bend under load, and anticipating this bend is what it is all about. Sharp tools deflect less than dull tools, but with each pass the tool dulls a little and the deflection becomes greater. If you try to machine a long shaft with a small diameter, the center will always have a slightly larger diameter than the ends because the part deflects away from the tool where it has less support. You can go crazy trying to machine it straight, or you can simply pick up a good, flat mill file and file it straight in a few moments. Machine tools will never replace the "craftsman's touch and machining is a combination of both good tools and good technique.

5.8 The great parts about running a business like this

I'm a hobbyist who has been lucky enough to make a living at a hobby I enjoy. I own and manage Sherline Products Inc. and enjoy coming up with new products. After working at if for over twenty-five years, this has become more of a hobby to me than a business. I still work the same number of hours, but it's more fun now that I don't have to worry about making payroll. I have a good staff to take care of the day-to-day business, and I get to spend most of the day thinking about better ways of doing things and deciding which new products to make. I appreciate it all the more because it wasn't always that way. At first I had to do it all; buying and maintaining machines, making parts, assembling, packaging and shipping them, doing the bookkeeping and paying the taxes. I realized I had reached a real benchmark in business when I found that a product had gone from raw material to delivery and 1 didn't know one thing about it.

Here's a miniature machine tool you won't often see. The ManSon lathe is a fully functional miniature machine tool made in the 1940's by a Los Angeles company. It had a number of accessories available, but its extremely small size limited the projects you could actually make on it. It is one of a number of miniature machine tools collected for display by the author. (Sherline chuck and toolpost are for size comparison.)

5.9 The satisfaction of watching others progress

Another thing I enjoy is determining how a particular part will be run through the shop. Designing new products has become easier for me now because of the wide assortment of tools we own — about a million dollars worth. In 1985, I could set up and operate every machine I owned, but that time has passed. I don't operate my own machines now because they are too complex to casually start pushing buttons. I have to rely on my employees, and I get a lot of enjoyment out of watching employees progress as they become accomplished craftsmen in their chosen trade. However, I still don't believe anyone in the shop knows more about making good parts than I do. I may not know what button to push any more but I'm still the best at solving problems in the shop. I've learned a lot about machining over the last 30 years and I'm going to try to pass on some of that knowledge. Because of my experience 1 can compare methods used by a hobbyist and a professional machinist. I've have also added information that I hope you will find interesting about machining. It will give me a lot of satisfaction if I inspire readers to strike out on their own and start a new business with a product that has been "prototyped"on Sherline machines.

5.10 The Inspection Department only finds mistakes after it's too late

Most of this knowledge I've gathered has been learned the hard way because money was too tight to hire experts. At Sherline we make all of our own parts and only contract out the plating, heat treating, and powder coating. In the past, we have also done a lot of contract machining and I've learned the problems one can get into by finding errors in the inspection department. It's just too late. Parts must be inspected as they are built, not after. Errors found after the parts are made mean you start over. Design errors found after the parts are made will always result in scrap. The only difference is who pays for the scrap.

5.11 Work extra hard to eliminate errors when "the chips are down"

I've never met a good craftsman who wants to do a job over, even when he is getting paid for it. It goes against his nature. I have also never met a good craftsman who has never had to do a job over because of his own mistakes. This is a good time to stay away from him, because he is mad at himself. The fact is, you can't work with this many types of tools, dimensions, and materials without making an occasional error. The trick is not to make errors when it counts. Good toolmakers will work with an entirely different attitude when they are making an inexpensive fixture than they will when working on apart that has thousands of dollars worth of material and labor in it.

5.12 Inattention can lead to more than just scrapped parts

You can't have a couple of beers and machine good parts. The job is too demanding. Machining is a serious business. Inattention can result in scrap or, worse yet, injury. You can always make another part but you can't grow a new hand. Even a machine as small as a Sherline lathe or mill can give you a nasty cut. Machinists may have to work for days at a time with their hands in close proximity to moving cutters and parts, yet there are few injuries. They pay attention to what they are doing.

5.13 The credit for a good part goes to the craftsman

Good craftsmen know when they have made an exceptional part and get much satisfaction from it. They also have the ability to produce good work on machines that should be in a junkyard. It just takes them longer. I have a great respect for good craftsmen, because they have to work without excuses or erasers. I try to keep reminding you of this fact in this book, because it is the craftsman, not the machine, who builds the beautiful things we see daily in this world. Modem machines have given this talented group of people a way to produce more and better work, but it will always be their "touch" that makes those parts beautiful. In my eyes they just don't seem to get enough respect.

5.14 An open invitation

If you ever travel to San Diego, California, the Sherline factory is less than an hour away to the North. It's also about two hours South of Los Angeles. I always offer an open invitation for anyone to stop by to see how modern production machines produce parts used in Sherline tools.

"You've achieved success in your field when you don't know whether what you're doing is work or play."

— Warren Beatty

Sherline's facility has a showroom where you can see the entire line of tools and accessories as well as some sample projects built on the tools. Factory tours are available for anyone who would like to see how miniature machine tools are manufactured.

Часть III

PROJECTS... A gallery of miniature craftsmanship

This section is devoted to showing you some of the great projects made on tabletop machine tools tike those discussed in this book. After all, it isn't really the tools you are interested in so much as what can be made with them. A column of figures about the size and accuracy of a machine will tell you how big it is and how well it is built, but it still won't tell you what can be built with it. These photos are some of the most important in the book because they show what these tools in the hands of craftsmen have actually done. And yet, as impressive as some of these projects are, they still only represent the best of what has been done to date, not the best that will ever be done. That is up to you.

Hundreds of years ago, craftsmen made timepieces and mechanical calendars that required tremendous precision. Modelmakers made tiny ships in bottles and detailed display models of ships. In fact, before naval architects began drawing plans of ships and shipwrights knew how to read them, ship designers built models and the builders used that as a guide. Despite the quality, accuracy and detail of these old projects, the tools they had to work with were crude by today's standards. As tools and materials have improved, it has become easier and more fun to make very precise parts. Almost all of the projects shown here were made by hobbyists, not professional machinists. If you have patience, some skill with your hands and a desire to make projects like these, today's tools will bring you a lot of satisfaction and enjoyment. There is not a project here that couldn't have been built on a tabletop in your own kitchen, den or home shop.

An American quarter and dime are used for size reference in many photos in this book. For those outside the United States who might not be familiar with these coins, they are shown here at actual size. A quarter ($.25) is .950" or 24.1 mm in diameter, while a dime ($.10) is .705" or 17.9 mm in diameter.

Steam tractor, Dennis Franz, Newton, Kansas

A lot of detail is packed into a very tiny package. This model won 2nd prize at the 1995 Sherline Machinist's Challenge contest in Michigan.

Stover "hit'n miss" gas engine George Luhrs, Shoreham, New York

Paint and pinstripes add a nice finish to this model which finished 4th in 1995. It has a 7/16" bore and 5/8" stroke. The speed control is quite detailed and complicated.

1/12 Ferrari V-12 F1 Engine Bob Breslauer Ft. Lauderdale, Florida
Approximately 1500 hand made pieces went into this display model engine and transmission. More photos of it can be seen in the profile on Bob on page 311 at the beginning of Section 5.

Single action steam engine Chris Thompson Colorado Springs, Colorado
At the extreme small end of the size scale is this tiny steam engine with a 1/8" (3.2 mm) bore and stroke.

Gattling gun, George Britnell, Strongsville, Ohio
This walnut and brass gun took 3rd place in the 1995 Sherline Machinist's Challenge contest. The barrels rotate and the elevation mechanism also works. The quality of finish on every part is superb.

Miniature micrometer, Dennis Scherf, Cedarburg, Wisconsin
Miniature tools are a popular subject for modelers. This tool and felt-lined box can easily be carried in a pocket and is a great "conversation starter."

Air Compressor, steam engine and miniature tools Kurt Schulz, Harper
Woods, Michigan Not just a steam engine, but the air compressor to drive it too, this handsome model is an interesting combination of round and hard edged parts, satin and shiny surfaces. At the bottom are some other of Kurt's projects: a miniature height gage and two small mill vises sitting on a ground surface plate. The small vise would make an interesting tie tack!

Hot air engine, Scotty Hewitt, Van Nuys, California
This delicate engine is powered by the difference in temperature above and below it. Set it on a hot cup of coffee, give it a turn and it will spin like crazy for over 15 minutes. Scotty produced a short run of these to sell in toy stores.

Lunkenheimer oiler, Jerry Kieffer, Deforest, Wisconsin

Just like the full size prototype, this tiny oiler delivers measured amounts of oil to a bearing or cylinder. The "sight hole" through the base allows the engineer to check the drip rate visually.

.010 Diesel model aircraft engine

A simple design and nicely made aluminum parts make for an interesting little engine. Not much in material cost here!

1/30 Corliss steam engine Jerry Kieffer, DeForest, Wisconsin

(Below) This model represents Jerry Kieffer's determination to build to scale down to the smallest detail. Even 1/4-20 bolts are scaled to 1/30 size. Though modelers will often use hidden springs to return the valve gear, the "pots"at the bottom actually pull a vacuum just like the real ones. A portion of a quarter can be seen at the bottom for scale. (More on Jerry and this engine can be found on page 112.)

Above is a photo of the real 1909 Viltcr Corliss engine Jerry used as a prototype for his model. It can be seen in a steam engine display in Sussex, Wisconsin. It is said to produce about 200 horsepower at 90 RPM, had a 15" bore and 36" stroke and a 10-foot diameter flywheel. The Vilter company still exists in Milwaukee and now makes refrigeration equipment.

This masterfully built model runs flawlessly on air supplied from a tiny aquarium air pump. Though others told Jerry he would not be able to achieve good performance in a model this small if he insisted on scaling every part, he proved them wrong.

The photoengraved name plate is typical of Jerry's devotion to detail. Notice the hollow air line going into the large brass elbow. It has a functional compression fitting and is made from a hypodermic syringe needle.

U.S.S. Roosevelt Richard DeVynck U.S. Virgin Islands

This model is now on display at the Bowdoin College Museum in Maine. To the left is a detail of the ship's boiler. Below can be seen the stack and some of me deck details. The model is left unplanked so that all the interior details can be seen.

1 -Cylinder 4-cycle overhead valve model airplane engine Ron Colonna, McKeesport, Pennsylvania

(Above) Ron built this engine from a design by Eric Whittle of England. The highly polished pieces and wood base make it a good display as well as a nice piece of engineering.

3-Cylinder engine, Jesse Brumberger, Macedon, NY

(Above left) This radial model airplane engine was an entry in the 1996 Sherline Machinist's Challenge.

Assorted small projects, Robert Culpepper

(Left) A small shop can tum out plenty of nice work.

Robot Hand, Carl Hammons, Escondido, California

Joe's partner Carl was interested in robotics and motion control. He built this 4" hand to test a concept he had in mind for gripping.

Fantasy Gun, John Winters, Seattle, Washington

Lost wax castings and machined parts are combined in this air powered, B-B firing gun that looks as if it came straight from a Buck Rogers episode.

Custom silver key ring, Jim Grabner, Leucadia, California

The spiral and radial geometric pattern on this silver key ring helped it win a blue ribbon at the San Diego County Fair in Del Mar. Projects like these are not what comes to mind when most people think about "machine tools but in the hands of a creative person, a good tool makes many things possible. Jim used a rotary table on the mill to create the patterns.

Hula-hula radial engine, Russell Kutz, Clinton, Wisconsin

(Left) This engine gets its name from the interesting action of the six oscillating radial cylinders.

1/6 Porsche piston and cylinder Pete Weiss, Escondido, California

(Above) As part of a project to build a running 1/6 scale Porsche flat 6-cylinder engine, Pete has so far built a number of the components. See page 120 for more photos.

Gap frame stamping press Glenn Busch, St. Clair Shores, Michigan

Here are two views of a solidly built and nicely finished model. The contrast of brass and aluminum parts give it a very rich look.

Gyroscope Tim Schroeder, St. Joseph, Michigan

(Right) This nicely finished gyroscope includes details like lightening holes in the support arms and chamfered holes and edges on the wheel. Tim is a professional photographer, so even the photos of his work are done with great attention to detail.

Marine engine and drill press/Water pump Scotty Hewitt, Van Nuys, California

Scotty's main project won 1st place in the 1995 Sherline Machinist's Challenge, but he also took 5th place with this one. To the right is another of Scotty's projects; an air powered water pump. Scotty's work always combines many materials, skills and a lot of imagination. Notice how the wood bases add a finishing touch like a good frame on a nice painting. For more photos and a profile on Scotty see page 24.

Radar study model Frank Libuse, Carlsbad, California

This waterline model was used to test radar targeting systems for antiship missiles. A number of small deck fittings had to be fabricated from metal. Simpler models were also made to see how much detail was needed for a missile to be able to recognize and target a particular ship.

Frank is a pilot and industrial designer who started his own design firm and industrial model shop after retiring from the Air Force. He is also Craig's father. and Craig worked with Frank for several years in the design and model business before starling his own design firm.

Miniature Stuart 10V steam engine Chris Dinardo Springfield, Illinois

The large hex bolt used as a display base really points out how small this engine is. Despite its small size, all the working details are still there, modeled in bronze, brass and steel.

2-Cylinder marine engine Raymond Hasbrouck, New Platz, New York

(Below) This model exhibits a nice combination of materials and finishes. Notice the engine-turned pattern on the base. The custom propeller is an interesting project all its own. (To learn how to make one, see page 56.)

Thimble steam engine Richard Long Wichita, Kansas

(Above) This tiny butane powered engine drives a stamping mill. Using the thimble as part of the design is a clever way to emphasize small size.

Model airplane display engines Edwin Teachworth, San Diego, California

This display model of a 1911 compressed air engine was built for an exhibition on the history of model aviation at the San Diego Aerospace Museum. Though it looks like metal, it is made from cut and machined styrene components and painted to look like metal. Styrene is easy to work with, glues together quickly and is popular for modeling.

This is another display model from the same exhibit and is a model of a Stringfellow steam model airplane engine. It is made from a combination of materials including styrene, wood and brass. The original engine won a prize for engine design in 1868 and developed about 1 horsepower. Display models need only look like the prototype, while function is less important than looks, cost and ease of building.

Stop motion animation dog, Tom Brierton, Illinois

With all the joint movements of a real dog, this framework is covered in clay and then photographed one frame at a time as it is moved in progressive steps.

Pre-lubricator for steam or air engine Salvatore Rubino, Naperville, Illinois

This device provides oil under pressure to lubricate bearings before an engine is started. This extends engine life substantially since most wear occurs when bearings are dry.

Scroll saw and die filer conversion Milo Bresley, Bloomington, Minnesota

Mr. Bresley designed and built a die filer and scroll saw powered by his Sherline lathe. The die filer is driven by the "Scotch yoke" principle. Many people find the chief source of enjoyment in their hobby is designing and making new accessories for their machines. It not only provides a fun and challenging project, but your machine shop is that much more complete when you are done.

Quick-change tool holders Roland F. Gaucher, Spencer Massachusetts

This working model of an Aloris toolholder is built 3/10 the size of the #1 size holder used for full size machines. These holders follow big machine practice, allowing tools to be quickly locked onto a special dovetailed holder. This is another good example of using the tools in your shop to build accessories to make your shop that much better equipped.

Model hot rod, Augie Histano, Miami, Florida

This 1/25 scale hot rod won the top national award for model cars. Shown here is just the engine and frame. Notice the scale Jaguar independent rear suspension made up of almost 100 separate parts.

Custom model boats and engines Don Martin, Sacramento, California

Don's small shop turns out some excellent R/C drag boats. ЛИ his tools are within easy reach and a vacuum cleaner rests under the

(Above left) High performance machined out-drive components and exhaust tips sparkle on Plum Nasty's transom.

(Left) A Connolley V-8 with supercharger sits on its test stand. The rig provides readings on temperature and RPM.

Shown above is the front part of the hot rod engine being machined from an aluminum block. Behind it is the photo of the actual Ford 427 engine Augie used for reference in detailing his model. More on Augie and his award winning models can be found in a profile on page 180.

Double Corliss steam engine Wilhelm Huxhold West Hill, Ontario, Canada

This beautiful and ambitious project demonstrates why retired machinist Wilhelm Huxhold's work is considered among the best being produced. The closer you look at every part, the better they look. Although Mr. Huxhold's shop is equipped with many full-size machines, his favorite projects are very small in size and are well within the capabilities of the tabletop machine tools discussed in this book. Now that he is retired, he still puts in a full day's work, but he gets to choose the projects.

Triple expansion steam engine (left) and machinist's vise (above)

This highly detailed steam engine won the 1997 Sherline Machinist's Challenge contest. The vise is only a few inches long and duplicates every detail of the original right down to the engraved angle scale. The handle is removable.

Naval cannon display (left) and steam engine (below) Timmy Perreira, Haiku, Maui, Hawaii

This 17th Century 24-pound naval cannon is set in its own diorama. The ship's deck setting adds a sense of purpose to the brass and oak cannon. Below is a Rudy Kouhoupt-designed steam engine Mr. Perreira built from brass, aluminum and cold rolled steel.

Часть IV

Scotty Hewitt...as much an artist as an artisan

One of Scatty Hewitt's fun projects — a 1930's air powered race car. For more on Scatty, see the next page.

Scotty Hewitt of Van Nuys, California is a relative newcomer to miniature machining. Scotty spent his life as a race car driver, but miniature tools always held a fascination for him. After seeing a Sherline display at a hobby show he decided to take up the hobby. Joe traded him a Sherline mill in exchange for some lessons in driving a race car. Since then his skills as a machinist have improved much faster than Joe's have as a race car driver, but a chance meeting took each of their lives in a new and fun direction.

Scotty's work is the perfect example of a craftsman developing an artistic style of his own. The toy-like quality of his models combines finely machined metal parts with brightly colored, hand carved wooden bodywork on his race cars. His marine engines are also nicely displayed on wooden bases or in models of skiffs and tugboats. The appeal of his work has been put to the test in Sherline's Machinist's Challenge contest at the North American Model Engineering Society's show in Wyandotte, Michigan. As judged by the show's spectators, Scotty's work won first place for three years in a row.

The projects Scotty produces are not copies of other people's work nor are they built from standard kits or plans. They are uniquely his own. Scotty builds not just with his hands or with his brain but with his heart as well. He is a machinist, but more, he is also an artist.

This bright red racer won 1st place in the 1996 Machinist's Challenge. Probably not the best machined or most complicated entry in the contest that year, it did have a special appeal that spanned the range of spectators who do the voting on the contest entries. Just about everybody who voted gave one of their five votes to this car.

Building things that are fun to display is part of the joy of tabletop machining. You don't have to be a machinist to appreciate a project like this. When friends or grandkids see it on your display shelf you get the added satisfaction of being able to say, "I made it myself."

Project: 4-cyl. oscillating marine engine

(Left) One of Scotty's first winning projects was this marine engine which won first place at the N.A.M.E.S.

contest in 1994. It features a throttle, lubricator, drain valve and forward and reverse mechanism which are all fully functional.

(Above) In 1995, Scotty made the engine in a much smaller size, displayed it in a model of a wooden skiff and took first place again.

Project: 5" Steam tugboat

This little tugboat is another good example of effective display and features a fully functional marine engine and boiler made from brass. It finished 3rd place in the 1996 N.A.M.E.S. contest.

Project: 5" CO_2 powered vintage racer

Under the hand carved wooden body is a complete frame and CO_2 engine that drives the rear wheels. The hand carved driver also adds a lot of character to the project and shows another facet of Scotty's skills as a modelmaker. The detailed display background makes the car seem much more real. Except for the quarter in the foreground, the photo looks almost as if it could have been taken at a race track in the 1930's.

Scaled-down machine tools and complete miniature shops are always popular subjects for machinists. Notice the details like charts and clocks on the wall.

These two excellent shops were seen at the North American Model Engineering Society (N.A.M.E.S.) Exposition in Wyandotte, Michigan. Both date from the days when machines were driven by a system of overhead pulleys and belts.

Mike Foti is a young man in his 20's hailing from Hillsboro, Oregon. He designed and built this American LaFrance hot rod fire truck, forming the bodywork by hand from brass and soldering the pieces together. All the small parts are machined. It was built to compete in the hot rod division of the national modeling contest in Salt Lake City for 1999. Mike is among the new generation inspired by the work of master modeler Augie Hiscano.

(See profile on page 180.) Although he didn't beat Augie, he got some good tips from "the Master" and will be back with even hotter projects in the future.

Robert Shipley of Knoxville, Tennessee designed and built this case to display an old clock from the dashboard of a 1920's automobile. The case is detailed identically on the back where the works of the clock can be seen behind the glass cover. In addition to providing protection, this case turns a simple clock into an impressive display.

Часть V

SECTION 1 — General Machining

Глава 6

Chapter 1 — Getting information on machining

6.1 The book every machinist needs

People new to machining are bound to have many questions. How fast should I turn my cutter for a particular material? How do I figure out the pitch of a gear? What are the tolerances for a "sliding fit"or a "press fit?"The most traditional sources for this type of information are books that can be found in your local library or bookstore. On-line sources like `www.amazon.com` and `www.barnesandnobel.com` make shopping for books even easier.

The single source I have always turned to first is *Machinery's Handbook*, which is published by Industrial Press. This book has been published since 1914 and is updated every few years. The small but thick book has over 2500 pages of information. A larger "easy-read"version is also available.

I used to recommend this book without reservation and always suggested that a purchaser get the most recent version available. After picking up a copy of the latest edition, however, I am inclined to change my opinion on the subject. 1 have noticed that the direction Industrial Press has chosen to go with the book is to direct it more to the engineer than the machinist. Information about machining has been deleted to make room for information about the strength of gear teeth and other details that will never be of concern to the average machinist. In light of this development, I now recommend that rather than coughing up $80.00 for the latest edition, you can get all the valuable information you need about machining and save money too by buying a used earlier edition from a used book store or over the Internet. Auction sites like eBay.com often have issues for sale. The most valuable information on metals, formulas and processes hasn't changed significantly for the past few years, and the 20th will probably provide all you need for a lifetime of machining. Use the money you save to buy an accessory or another book.

Machinery's Handbook should be considered the basic reference source for metalworking questions.

6.2 The Internet gives instant access to a world of information

If you are one of those who is resisting getting hooked up to the Internet, you are putting yourself at a great disadvantage in today's world. With computers as cheap as they are now, there is no excuse for missing out on this great resource. A connection to the Internet gives you access to search engines that can find information about any subject almost instantly. Newsgroups can also put you in touch with others who share your interests and allow you to ask and answer questions about your hobbies. You also have instant access to product information about tools, accessories, raw materials and other resources for your hobby or business. More importantly, you will be missing out on a lot of fun, as, in addition to pure information, the Internet also gives you access to personal sites that feature projects made by many talented individuals. You may even find that you want to have a web site of your own where you can display your machining accomplishments to the world.

With a computer, a scanner or digital camera and an Internet connection, you are plugged into a new world of information. Internet access can cost as little as $20 a month or less for a regular phone line connection to $50 or more a month for higher speed connections. It just depends on how fast you want the pictures and information to load on your screen. They say "time is money."and in this case, less time is more money.

6.3 Search Engines do the work for you

It amazes me that I can type in a few words on a search engine and have it search the entire worldwide web for those words in a few seconds. For example. I just did a search for the word "lathe" on my favorite search engine, `www.google.com`. It took just .15 seconds to return a list of 183,000 sites using the word lathe. Of course, if I were looking for more specific information, I would have refined my search with other words like a brand name or model number, but the fact that a free resource can search so much information so quickly is simply incredible. Keep in mind that, unlike an encyclopedia, anyone can post information to the Internet, so the responses turned up by your search have to be judged by you as to their authenticity and reliability.

6.4 Newsgroups and chat groups

There are special interest groups on virtually any subject you can think of where people of like interest can ask and answer questions by e-mail. Machinists have many groups they can join that can be about machining specific projects like steam engines or about using specific machines like Sherline tools. For example, the Sherline group can be found by going to `http://www.yahoogroups.com` and doing a search for the word "Sherline". As of June, 2001 the group had 579 members.

Newsgroups generally offer a list of "threads" of conversation that you can read. If you feel like responding, you can send your message to the group via e-mail. Your message will be posted and others can respond to it, Chat groups are more personal and are more like talking to other people through your keyboard. You type a response and the answers pop up on the screen as fast as others who are on-line at the time can type them in.

6.5 Model engineering societies and clubs

There are local and national groups for modelers and machinists that have meetings and shows. This can be a good source of meeting people in your area that not only share your interests but who can also help you in learning a new skill. They may have tools that you don't for special jobs or they may have experience in an area like heat treating or casting that you need to learn about. A couple of examples are the North American Model Engineering Society in the Midwest (`www.modelengineeringsoc.com`) and the Pacific Rim Model Engineering Society in the West (`www.evmes.org`). These organizations each have an annual show that is open to the public. Many areas also have local metalworking clubs that meet monthly. This can be a great source of information for the new machinist, because it puts you in touch with people with years of experience who are willing to share their expertise with you. A list of local clubs that have web sites can be found at `http://www.metalworking.com/clubs.html`.

6.6 Robot battles on TV

This is a little off the subject of learning about machining, but a new trend on television has the potential to bring a new and younger audience into machining. Several television shows now offer competition for home-built robots that include speed and agility tests as well as the ultimate test of a person's building ability — competition. While some robot purists see this as a negative portrayal of robotic abilities, I see it as an excellent introduction to the need for precision metal parts for a whole new group of young thinkers and builders. Shows like Comedy Central's BattleBots® and The Learning Channel's Robotica® follow the lead started by a British show called "Robot Wars."Events include racing around a figure "8"course or through a maze of obstacles. The final winners are usually determined in bot-to-bot combat. Although these "robots"are actually just armored radio-controlled vehicles, they do exhibit many innovative features and it requires a great deal of skill to build a winner. Despite the juvenile over-dramatization of some of the shows, the heart of the matter is that they are getting kids thinking about actually building things that will stand up to the riigors of competition. I feel this is a healthier trend than encouraging them to simply lose themselves in video games, and I hope that its success will lead to more bright kids finding satisfaction in building things. This is the group that will become the future engineers and designers who will shape the inventions of our future.

6.7 So universal they mode toolbox drawers just to hold it

Toolboxes made for machinists have a number of flat, felt lined, drawers to hold cutting tools and measuring instruments. In addition, many have an oddly shaped vertical drawer right in the center. It was designed to hold Machinery's Handbook. It was and still is considered as important as any other tool in the machinist's toolbox.

This old machinist's toolbox was made by H. Gerstner & Sons. The company is still producing high quality wood toolboxes. The clock must have been added by the machinist who wanted to know when it was getting to be "quittin'time".

Глава 7

Chapter 2 — Do you need a lathe, a mill or both?

The lathe and the vertical milling machine each have their place in the machine shop. Though the lathe is a basic metalworking tool, the mill is the workhorse in most machine shops. Unless your needs are very limited, you will eventually need the capabilities of both to be able to accomplish all your machining tasks.

7.1 Which tool is the most important when getting started?

The lathe is the first complex piece of machinery an apprentice machinist will use to cut metal. A mill is the machine an apprentice machinist will use to make his or her first complex part. Lathes have always been a great way to leam about cutting metal, but as soon as you have that urge to build a miniature version of a steam engine, you'll find out that a mill is needed more than a lathe. The truth is, to make complex parts you need both. I would estimate I have spent 90of my time working with a mill compared to a lathe; however, when a part has to be turned and threaded you need a lathe.

A lathe is a good place for a novice to start. It will allow you to find out about cutting metal and requires a smaller investment. I don't recommend buying every metal cutting tool in sight until you know you like cutting metal. Metal cutting is a complex, slow process that should be enjoyable before any large investment is made. I would suggest that if your funds are limited and you still want full machine shop capabilities, get started by buying the best mill you can afford and the least expensive lathe you can get by with. The reason is that most likely the majority of critical operations you will perform will require a vertical milling machine.

7.2 The difference between mill and lathe isn't just square or round parts

The main difference between a lathe and mill is that the work turns on a lathe while the tool turns on a mill. Most people believe the difference would be rectangular vs. round material. This isn't true. A four-jaw independent chuck can be used to hold a rectangular part on a lathe. Four-jaw independent chucks allow the work to be mounted with the center being wherever you want it. The only problem is the offset weight of the part can make for a very out-of-balance setup. When tools are cutting, the material being cut doesn't care which is turning, and the same cutting speed laws govern the process whether it is a lathe or mill. Old manuals on machining will show many ingenious setups using lathes. Mills were slow to catch on because the end mills we use today were not available. The new tool steels that improve modern day cutting tools constantly affect the design of the machine tools to which they are mounted as engineers take advantage of these new materials and products.

7.3 Milling with a lathe and vertical milling column attachment

Sherline has an attachment to turn a lathe into a mill that works well as long as the work is small enough. A lathe doesn't have to be as rigid as a mill because the cutting loads are lower; therefore, in this configuration the XY portion will not be as rigid as a mill. This accessory is called the vertical milling column. It is basically the same as the vertical slide on the Sherline mill; in fact, the vertical column attachment that is presently manufactured could be bolted directly to the XY milling base. The headstock/motor/speed control assembly from the lathe is exactly the same as the one used on the mill and can be switched from one to the other in less than a minute. This allows a novice to work or buy his way into miniature machining a little at a time.

To summarize, money saving alternatives that would allow both lathe and mill operations to be performed would then consist of 1) a lathe with a vertical milling column, or 2) a lathe and mill XYZ base. The headstock/motor/speed control unit would be switched back and forth between the two machines saving the cost of duplicating a second drive unit. The first alternative is the least expensive but results in slightly reduced milling capabilities. If most of the parts you make are turned on a lathe and you only occasionally need to do a milling operation this would be a good choice. The second alternative, although it takes a few seconds to change drives from one machine to the other, results in no compromise in milling capabilities.

Maybe we'd better rethink the pricing on this new accessory just a bit...

7.4 Pricing based on the "flinch factor"

In the future we may manufacture a mill that could be turned into a lathe, but that would result in a higher initial investment for customers. I try to come up with prices that are set by what I call a "flinch factor". This is what prospective customers automatically do when they find out what something costs at a trade show. If they walk away without asking any questions, the price may be too high. If they take out their hard-earned money on the spot and buy one, it may have a price that could be raised. I price things accordingly, and I don't necessarily make the same percent of profit on each item. I try to make a profit on the overall product line rather than each item. I guess I will always be more of a hobbyist than a businessman.

7.5 Inch vs. metric machines

Machine tools come calibrated in cither inch or metric increments. Choosing a system of measurement will be one of the more basic choices you will have to make. For a more thorough discussion of the advantages and disadvantages of each system see Chapter 5 in this section on measuring. The simplest advice I can give is to buy a machine in the system you are most familiar with and for which you already have measuring tools. If you grew up with the inch system, buy an inch machine. If you think in millimeters, buy a metric machine. All Sherline tools and accessories are offered in cither system at the same price. There is no significant advantage in accuracy to a machine calibrated in one system as opposed to the other.

Converting dimensions from one system to the other is a pain and a possible source for errors. If you buy a metric machine thinking that is the way the world is going, but you are buying plans for projects that are dimensioned in inches and own inch micrometers, you are going to be in for a lot of extra work. Although it is possible later on to convert a Sherline machine from inch to metric or vice versa, it involves more than just swapping handwheels as the leadscrews and nuts must also be changed. In most cases, the choice of which system to use will be an easy one for you, and that is to simply choose the system with which you are most comfortable.

Глава 8

Finding the right Sherline tool for your needs... a guide through the product lineup

The motor and speed control are the same on all Sherline lathes and mills, so the difference in tools is mainly in size and included features. Assuming you have made a choice of your system of measurement, I will describe the differences and advantages of the various machines in the Sherline tool line.

(NOTE: Where model or product numbers are listed, the inch version is listed first followed by the metric version in parenthesis.)

8.1 LATHES

Model 4000 — The basic Sherline lathe is the Model 4000 (4100) which has a 15" bed with 8" of clearance between centers. This is the modern version of the original Australian-designed Model 1000 lathe introduced in the early 1970's. All Sherline lathes come with a faceplate and drive dog, two dead centers, hex adjustment keys, tool post, presharpened 1/4"cutting tool and spindle bar.

Model 4400 The longer lathe Model 4400 (4410) has a 24" bed with 17" of clearance between centers. It also comes with adjustable "zero"handwheels on the leadscrew, crosslide and tailstock spindle. It replaces the standard tool post with a rocker tool post. This allows you to precisely control the height of the cutting edge of the tool, which gives better control over the cut. This is particularly useful when using older, resharpened cutting tools where the height of the cutting tip may have changed when it was resharpened.

This photo shows the relative size of the two lathes. The main difference is the length of the bed which provides 8"between centers on the Model 4000 and 17"between centers on the Model 4400. (This photo shows the older style tailstock without the cutout for table clearance which was added in 1996.)

8.1.1 Is Sherline's bigger lathe worth the extra money?

Additional capacity may just be wasted if you don't need it. If you don't need 17"between centers you might as well save the workbench space and spend the money you save on more accessories. If you do need it, however, the relatively small extra cost is well worth it. The additional 9"of distance between centers obviously allows larger parts to be worked on. It also allows for greater versatility in setup and the use of a larger 3/8"tailstock chuck. Using larger chucks and tools on the smaller machine is difficult as the length of the chuck and tool eats up a good portion of your available 8"leaving little space left for a part. The longer bed lathe was only introduced in 1993, but it now accounts for just about half the Sherline lathe sales. Though more expensive, because of the extra features it offers as well as the increased capacity, I feel that dollar for dollar it is the better bargain of the two.

8.1.2 What you need will be determined by the hardness of the parts you intend to make

That gives you the physical limitations of the machine, but what does the hardness of the material you wish to turn do to those numbers in the real world? A good rule to remember when it comes to purchasing any lathe is to take the average diameter you plan to work with and multiply that times 3 for free machining materials and times 4 for tough materials like stainless steel. If the materials you plan to work with are free machining (aluminum, brass and free machining steel), you will be pleased with a Sherline Lathe if the average part you make is approximately 1"(25mm) in diameter. Wood and plastic are so easy to machine that only size limitations need be considered. I don't mean to imply that you can't machine a 3"flywheel, but if you are planning to consistently make parts of that size, you will probably be happier with a larger machine and more horsepower. Removing large amounts of metal on a small machine takes time. If you have lots of time, the size of the part is less critical. Users of any machine are happier with its performance when they are not consistently pushing the limits of its capabilities. If you usually make small parts well within the capabilities of the Sherline lathe and every once in a while need to turn a part sized near the machine's limits, you will be very satisfied with the its performance.

8.1.3 Accessory Packages offer more "bang for the buck"

The accessory or "A"packages are a good investment for a new purchaser, as they include the most popular accessories in a package that offers a price savings over purchasing them separately. These are all accessories you would no doubt be buying anyway, so you might as well save some money. In addition to the standard equipment mentioned previously, the "A"packages include a 3-jaw chuck and tailstock chuck, chuck key and arbor with drawbolt to use the tailstock chuck as a drill chuck in the headstock. A4-jaw chuck may be substituted for the 3-jaw if you already have one, but in most cases, the 3-jaw is what most people will want to start out with. In the case of the Model 4000A (4100A) the 3-jaw chuck is 2.5"in diameter and the tailstock chuck is a 1/4"Jacobs chuck. The longer Model 4400A (4410A) includes a larger 3.1"3-jaw chuck and a 3/8"Jacobs tailstock chuck and key.

8.2 VERTICAL MILLING MACHINES

Sherline's basic Model 5000 mill.

8.2.1 The physical limits of a mill

A vertical milling machine is capable of holding larger parts than a lathe of similar size because the part is held and only the tool turns. A mill also has a much longer table throw (X-axis). A deluxe version of the Sherline mill also is available which offers an additional 2"of Y-axis travel compared to the standard Mill. It also includes a mill headstock spacer block which adds 1-1/4"to the throat distance (clearance between the tool and the vertical column). With the addition of a horizontal milling conversion, surfaces up to 6"x 9"can be machined without moving the part. This is a very large machinable area for a tool of this compact size.

Because of its importance in the machine shop, adding a vertical milling machine was one of my first priorities when 1 took over production of the Sherline tool line in the early 1970's. The standard Sherline mill is the Model 5000 (5100) which has a 10"base. It has 8"(203mm) of clearance between the table and spindle. The travels of the three axes of movement are: X=9.00"(228mm), Y = 3.00"(76mm) and Z = 6.50"(165mm). It has red anodized handwheels with laser engraved markings.

8.2.2 The Model 5400 Deluxe Mill

An upgraded or "Deluxe"Model 5400 (5410) mill is also available which offers a 12"base. This increases "Y"Axis travel from 3.00"to 5.00"(127mm). It comes with a headstock spacer block which increases the throat distance from 2.25"(50mm) to 3.50"(90mm). (This spacer is available as an option on the standard mill.) It also includes a 1/4"drill chuck, arbor and drawbolt. In addition, the base and table have laser engraved scales cut into them which makes keeping track of positions and movements easier. Adjustable "zero"handwheels are standard on all three axes. (See photo on page 36.)

The Model 5400 mill adds 2"more Y-axis travel, laser engraved markings, a headstock spacer block and a 1/4 "drill chuck and key.

8.2.3 The Model 2000 8-Motion Mill

The latest addition to the model line is patterned after the movements available on the most widely used and imitated full size machine tool in the world — the Bridgeport mill. In addition to the standard handwheel adjustable movements of the X, Y and Z axes, and the pivoting headstock, the new mill offers four additional movements. The new round column base allows the column to be moved in and out and pivoted left or right. The addition of the rotary column attachment allows the column to be rotated in a clockwise or counterclockwise direction up to 90^o either way. A "knuckle"on the back of the rotary column attachment allows the column to tilt forward or back. Laser engraved scales on each of these movements make it easy to set the column to angled settings.

The Model 2000 mill takes tabletop machining into the year 2000 and beyond. With eight directions of movement for the part or tool, a part can be milled or drilled from any angle while mounted square to the table. *For more on the development of the new mill see page 193.*

The Model 5000 or 5400 mills can mill an angle by rotating the headstock. To drill an angled hole, however, requires either mounting the part on an angle or adding the optional rotary column attachment. The Model 2000 mill allows a part to be drilled or machined from any angle while it is mounted square to the table. These additional movements bring all the capabilities of professional mills down to tabletop machine shop size.

Adjustable "zero" handwheels follow large machine tool practice by allowing you to return your handwheel setting to zero at any time without moving the leadscrew. They can be ordered on new machines or added as a retrofit to older machines.

8.2.4 ADJUSTABLE "ZERO"HANDWHEELS

Most expensive full size machine tools allow the machinist to reset the handwheel to "zero" (or any desired setting) at any time during the machining operation. All Sherline tools now offer that option.

Operation is simple. Just release the locking nut while holding the handwheel. Then reset the handwheel barrel to "zero"and retighten the locking nut. Now you can dial in the amount of feed you want starting from zero without having to calculate your stopping point. It's a great time saver and also reduces the chance for errors.

If you own an older Sherline machine, the adjustable handwheels can be ordered separately and swapped for the standard handwheels. The old handwheels come off by simply releasing a set screw. The new ones go on just as easily. If you are buying a new machine, you can save some money compared to switching later by ordering a machine with the adjustable handwheels already installed. The Model 4400 (4410) lathe and Model 5400 (5410) mill already come with these timesaving handwheels installed. It costs about an additional $40 on a lathe and 60$ on a mill to order them with adjustable "zero"handwheels. This saves about $20-35$ (1998) over buying them later, plus you don't have to install them. A standard lathe with adjustable handwheels is known as Model 4500 (4530). A Model 4000A (4100A) becomes a Model 4500A (4530A). A Model 5000 (5100) mill changes to a Model 5500 (5510) when adding the adjustable handwheels. Naturally, the XY base and the XYZ base can also be ordered with or without adjustable "zero"handwheels. Rather than quote even more model numbers, it's easier just to say that information can be found on Sherline's web site or in their price list. My main purpose here was just to let you know they exist and that any handwheel on any Sherline tool, new or used, can be replaced with an adjustable one to make your life a little easier.

8.2.5 Things to ask when buying a used machine

Like full size equipment, a well maintained used miniature machine tool can be just as good as a new one and sometimes much cheaper. Check for obvious signs of abuse like major cuts in the table or noticeable play in the movement of the parts. Check for excessive backlash in the leadscrews.

Many people buy machines thinking they will use them only to find out the hobby doesn't really appeal to them. Older tools can sometimes be found that have seen almost no use. If you happen to find a good used machine, you can usually check with a manufacturer to find out if that model is still available and if parts are still offered for it. With Sherline tools this isn't a problem, but there are used tools on the market made by companies that no longer do business in the United States, and getting parts for them could be a problem.

8.2.6 Accessories sweeten the deal

If you can find a good used machine for sale ask what accessories come with it, If the sale includes a number of expensive accessories, you could be getting a really good deal. Even if you may not think you need them now, you'll probably be glad you have them later on as you learn how to use them.

8.2.7 Check new prices to make sure it's a good deal

Regardless of the manufacturer, before you buy a used machine, check the latest factory product literature for current models and prices. Sometimes the "bargain"prices asked for used machines might be only slightly lower than what you would pay for a new one and you wouldn't be getting any warranty. Though the product numbers and sizes listed in this book for Sherline machines are correct at the time of printing, in the future, additional models and features will undoubtedly become available.

8.2.8 CNC versions of miniature machine tools

As we move into the 21st century, the computer will continue to enter more phases of our lives. One could not hope to become a production machinist these days without learning to program a CNC machine.

Even one-off and prototype jobs are often done on machines that offer the option of hand cranking the dials or using computer controls for appropriate operations. As machinists become more familiar with using computer controlled machines in their work, they sometimes wish to extend those advantages into the small parts they make, either at work or at home. Even those who have never worked with computer controlled machines can learn to use these smaller versions if they have the need or simply the desire. Just like their larger counterparts, these machines can take the drudgery out of making the same part over and over and can also machine three-dimensional shapes that would be difficult or impossible by hand.

8.2.9 CNC machines for education

Educators have found that training new machinists to use computer controlled machines is done at much lower cost using small machines that duplicate all the functions of the larger ones the future machinists will eventually be using. Also, a mistake in a program that causes a tool to crash into a chuck can do some very expensive damage to a full-size machine. It is better to make your mistakes in miniature as you learn.

A CNC machining center designed for educational or industrial use has all the features of larger shop CNC machines, but these features add to the price.

Stepper motors drive the threaded leadscrews on each of the machine's axes to produce controlled movements based on coded instructions sent from a computer. They produce good results at a much lower cost than the servo motors and ball lead screws used on larger, more expensive CNC machines. Shown here are stepper motors with handwheels mounted to the rear shafts. This provides the operator the option of manual control when appropriate.

8.2.10 A number of manufacturers to choose from

Because of the demand for small CNC machines, in addition to Sherline Products, there are now several companies that offer both conversions for existing Sherline machines or complete, turn-key miniature CNC machining centers based on Sherline machines. There is a broad range of price depending on how many "bells and whistle"you require, but the basic models are amazingly inexpensive. Stripped-down home versions are available, while the educational models come with housings and safety features that duplicate those found on full-size machines. A complete CNC Sherline mill including three stepper motors, four drivers with power supply and even a new computer with pre-installed operating system and software can be purchased for under $2500.00 (2004) with retrofit kits for your own machine starting under $1800.00. A fourth (rotary) axis can be added for $395.00. CNC lathes and complete CNC lathe/mill/accessory shop packages are also available. Versions where you supply your own computer offer additional cost savings for those who have the computer skills to install the appropriate operating systems and software.

A list of companies dial offer CNC retrofits or complete machines can be found in the "dealers"section of Sherline's web site at `www.sherline.com/cncdlrs.htm`.

Any technology sufficiently advanced is indistinguishable from magic."
— Arthur C. Clarke

A full size Bridgeport vertical milling machine. Unlike its miniature counterpart, this one cannot be stored on a closet shelf and requires a forklift to move it. The mill shown combines old and new technology. The handwheels can be cranked by hand or driven by computer numeric control (CNC). The directions of movement of this machine served as a model for the Sherline Model 2000 mill

Глава 9

Chapter 3 — Materials for metalworking

9.1 Some good materials to work with

As with many of the other sections of this book, I am purposely staying away from engineering data and only giving the practical information you need to get started. The book I would recommend for technical information would be Machinery's Handbook. This book is the best book ever written on metals and the machining of metal (See chapter 1 of this section.) As a beginner, I would also avoid complex parts that require heat treating. If you try to accomplish this with a torch, you will find it an excellent way to destroy perfectly good parts. This can be heartbreaking to novices because they haven't "started over"enough in their life. I recommend using "leadloy"12L14 for soft steel parts. "Stress proof steel is the next real improvement in steels. It is a better material that is a little harder to machine. Use 4130 or 4140 steel for extra strong or tough parts, 6061-T6 for aluminum parts, and 303 for round stainless steel parts. These materials are readily available and work quite well. Ordering stock sizes that aren't readily available can be a waste of time. If you only have one part to make, it may take just a few minutes to cut a piece of stock to its proper starting diameter, but it could take an hour on the phone to find the perfect size.

A good cutoff saw is an important time-saver in any shop. Miniature machine tools weren't meant to remove a lot of metal in a hurry, so getting a rough part as close to size as possible with a cutoff saw saves a lot of time and wear and tear on your machines.

A treasure (rove of raw materials can be found at most scrap yards. Knowing the properties of the material you are looking far is helpful, because often it is not marked.

9.2 Eliminate machining time by cutting material close to size first

A good investment for your miniature machine shop is a cutoff saw. There is a saw available at many discount tool stores that is sold for less than $200 (1998) that is just right for home shop use. It uses a band saw design and can cut off diameters to four inches (100 mm). It can also be used in a vertical position making a standard band saw out of it. You need to have a way to cut metal to length in a pleasant fashion, and, believe me, trying to saw off a large piece of stock with a hacksaw isn't pleasant. It will drive you out of the hobby faster than anything I know. When you are working with small machines it is very important to eliminate as much machining as possible by cutting stock to its proper length before starting. A little cutting oil now and then will help the process and keep blades sharper longer. If you have a friend with a good saw it is almost as good, but eventually you'll want your own.

9.3 Cut off tool cautions

A cutoff tool or "parting-off" tool shouldn't be used in place of a cutoff saw. Cut your material to size with the cutoff saw, and only use the cutoff tool on the lathe for separating the finished piece from the blank. By the way, don't attempt to use a cutoff tool holder and tool on a lathe at any place other than close to the three-jaw chuck. It will bind in the material and get ripped out of its holding device and may end up damaging your machine.

Brass is easy to work with and polishes up nicely so it is a popular material for model work. The chips are like little splinters, so work with it carefully.

9.4 Dealing with minimum orders and small quantities The choices for metal

seem endless, but there is a problem. It's called the "minimum order". Let's say you want to start on a project that contains several types of steet, brass, aluminum, and cast iron. Chances are each of these products will be sold by a different supplier; each with their own rules when it comes to extra charges for small orders. You should also understand that most bar material used in machine shops comes in twelve-foot lengths and material used in construction and fabrication shops comes in twenty-foot lengths. It may cost as much as $25 to have a single bar cut to length. If you call up one of these suppliers and try to order a four-inch piece (100 mm) of half-inch (12 mm) aluminum they will probably ask if you are joking. You will exist to service manufacturing companies that buy in very large quantities, not for the home hobbyist.

9.5 Sources other than the big industrial suppliers

You will have to order from a supplier that caters to the hobby market. We have several listed on our web site and we wish them well because they provide a service that is well worth the extra cost. You can order all your materials from one source at one time. This allows you to spend your time building things, not talking on the phone to somebody who considers your order not worth the effort. If you are a novice, aways buy enough material to make three parts in case you have to start over.

9.6 Salvage yards

If you are lucky, there could be a salvage yard in your area that sells bar stock. Bring your own hacksaw because they will not cut it for you without price is right. Surplus yards don't have a standard inventory, and just because they may have a good assortment of material today, it doesn't mean it will be there tomorrow. What is available quite often are bar ends. These are pieces left over after a bar of stock has been cut up which are too short to use for their particular part. The problem is knowing what the material is.

Wood can also be machined on miniature machine tools with the use of a tool post to support (he hand held cutting tools. Small items like pens made from exotic woods are popular items as gifts. Kits are available for the working parts of the pen. Because these projects require such small pieces of material you can afford to use beautiful and exotic woods. Low material cost is one of the big advantages of working on small projects.

9.7 Identifying various aluminum materials in a scrap yard

Material is usually color coded with paint on the end of the bar. I wish I could put a chart of colors vs. material in this book, but for some idiotic reason, each producer has its own colors. Aluminum will have the grades printed on the entire length of the bar. The grade I recommend is 6061-T6. The "T"indicates the hardness. Another grade you may find in a salvage yard is 2011-T3. This has a texture similar to cast iron and it was developed for making round parts on automatic machines. The chips are splinters and will not tangle a machine up with long, stringy chips. Softer grades of aluminum don't machine very well and lack the stiffness required in mechanical parts. The extruded aluminum shapes sold in hardware stores are usually a soft, gummy aluminum such as 6063-T3. Another type of aluminum available is the 2000 series which is usually found in extruded shapes such as rectangles and squares. The last one worth mentioning is the 7000 series. This grade is commonly used for aircraft parts and is available in a hardness to T8. This grade can have a surface hardness equal to some steels so it can be very useful for tooling.

9.8 Buying scrap steel is a little tougher

A whole new set of problems arises when you try to buy steel at surplus yards, for it isn't labeled. If it is rusty, it probably is "hot rolled which is a terrible material to work with for small parts. These are fabrication materials that, as an example, are good for making a wrought iron gate. The best steel material to machine is called "leadloy"or 12L14, It is available in round and square cross sections and can be case hardened. Using 12L14 will ease much of the pain of machining steel as it is a pleasure to cut. Many of the parts of Sherline tools are made of this material. Excellent finishes are easy to attain. The chips break as they are machined off, eliminating the danger of long, sharp chips.

Aluminum grades are normally printed on the bar stock. Color coded ends also identify each type of aluminum, but color coding varies depending on who produced it.

A material called "stress proof would be the next real improvement over leadloy. It isn't too expensive and machines better than cold rolled. Cold rolled steel is miserable stuff to machine by comparison. It is tough and gummy and has a low cutting speed, but it is slightly better for case hardening than leadloy. Normally you would have to grind it to get a good finish. For some reason that I don't understand, you can cut cold rolled and similar hard-to-machine steels at cutting speeds way above the recommended speeds (as much as four times) and get a mirror finish. The catch is you have to use carbide insert tools. These tools can cut machine times in half and are a basic cutting tool in a modern machine shop. (See Chapter 6 on Cutting Tools in this section.) The chips are very hot and care should be taken to protect yourself.

Tools steels can be hardened completely, not just the outside as in case hardening, and can be very expensive and hard to machine. They are used when high strength or holding a sharp edge is important. A stamping die would be a good example. I would recommend that you purchase these materials only when the material is clearly identified. It takes too long to make parts out of this material to have them ruined in heat treating. Because of the many uses of steels and the many kinds available, I'm limiting the information I provide on these materials. I would end up with a book filled with charts and tables that would be just like the books that line the shelves of your library's engineering section. Before starting on a project that requires heat treating, get the advice of a local heat treat shop, The positives and negatives of brass, copper and bronze Brass is usually sold in a half-hard condition and is very easy to machine. I don't like to machine it because the chips are like small splinters that stick in your hands and break off. However, the parts always look nice and can be easily polished and plated. Copper can be machined but the surface has a tendency to "tear"as it is being cut making for poor finishes. Diamond tools are used to cut copper in a production environment if good surface finishes are a must. Some grades of bronze can also be difficult to machine because they will wear tools, even carbide, at an alarming rate.

9.9 Cast iron

Cast iron can be purchased as bar stock or cut out of an old piece of junk that contains cast iron. It is easy to machine, but also dirty. The chips look like powdered coal, and you should clean up your equipment after cutting it. The good part about cast iron is it is very stable and will not warp as it is machined. It is surprising how much some materials can warp when cut. Manufacturers of complex, close tolerance parts will have materials "normalized"

With the addition of the wood tool rest, small wooden parts are easy to turn on a Sherline lathe. Here, exotic woods are used to make a handsome key fob and a small flute. Model ships and dollhouse miniatures also require small turned wooden parts.

several times between machining operations to counteract these forces. The bigger the part the bigger the problem unless you are using cast iron.

9.10 Woods and plastics

Wood and plastic can be easily machined with tools designed to cut metals. For best results when machining wood, use a very hard, fine grained wood such as maple. Soft woods will crush rather than cut. This causes poor finishes and splintering. Use two-fluted end mills when machining these materials.

The problem with plastic is "melting". You can't allow the chip to clog up the cutting action when machining any type of plastic. For example, if a drill feed is low and the RPM is high, the chips will be numerous and thin. They pile up in the drill's flutes and not only create heat from friction but also work as an insulator. The plastic melts and you have ruined your part. Plastic has a very high temperature expansion rate when compared with other materials and it might be wise to take the close tolerance cuts when the part has cooled down to room temperature. Use high feed rates and sharp tools to eliminate or minimize these problems.

9.11 Don't knock plastic…sometimes it's the best material for the job

I was at a trade show once when a youngster in his teens stopped by our booth. He brought with him a complex part used in the front end of a radio controlled model car. It was made out of plastic and

A plastic mold used to make a housing for the new digital readout for a Sherline mill. It can take a very expensive mold to produce what looks like a simple part. The longer the machine runs, however, the cheaper the parts become.

A selection of plastic raw materials. The dark brown block in the upper left is phenolic. Next to it is black Delrin. The red block is fiberglass. At the far left is a piece of white Delrin and next to it is a block of white Nylon. The two piles are new clear beads and recycled black chips used for injection molding.

the part was constantly failing in crashes. He wanted to buy a machine to build this particular part out of metal and save money. He thought he was getting ripped off because the plastic parts cost $3.00 each. I told him I could not build a part to replace the one he showed me in less than six hours and a metal part probably would not last any longer, because metal will not spring back to its original shape like the plastic part. I don't think he ever understood why il would take me six hours to make a three -dollar part.

Plastics have changed the way we think about value. To injection mold a complex part, it takes a complex mold, yet the machine cycle time and the skill to run this plastic injection machine remain constant. The machine time is based on the thickest cross-section, not the complexity of the part. In order for the mold to work it must be made with very tight tolerances, even if the part itself has liberal tolerances. With a good mold, plastic parts can be manufactured so inexpensively we consider them disposable, but don't think for a moment that all plastic parts are junk.

Take for example your new cellular phone. The molded forms of the body would be very difficult to produce in any material other than plastic. They arc sturdy, light in weight and have the desired color molded in so they don't have to be painted. If they were made out of metal they would be heavier, more expensive and no more attractive. Plastics can be formulated to achieve just about any desired characteristic from flexibility to heat resistance to color or clarity. The development of plastics in our lifetime is probably the most important advance in materials since the discovery of how to work with metals many centuries ago.

9.12 Buying plastic for molding and machining

Plastic can be purchased in granular form for injection molding or in bar stock for machining. For machining I prefer Nylon where strength is important and Delrin for general work. In bar form, plastic can be very expensive. A two-inch diameter Delrin rod may cost over one dollar per inch compared with two dollars a pound in granules for injection molding (1998). Injection molded products are the preferred choice for use in manufacturing. As always, the tooling costs are high in order to produce a low cost part. If you are thinking about a new product to be produced in high volume you have to consider using plastic.

9.13 Machining plastics

Machining plastic can be fun. You don't need coolant and the chips are easy to control and clean up. Use an RPM that allows heavy feed rates and use sharp tools. This will keep the plastic part from melting as it is being machined. When drilling holes use a very fast feed rate to keep the drill flutes from clogging. We ran a very profitable screw machine part by drilling a hole in Delrin at 10 times the suggested rate. The plastic would extrude out the flutes without generating any heat yet the drilled hole had a better finish and tolerance than our previous slower method. Remember that the surface of plastic is slippery and softer than metal. You have to consider this when work is held in a vise or chuck. Thin sections can be easily deformed when clamped. Temperature is also a factor. Plastic has a high coefficient of expansion, and a two-inch part can vary several thousandths of an inch from a hot day to a cool day.

9.14 Galling of materials in close fits

In summary, I find aluminum the nicest material to work with. It is clean, strong and rust free. You should also be aware that aluminum can "gall which is the surface of one part sticking to another of the same material. This usually happens when you check a fit by putting a shaft in a hole made of the same material. Stainless steel can be just as bad as aluminum when it comes to galling. If you have to do a lot of work in these two materials plan to use an anti-galling agent on close fits. It is available in automotive shops.

This 7" high display model of a 1911 "Baby" model airplane engine by Edwin Teachworth was built entirely of styrene and painted to look like metal. It is on display in the San Diego Aerospace Museum.

9.15 Hard-to-find fittings

Novices believe that some catalog somewhere will always have what they need, and all they have to do is order it. This is not always the case. Many catalogs are filled with sizes that won't actually be produced unless they get a substantial order. When you try to use "off-the-shelf" items, you often must compromise your design. Of course, I'm not suggesting that you make things like nuts or bolts, but you might have to make that special washer, There are plans around for interesting projects that were drawn with the materials that were available then. (Try and buy a BSA screw at your local hardware store and you will understand the problem.) Unless you are building "super scale you can save yourself a lot of grief and use the materials and fasteners available today. Fortunately, you have chosen a hobby that gives you an alternative if the exact part you are looking for can't be found. You can always make it yourself.

Глава 10

Chapter 4 — Processes for metalworking

This chapter contains information on the processes used to harden, plate, finish, cast and join metals. While some of these processes can be done in the home shop, a number of them are best sent out to a vendor as they require equipment and processes that are not practical to set up in a home shop. Understanding these processes, whether you attempt them yourself or not, is an interesting part of working with metal.

10.1 4.1 — HEAT TREATING

10.1.1 Some "do-it-yourselfers"have more success than others

Tve got to be honest with you, heat treating is something I know less about than I'd like to. After investing three days labor in a part only to destroy it trying to heat treat it myself, I decided to have contract heat treating companies take care of the small amount of heat treat work I generate. If you have a small heat treating furnace available capable of heating up to $2000^o F$ you can do simple heal treating jobs. If you plan to make parts that require heat treating I would use "air hardening"steels such as A-2 for standard use or S-7 for parts subject to shock loads. Don't consider using a torch unless you're treating a very small part made of drill rod. It is very important that the type of steel you use is documented so that proper heal treat information is used.

A heat treating oven heats items to he hardened almost to their melting points making temperature control critical.

10.1.2 Case hardening vs. tool steels

Tool steels harden all the way through and case hardened steels are only hardened on the outer surface of the part. This gives a very hard surface that can be controlled by the time it is heated to harden to a specific depth. The part is brought to temperature in a cyanide bath where carbon atoms change the makeup of the surface to allow it to be hardened. There is a limit to the depth of this process (up to .010"or .25mm). but case hardening is inexpensive in production quantities. You can case harden low carbon steels in a home workshop with a marvelous material called "Kasenite". After the part has been brought to about 1650^oF; it is dipped into the powdered Kasenite. The powder adds carbon atoms to the surface, allowing the surface to be hardened. You can get more depth with this process by repeating it several times.

10.1.3 Hardening your own parts

The part should be placed in a stainless steel "envelope"to protect it from excess oxidation. The stainless is 316 shim stock which is .002"thick and goes by the trade name of "Tool wrap". It is very thin and can be easily folded. The envelope should be as small as possible and sealed with a sharp fold. Stainless steel wire can also be used to hold the envelope in place. A heat treat furnace is a must and the temperature must be accurately controlled. Be sure the work is allowed to "soak"at the recommended setting so that the entire part has time to be brought to the proper temperature. A general guideline is one hour for each inch of thickness. The makeup of the material you arc dealing with in heal treating must be known to properly heat treat metals, and these rules must be followed exactly. The temperatures used in heat treating arc very close to the melting point of the material. The parts being heat treated must be heated evenly. An acetylene torch used carelessly may "burn"the corners off while never getting the center of the part hot enough to be hardened.

10.1.4 Rockwell testing for hardness

After the part has been hardened it is reheated to "draw"the part to a specific hardness. The lower the drawing temperature the harder the part. As steel gets harder it also becomes more brittle. The numbers arrived at will usually be a compromise. There are several ways to determine the hardness, the most popular being "Rockwell"testing. A diamond point is pressed into the surface of the hardened part and the amount the diamond penetrates the surface at a given pressure can determine the hardness.

A Rockwell tester is used for determining the hardness of a material by measuring the penetration of a diamond point into the material's surface.

If you ever have the time, look up the ingredients in a good steel and compare these ingredients to stainless steel. The ingredients may be close, but the final product is entirely different. In most cases, stainless can't rust and is non-magnetic. I would recommend working with popular, common materials...nothing exotic. Talk to your local heat treat company for suggestions.

10.1.5 Annealing is the opposite of hardening

The term "annealing"is used frequently and is basically the opposite of hardening ferrous steels. As an example, materials that have been work hardened by machining may have to be annealed after being "roughed out"to size. Annealing is usually accomplished by heating the part to a temperature determined by the composition of the material and allowing it to cool slowly. Nonferrous metals can be annealed by heating them to the desired temperature and quenching them in water.

10.1.6 Hardening and aging aluminum

Aluminum can be hardened at much lower temperatures than ferrous materials. A period of several days after heat treating may be required to get to the required hardness. This is called "aging".

10.2 4.2 — METAL FINISHES

10.2.1 Black oxide

There are a variety of finishes that can be put on metal. A popular finish for steel parts is "black oxide". This is basically "gun bluing"and a gun shop would be a good place to purchase small amounts of the material needed to do this at home. Fingerprints that haven't been removed can leave blemishes on the final product in all plating processes. You have to work in a very clean way in a very messy process to do plating. If you have a plating company do a small job for you, it may save money if you don't demand fast service so they can run the part with a larger order.

These parts have a tough black oxide finish. This finish is often used on guns as it offers good protection as well as a nice looking blue-black color.

10.2.2 Attempting plated finishes at home

There aren't many other plating methods that can be done without building special equipment. The process of plating is more electrical than chemical. I've seen some interesting articles over the years on how to build plating tanks and rectifiers to accomplished plating at home. Some craftsmen prefer to control the quality of every step of their project. I believe the average machinist would be heading in a direction with little rewards if they try plating at home. The chemicals are difficult to buy in small quantities. It would be like developing your own film if you only used one roll of film a year.

Anodized finishes like the black of the table and the red of the handwheels provide a tough, easy-to-care-for finish on aluminum parts. In this case, they also provide the additional benefit of helping the laser engraved markings show up in high contrast. The laser cuts through the finish into the raw aluminum underneath making what appears to be white lettering. Several other colors of anodized finish are also available. The process gives a good looking finish and is not particularly expensive.

10.2.3 Chromium plating is a multistep process

Decorative chrome plating like you see on automobile bumpers doesn't work well for small machined parts. The process has several steps and the first step is to plate copper on to the steel surface. The copper is polished and a plating of nickel is then added to the surface. Nickel has a "smoothing"effect to the surface but also has a slight yellow color. Chrome is then plated on the nickel in very small amounts which gives you a beautiful finish for bumpers, but it is not too good for precise mechanical parts. This is because the chroming process is done in layers with lots of polishing, and detail can be lost in small parts. Plating also builds up more on corners than flat surfaces, and chrome is so hard that it can't be machined off. A tapped hole on a part that has been plated may cause problems even if you use an oversized tap. The first thread may build up with plating material and the remaining threads will not be plated. Plating doesn't get into holes unless special electrodes are used. A tapped hole that will not accept a standard machine screw may be the result in this type of plating process. Remember, a polished steel surface can have the appearance of chrome if it is done properly.

This 1/12 scale model of a blacksmith's trip hammer by Jerry Kieffer remains unpainted to show that no fillers were used or mistakes covered up. Sometimes the ultimate finish is no finish at all.

10.2.4 Hard chroming has specific uses

There is another chrome plating process called "hard chrome". This is expensive and doesn't give the shiny surface usually associated with chrome. The process is controlled by carefully positioning the part and electrode to control where the chrome is applied. This method is used to create a good wear surface. Molds that are subject to abrasive materials have their cavities hard chromed. Hard chrome has to be polished or precision ground. It is also used as a "putting on tool"to save a worn or undersize shaft, but the home hobbyist may find the cost of doing this too expensive. When one-off parts are hard chromed you can expect the cost to be over one hundred dollars.

10.2.5 Barrel plating large quantities of small parts

Barrel plating is a production method used on small parts. Screws would be a good example of this type of plating. The parts are not "racked"one at a time but are plated by the barrel as the name implies. Nickel and cadmium finishes are commonly used with this process.

10.2.6 Colored anodized finishes on aluminum

Anodizing is the preferred method of finishing aluminum. This is a method that forms aluminum oxide on the surface. Parts will have their surfaces grow slightly with this process. The oxide finish has a "porous surface". This allows it to accept colored dyes with excellent results. Black and red are two colors that anodize well. The surface is then "sealed"with hot water, but please don't ask me how that works. You should realize that colors will vary because of the many variables that take place in the process. It is not an exact science unless you are willing to pay for new chemicals and test runs. I would not bid a contract part if I had to be responsible for the plating color. Many perfectly good parts have found their way to the scrap heap because a buyer didn't like the color. This is one of the reasons I gave up contract machining. There are a hundred ways to lose, and you only win if everything goes exactly as planned.

10.2.7 Hard anodizing

Just like hard chroming, the anodizing process has hard anodizing. This allows the surface to be built up with one of the hardest materials on earth, aluminum oxide. It can be used to protect the surface against wear; however it isn't very strong and can only be applied a few thousandths deep. One half the thickness of the plating will be impregnated into the metal and the other half will be added to the surface. As an example, if a 1"diameter bar were hard anodized .002 the bar's diameter would increase by .002". This is somewhere around the maximum amount you can hard anodize. If machining is attempted on a part that has been anodized, enough material should be cut on the first pass to keep the cutter from rubbing on the anodized surface. Carbide tools will help but the oxide surface is still harder than carbide.

Though not particularly exotic and certainly not expensive, a nicely done painted finish does add realism and appeal to a model. An airbrush will give the most control, but good technique with a spray can yields good results too.

10.2.8 There's always good old paint

Painted finishes need special attention when working on miniature replicas of machines. You just can't slap on a couple of coats of paint and be satisfied with your work. You should carefully mask the surface to keep paint off the areas where it shouldn't be. A primer should be used to assure the proper adhesion of the paint. This should be applied in very light coats. I have always preferred lacquer based paints because a surface can be built up with many coats to get the desired results. The inside corners must be painted using very light, dry coats or the lacquer may pull away from these areas because paint shrinks as it dries. Enamels may wrinkle if a second coat is added without allowing enough drying time between coats. The thinners in the paint must be allowed time to evaporate before the next coat is applied.

10.3 4.3 — CASTINGS

There are many ways to cast metal parts, but this is not a process 1 would recommend trying at home. This section is provided as general information so you have some idea how metal casting is done. If you are one of those builders who likes to do every operation yourself, read up on casting techniques before buying or building any equipment.

10.3.1 Casting techniques from the jewelry trade work well for small parts

The type of castings that could be used for miniature projects at home actually come from the jewelry trade. They have developed a small centrifugal casting machine that slings the molten metal into a ceramic mold that has been made by the "lost wax"method. Commercial casting companies use a sprue system. This is a method of getting molten metal to the mold and casting more than one part at a time. It resembles a funnel and many parts may be cast at one time by pouring molten metal into the sprue system which feeds each part. The top of this assembly has provision for a small pool of molten metal to continue to feed the parts as they cool and shrink. They call this assembly a "tree". The sprue can be attached to the part in a manner to allow variations in length which is normal to the casting process. The part is then machined to its final length as the sprue is cut from the casting.

Die cast lathe bases as they come from the foundry and before they are machined. Proper draft angles and shrink rates must be considered in the design so that the parts will release from the mold and end up the right size.

10.3.2 Making molds for investment casting

The ceramic mold is made by coating the wax pattern with a slurry mix that air dries. It may take several layers to get the desired thickness. The wax is then removed from the inside of the mold with steam or heat.

This leaves a mold with no parting line. The ceramic mold is then healed to over $1000^o F$ to harden it and burn away any remnants of the wax. After the mold has been filled with molten metal and cooled, the mold is destroyed as it is broken away from the casting. This is called "precision investment casting". The part is produced by casting or machining a wax model of the final product. If many parts must be made, a mold can be built to cast the wax pattern. The molds can be simple if you are willing to accept some second operations machining the wax pattern.

10.3.3 Shrink rates of various cast materials must be considered

The model must have the appropriate amount of shrink rate figured in so the final casting is to size. If the wax model was machined, the shrink rate of the wax doesn't have to be figured in, but if it is cast it has to be calculated from information that is available from the companies that manufacture wax. If you want a close tolerance cast part it may be worth the effort to run a test part to determine the shrink rate for a particular shape. The test part does not need the detail the final product has, just the general size and shape. From this information a wax pattern can be built that is surprisingly accurate. This is a very accurate process and parts like turbine blades for jet engines are made this way. The part finish of small model parts will usually duplicate that of its full size counterpart. It is possible to cast many types of metals with this method. Making the wax pattern and having a professional casting company do the final casting may be the way to go. By taking off on tangents like this you may end up never completing what you started and end up making jewelry, but projects done in home workshops are for fun so do whatever you enjoy. As you can see, it takes a lot of steps to make a good casting and if you're only making one part, it could be easier to machine it from bar stock and sandblast it to get the look of a cast piece.

10.3.4 Die costing for commercial parts

Most complex metal shapes found in commercial products are "die cast". The molds are similar to injection molds for plastic. These molds are built to withstand internal pressures of 10,000 P.S.I. (1800 kg/cm^2). These types of molds are very expensive and should only be considered for production parts made in high quantities. As an example, the Sherline steady rest mold would cost over $10,000 to replace. Molds of this type are attached to the platens of die casting machines. The hot side is fixed and the ejection side can be moved. Leader pins align the two halves with the utmost precision as the mold is closed. These machines are rated by how many tons of force it would take to spread the two halves apart once they have clamped. A 100-ton machine would be considered small. They may use a past-center clamping arrangement or a hydraulic cylinder to keep it closed. After injecting molten material into the mold, the casting is allowed to cool for several seconds. Cooling time is dependent on the thickest cross section of the part and the cooling method. When the ejector side of the mold is pulled away from the hot side, a plate on the ejector side is pushed forward. Attached to this plate are ejector pins. Die casting molds may have over fifty pins. These pins push the part from the mold and let it drop out. The mold then closes to start the sequence over again. I believe mold making is the best and most interesting job in the machine trades, but it is very demanding. The parts you work with daily are too valuable to get careless and screw one up.

10.3.5 Sand casting. . . an old method that it still in use today

The oldest method of casting metals which is still used today is sand casting. The tooling to produce cast parts can be a wooden (usually Honduras Mahogany) model of the finished product you want to cast. The expert craftsmen who make these wooden molds are called patternmakers. The trade requires not only good woodworking skills, but a vast knowledge of how metal will react when molded. Shrink rate has to be accounted for and draft angles are needed on sides that would otherwise drag when the wooden model is lifted from the sand. The model is set in a "box"and sand is packed around one half of the model. The opposite side is done the same way and the model usually has some method to increase the accuracy of this process. At me same time a sprue system is added. Sand used in sand casting has been treated to stick together. A hollow section in the casting can be obtained by having a "core". Cores are made of a processed sand that will

A mahogany pattern is the first step in the sand casting process. A skilled patternmaker requires not only a *knowledge of the properties of metal and how it will react as it cools, but also requires masterful woodworking skills. Here Howard Parry applies a wax bead to an inside joint. A heated metal ball tool is used to shape the wax into the desired radius fillet.*

harden with temperature. The cores are very fragile and are designed to be this way so they can be broken into small pieces to remove them from the finished casting. Cores are held in place by the parting line of the mold. The two halves are put together and molten metal is poured into the mold through the sprue system. The sprue system will normally have an extra pool of melted material that helps keep the mold filled while the metal cools. After the metal is cooled the sand is knocked away from the part and the sprues are removed. It is difficult to get the degree of accuracy needed in miniature models with sand castings, but they are an inexpensive method to produce large parts in low quantities. The base for our 24"(609mm) lathe is produced by the Edelbrock Company. They have a sand casting facility that is second to none. They use automated equipment that can fill a mold every 45 seconds. The sand molds are made in two halves by automatic machines. The molds are also a cast product and are usually aluminum. I made a model of what I wanted and they used this model to build a three-cavity mold. The tooling cost was less than $5000.00 and the part price was reasonable by doing three at a time. You may be familiar with the Edelbrock name because they manufacture many fine products like manifolds and other performance parts for hot rods and race cars.

10.3.6 Casting using matched plates and gravity

There is also a method of casting that uses matched plates. This is simply a metal mold made in two halves. The major difference between these molds and die cast molds is the cavity is filled by gravity. not the very high pressures used in die cast molding.

10.3.7 Dealing with foundries to get your parts made at a price you can afford

Most foundries specialize in only one material. It could take several different foundries to get the parts you need and each one may have a minimum order. Be sure to remind the foundry that this is a model project where time isn't as important as money, and see if it would be possible to run your job with other commercial parts to keep the price low. You have to be nice to large casting companies who are willing to take an order to run a few parts for you even though they probably still wouldn't make a profit on them at twice the price.

The quality of castings that come in kits varies from good like the ones shown above to downright unusable.

10.3.8 Beware of poor castings in some kits

Many steam engine kits contain castings that belong in the junkyard. The tolerance of the part can be lost in a deformed casting. The manufacturers of these castings do the industry a disservice by selling castings of poor quality. A novice may believe they are at fault when a kit can't be finished, but the truth could be the castings are in error. The sorry part is that sometimes these novices give up and go on to another less demanding hobby because of it. Kits should always be designed to make the project easier and more fun to build. If the model engine kit manufacturers would switch to precision investment castings for their kits, both manufacturer and customers would benefit.

10.4 4.4 — OTHER WAYS TO FORM METAL

10.4.1 Extrusions

Extrusions are something we are very familiar with at Sherline. Most of the cross sections for the lathe and mill started out as an extrusion. The basic method of producing a extruded shape is similar to decorating a cake. The frosting is forced through a hole which gives the material coming out the shape of the hole. A cross section with a hole can he extruded by forcing the material around a core piece that is shaped like a torpedo.

It takes a lot of power to push a 500-pound billet of aluminum through a small hole, so the first thing you need to extrude metal is a gigantic hydraulic ram. The aluminum billet is heated but not melted as it is loaded into the cylinder. The method of loading is similar to loading a cartridge into the barrel of a rifle. The aluminum shape will usually be twisted and crooked as it leaves the extrusion die. This shape is then pulled from both ends to straighten it. It is the same method used to straighten a piece of wire or copper tubing only the forces used to straighten a shape with a large cross section are tremendous. This method doesn't allow tight tolerances. At Sherline we have to machine all mating parts on the extrusions we buy.

Extrusion dies are relatively inexpensive, around $1,000, and the cost to produce these dies has come down because of a new machine tool called a "wire EDM". A wire about .010 inches in diameter cuts the shape as it is fed through the part by using the "spark erosion"method. The wire never touches the part it is cutting. The sparks that jump the small gap between the wire and the part erode the material away. This isn't a fast process, but it does the impossible. The tool steel die can be heat treated before the shaped hole is cut. The table is computer controlled and very accurate. A process called "cold drawn"is also used to more accurately shape extruded parts in metals. This is similar to extruding but it is accomplished in more than one pass.

10.4.2 Forging

Forging is taking a slug of metal and reshaping it in a die mounted in a press that acts like two giant hammers hitting the part at the same time. One of the main advantages of this process is the strength of the part produced. The ”grain"of the metal can be controlled by forging making the part much stronger and less likely to fail. It isn't something a home hobbyist could do but worth mentioning.

Quality wrenches are forged. This method can be more exact than you could imagine. On TV I saw a complete frame for a handgun made in a few seconds by forging, and it was a very complicated part. Forging tooling can be quite expensive.

10.4.3 Powdered or sintered metal parts

Powdered metal parts are made in a specialized press that compresses "powdered metal"from both the top and the bottom at the same time. This produces a part that has a more equal density than one hit from only one side. The cast part then goes through a "sintering oven"where the powdered metal is fused together. Additional strength can be added by filling in the microscopic voids with a material such as copper. After sintering a piece of copper is placed on the part and it is run through the furnace again. If done correctly the copper will disappear into the part making it stronger. Door locks are usually manufactured in this manner.

10.5 4.5 — JOINING METAL

10.5.1 Soldering irons and flux core solder

The method of putting two pieces of metal together that most hobbyists are familiar with is soldering. This type of soldering is called "soft soldering". Soft solder melts at temperatures below $800^{O}F$ and is a combination of lead and tin. Hobbyist have built many ingenious devices by soldering together piano wire and brass tubes. These standard items are sold in hobby shops and are used to build gadgets that are held together with solder. The first thing you find out about soldering is the surfaces to be joined have to be clean and free from oxidation. A flux is used to clean and protect the surface from oxidation as the parts are heated. Many solders have a flux core. These are fine for work that will be heated with a soldering iron. If you are heating the part with a soldering iron, the iron should be cleaned by wiping. If a new iron is used or a thin coat of solder doesn't cover the tip of the iron, the tip of the iron has to be "tinned". This is accomplished by a dipping the tip of the hot iron directly into the flux and melting solder on the tip and then wiping the tip with a rag. Repeat until you get the desired results. . . a shiny silver tip on the iron. It is then ready to use.

10.5.2 Soldering torches and solid tore solder

For larger parts that have to be heated with a torch a paste flux must be used. This keeps the area around the joint clean as the part is being heated. Propane torches are somewhat dirty and flux is a must. Acetylene torches work better but they are too costly for the average hobbyist. In general, solder will flow towards the heat source (even if it is uphill). It is usually best to heat the side with the most mass and apply the solder to the opposite side. Always use a little flux and solder to transfer heat from the iron to the part. When soft soldering a part that is dependent on the strength of the joint use a solder that contains about 65% or more lead. A 60% tin content is used for soldering electronic circuit boards and cabling, Flux should always be removed from the joint after the solder has hardened. It will cause a corrosion problem because it contains acid. You can also wipe the excess solder and flux away with a rag before the joint has hardened. Plumbers use this trick to get an excellent appearance when they solder copper tubing. In general, soldering is a skill that has to be learned, and the best way to learn is by doing. Try soldering on a similar piece of scrap material before trying to solder a part that may contain a lot of work.

Here's a close-up detail of part of the blacksmith's triphammer shown on page 47. The silver soldered parts are perfectly joined, filleted and finished to look like castings. Jerry Kieffer's skills as a modelmaker are highlighted by the number of different metalworking techniques he has mastered.

10.5.3 Brazing and silver soldering provides more strength

When strength is critical brazing should be considered. Brazing materials melt above 800^oF and below the melting temperature of the materials being brazed. Some brazing materials may penetrate the surface of the materials being joined giving very strong joints. They will always "wet"the surface for a successful braze. Silver solder is probably the best known brazing material. It is expensive but it is also used in such small amounts that cost shouldn't be an issue. Flux is a must and surprisingly it is usually water based. Liberally apply the flux to the area around the joint and heat the work in such a way that you don't boil off the flux. I usually use a soft flame to start and get the water out of the flux. This will leave a white coating. The part is then brought up to silver soldering temperature. More flux may have to be added to insure clean soldering surfaces, bleat the silver solder rod and dip it into the flux. This coating will protect it from oxidizing as it is applied. Just like soft soldering, the melted brazing material will go towards the heat. Try to bring the work up to temperature evenly and apply the brazing material to the opposite side of the heat source. I have found that when the flux melts and wets the surface of the joint the temperature is ready for the silver solder to be added. If it doesn't flow the work temperature must be raised. Keep adding flux if necessary. Holding any materials at high temperatures for a long period of time with a torch can cause problems. Propane torches are usually not hot enough to silver solder large parts successfully. They also have a dirty flame that creates problems at the higher temperatures used in silver soldering. If you attempt to silver solder with propane you must use an excess of flux.

Some sample aluminum welds. Controlling the puddle of molten metal is the key to a good weld. A close-up

of an expert weld in aluminum shows a good, even head with proper penetration. Like all skills, welding takes a lot of practice and a good knowledge of your tools and materials to get good results. Being able to do some basic welding is probably one of the more useful skills you can obtain. Though not often used in miniature machining, it can come in handy for many other construction and repair projects you will run across.

10.5.4 Arc welding

The small parts normally made with Sherline tools are too small for arc welding, which is the most common way to weld. Unlike brazing, welding is a process which melts the material being joined and the joint can be as strong as the original material.

Some welding shops specialize in exotic metals. Welding titanium such as this Mako mountain bike frame requires special tools and a lot of skill. The advantage gained here is a frame that weighs 2.5 pounds instead of the 5 pounds it would weigh if made from steel.

There are several ways to weld, and the difference is mainly where the heat comes from. Low voltage and high amperage is the usual source. Arc welding starts by dragging a flux coated rod across the weld joint until an arc is established. A very steady hand is required to control the end of the rod that may be 10"away from handle and clamp that is holding the rod. The puddle of molten metal is controlled by minute movements. Good welders can arc weld a perfect joint standing on their heads if need be. A poor quality weld in a hard to get place can fail as easily as a weld on the front side. The weld temperature is controlled by the machine settings and rod diameter. The "ground"has to be perfect to weld properly. Welds must be perfect for they must hold buildings, bridges and a large part of the industrial world together. Our lives are much more dependent on the skill of this group of tradesmen than one would think.

10.5.5 Spot welding

Resistance or spot welding is very common in our lives. It holds together most of the automobiles that we drive daily. It is a quick process but only certain materials can be spot weld successfully. The metal is clamped together by two copper tips. A short blast of electrical energy is fed across the joint and the metal fuses together. The welds done at automobile factories are now done by CNC robots and have thankfully eliminated this job from assembly lines. I have used spot welders that are very small and called "tweezers welders. They can be used to attach thin shim stock to thicker parts.

10.5.6 GMAW welding (or MIG welding)

Another type of welding that is becoming very popular is technically known as GMAW welding which stands for "Gas Metal Arc Welding but it is more popularly called MIG welding. An inert gas such as argon floods the area to keep oxygen away from the melted surface. The welding material is a spool of wire that is mechanically fed down the center of the welding cable. It comes out through the torch through the center of a ceramic cup where the inert gas is also streaming out. The rate and amperage has to be adjusted so the material will melt at the same rate it is fed. The first time I tried it I moved the torch away from the work and in less than a second I had a 6"long wire that was incredibly hot. I realized this was going to take some getting used to. MIG welders have come down in price over the years and can be useful to build stands and trailers, but it would be hard to find a use for them on parts normally associated with miniature machining.

Though an oxy/acetylene torch may be the first thing many of us think of when we hear the word "welding most industrial welding is done using electrical current as a heat source. Shown here is a TIG (Tungsten Inert Gas) welding setup that brings the price down in the "home shop"range. This foot pedal controlled unit sells for about $1300 (1998) with the wheeled cart adding another $170.

10.5.7 TIG welding

TIG (Tungsten Inert Gas) welding is a method that may be of some use when working with small parts, The tungsten rod is located in the center of a ceramic cup that directs an inert gas such as argon over a clean surface that is going to be welded. A high frequency contact is made between the work and the tungsten tip. An arc is established and the high frequency is turned off automatically. The size of this arc can be very accurately controlled by machine settings and a foot pedal similar to an accelerator. You have to hold the tungsten very close to the work to TIG weld. The diameter of the tungsten has to be proper for the welding machine settings to keep it from melting. If a weld is critical, any tungsten that falls or is broken off in the weld must be ground out. If the tungsten is dipped into the melted puddle, the melted material will attach itself to the tungsten and form a small glob. When this happens the torch is hard to control and an arc may suddenly shoot out on an angle and destroy a delicate part. The point of the tungsten must be shaped to a point to accurately aim the "flame". I prefer a fine tip with an elliptical shaped taper going to the outside diameter of the tungsten. One thing that you can do with TIG welding is fuse two pieces of metal together. Stainless steel can easily be fused together and very delicate welds can be done by fusing. When welding very small parts a "chill block"may have to be used to protect the main body of the part from excessive heat. These are usually made of copper and clamped just below the weld.

10.5.8 TIG welding aluminum

When aluminum is TIG welded it must be very clean. The entire part to be welded has to be cleaned with an acid bath before welding to insure a good weld. Because aluminum can dissipate heat so quickly, large parts have to be preheated. I use an oxygen/acetylene torch. By turning down the oxygen the flame will create "soot". This soot will stick to the part and will be released from the aluminum surface when the aluminum is the right temperature to weld. Aluminum never looks hot, and a hot piece that has just been welded should never be left alone to cool where someone may inadvertently touch it. At least put a sign on it. Don't cool it with water as you may anneal or soften the material.

10.5.9 Star Wars welding with lasers and electronic beams

Exotic fusion welds are now being done with lasers and electronic beam welding. These can be microscopic welds that are controlled with the utmost precision. This type of welding is used by laboratories and production equipment, and because of the high cost it normally wouldn't be considered for the home hobbyist.

10.5.10 Taking your skills in these areas to the next level

In closing this section I want to remind you that I'm not an expert in these fields. I have dabbled with each process enough to know that I would need a lot more practice to be really good at any of them. On the other hand, trying your hand at something really helps you appreciate a good job when you see it done by an expert in the field, and there is a certain satisfaction in simply knowing a good piece of work when you see it. Books have been written about each subject mentioned and you really need to understand the process more than I described it before attempting welding or brazing. If you have a friend who understands these processes, buy them dinner and pick their brain, but remember there aren't many welders who work with parts as small as we work with daily. It will very seldom be useful to fix a mistake by welding a small part and, like it or not, the best way will usually be starting over.

How would you remove this nut which appears to be thoroughly welded to the bolt? This fun puzzle by Larry Lamp was an entry in the 1995 Machinist's Challenge contest in Michigan. The solution is obvious once you know how it works, but many spectators took one look at the massive weld and said it was impossible.

Глава 11

Modeling tricks of the trade from Phil Mattson

11.1 Making a brass ship's propeller

Most kits come with a cast propeller which you file to final finish. If you are building a model from scratch, making a nice looking scale propeller can be a tough project unless you have a plan. Phil Mattson has made many of them, and here's how he does it.

1. A hub is turned on the lathe and left on the end of its piece of stock. The chuck is put onto the indexing attachment (or a rotary table) and held on the mill. The headstock is offset to the angle of the desired pitch for your blades and a slot is cut for each blade.

2. Four blade profiles are cut from sheet brass and filed to shape. The photo shows the hub and the four flat blades along with a finished prop.

3. Each blade is placed on a block of hard rubber and a brass billet of the proper diameter is laid on top of it. The billet is hit with a hammer (protect it with a piece of wood) and the proper curve is bent into the

blade. The photo shows a fiat blade on the rubber sheet and a finished blade on top of the billet.

4. The hub is placed on the shaft and blades are soldered into each of the slots. As a final touch, the prop is polished to a mirror finish.

Глава 12

Chapter 5 — Using hand tools and abrasives

The Nicholson® file company started manufacturing files in 1864 and produces files that have become the standard for the world. Today (1998) you can still purchase an 8"mill file, smooth, for $6.12. There are cheaper files, but I believe a good file is worth the extra money and is really a bargain when you consider what can be accomplished with one. Files give a machined part its final shape and finish. Too often I see parts that have been accurately made to size, but lack that special appearance that a good craftsman can add. The "final touch"is usually accomplished with a simple file, a good set of hands and a good mind controlling the process. When machining parts for pleasure, you are in a sense a sculptor, and your medium is metal. Parts should do more than just work. They should have the detail to make them look perfect even if they are scrutinized under magnification. Try as we may to eliminate the craftsman with fancy CNC machines, it is still a craftsman's touch that produces "beautiful"parts. You can't expect the average person to appreciate this extra effort, but your peers will.

I am going to stay within the bounds of using files on small metal parts. The material being filed must be hard enough to be successfully filed. Soft materials like wood should be sanded.

SINGLE-CUT FILE
DOUBLE CUT FILE
CURVED-CUT FILE

The grooves in files can be cut at a number of different angles. For the purposes of miniature machining, a single-cut mill file will be the most useful tool.

MACHINIST'S FLAT BASTARD FILE
HAND FILE
PILLAR FILE
SQUARE FILE
ROUND FILE
THREE SQUARE FILE
HALF-ROUND FILE
KNIFE FILE

Files come in all sorts of shapes and sizes. Each has a particular purpose and having a good assortment on hand can make your life a lot easier.

12.1 File shapes

Files come in all sizes and shapes. Round, fiat. triangular, square and half round are just a few of the standard shapes. These shapes and sizes can be ordered through mail order industrial suppliers. We have several listed on our web site that have hundreds of styles listed, and it is up to the craftsman to find the right tool to do the job. One point worth noting is that files can be ordered with blank or "safe"edges. This is very helpful when filing up to a shoulder. Swiss pattern needle files are sold in sets that have been manufactured throughout the world and have become one of the real bargains for the home machinist. A good needle file set is a "must".

12.2 Riffles

There is another type of file that not too many people know about. They are called "rifles"or "rifflers"They are great to add detail to parts that have nonstandard shapes. Riffles were developed for tool makers to put the final touches on complex shapes.

Rifflers are used for filing the finishing touches onto complex shapes. There are many choices of shape to choose from.

The files have many cross sections and have a file on each end of the handle that have been "bent"to get into tight places. When you get working at this level of detail, engraving would better describe the work you are performing.

Needle files are also good for working in small areas and come in a large selection of cross sections and shapes. Files are amazingly inexpensive considering the work involved in making them.

12.3 Powered rotary files

I'm sure everyone has seen kits that have a high speed motor to drive a wide assortment rotary tools. Dremel is by far the largest manufacturer of these neat little sets. They can be real handy but don't use them in a small cavity. If they dig in, they bounce to the opposite side and you can destroy a part in a split second. It is really worth the extra effort to machine good finishes in cavities. They are very difficult to clean up later.

12.4 Working with files

A single-cut, flat mill file is my personal favorite. These files have ridges in only one direction rather than two directions. This doesn't allow them to remove material quite as fast, but when you are working with small parts, time isn't as important as quality. Mill files have straight teeth angled to the body. This creates a self-cleaning action. For general work such as deburring, I use a 6"to 8"long file with a smooth cut.

When a file first comes in contact with a part, it should be allowed to find its resting point before any pressure is applied. This keeps the edges from digging in. The direction the file is driven should be at an angle that allows the teeth to cut the part at an angle. If the teeth hit an edge squarely they have a tendency to chatter. Remember, a file has a built in angled cutting edge.

12.5 Keep your files clean and sharp

Files should be replaced when they get dull. The sharpness of files should be judged by their performance. When files start cutting on their ends better than in the middle they are worn and it is time to replace them. A File should cut with little "downforce". To cut properly they need to be clean. The grooves on the backside of the cutting edges are the same as the flutes in a drill or mill cutter. A drill wouldn't be expected to work with its flutes clogged and a file will not work properly unless it is frequently cleaned. I use a small wire brush that has the shape of a toothbrush.

12.6 Precautions when working on spinning parts

A file used on a lathe can be very dangerous. If the point of the file comes in contact with the three-jaw chuck, it will be driven backwards into your hand. These can be nasty injuries and can only be avoided by concentrating on the job at hand. Machining is a process that requires hands to be in close proximity of moving cutters and spindles. When operating manual machines, the only safety device that really works is the brain keeping the hands out of trouble.

12.7 Putting handles on files

For safety, all files should have handles on them when they are used, but it is especially important when lathe-filing. By the way, the proper way to seat a file in a handle is to bang the handle end down on the workbench, using the file's momentum to seat it into the handle. Never hold the handle end up and hit the metal file end on the workbench.

12.8 Magnifying eyewear makes miniature work easier

I strongly recommend a magnifying headset for doing work like this. It is wise to use the minimum amount of magnification that can be used to get the desired results. Powerful lenses distort your surroundings so much they hurt more than they help. They must be comfortable to wear. Magnifying glasses are inexpensive and should also be considered a necessary tool for fine finishing.

12.9 Deburring the edges and corners of a block

If the edges on a small rectangular block need deburring, the amount of corner break should be equal on all edges. This is when your eyes become more accurate than you thought they were. You can

The photo above shows blocks in various stages of finish. The unfinished block on the left has square. machined corners and a drilled hole. Its fly-cut surface shows machining marks. The block in the middle has been lightly sanded in two directions with 320 grit sandpaper on aflat surface and has had the corners slightly softened with a flat mill file. The hole has been chamfered with a chamfering tool. In addition to surface sanding, the right block has had the edges beveled with a mill file and then sanded. The corners have been slightly rounded off. The hole has been chamfered and lightly spot-faced with a counterbore.

easily distinguish a difference of only .005"(.127mm). If appearance is important on this block I will go one more step to put the final touches on exposed corners. The chamfered edges now have the appearance of three separate edges joining. They would look better if these surfaces flowed together. After the edges have been equally chamfered, use your file with light pressure and file around the comer. This will round off the comer on one side. Sides two and three are done the same way. The final comer will have a beautiful shape that can be polished to perfection. This should only be done to comers that do not mate with another part.

12.10 Removing tool marks and final finishing

The part is now complete, or is it? It has been milled to shape and carefully deburred, but it doesn't have the look you want. You remember the parts you saw which were built by one of the masters of our hobby. They looked more like pieces of jewelry than mechanical parts. If this is what you want, the part still needs a lot more work. The next step is removing tool marks. Nothing looks worst to me than a surface that has been polished too soon. The shiny surface will magnify the flaws.

12.11 Polishing stones

If you have a nice, flat, machined surface that shows a few tool marks, it will not be improved by filing. I switch to abrasives. Inexpensive "polishing stones"that come in a variety of shapes, sizes and grits are

A selection of small polishing stones. Keep them clean by frequently dipping them in kerosene as you work. Work from rougher to finer grits to achieve the finish you need.

The photos in the background show the actual deck fittings from a vintage Chris Craft boat. In the foreground is a model part that duplicates the highly polished sheen of the chrome on the original bow light. The model is by M. H. Ellett.

available. These aren't things that are sold at your local hardware stores and a mail order company would be your best source. I have found a 1/4"square shape the most useful. The end can be shaped on a bench grinder to get into tight spaces. The stone is dipped into kerosene frequently to keep the surface being cut awash with fluid. I've found that by changing the direction of cut as much as possible on each pass across the surface, the process will be speeded up. You make as many passes as it takes to get rid of all tool marks. Do not try to do large surfaces at one time. This is a very slow process and the average person will get very sloppy if they try to take on too big an area. The next step is to use a finer grit stone and remove the scratches left by the previous stone. This process is repeated until you have a finish that is flat and free from all but microscopic scratches. The next process is polishing the surface.

12.12 Sandpapers

1 have gotten excellent results with 320A wet and dry sandpaper glued to small sticks, I buy these wooden sticks at hobby shops and prefer spruce. I glue the sticks to the paper with instant "super glue"and make up a batch of them at one time. The glue hardens immediately and the sandpaper can be trimmed to the stick size. This glue works well because it doesn't seem to break down with the kerosene that must be used to maintain a cutting action. Many times this is all that is needed to finish a part to your satisfaction. Highly polished parts don't always look good because the finish will exaggerate any flaws.

These "sticks"will work well for most metals, but may be to slow to remove deep gouges in the harder materials. The 320A paper is the only type I would recommend. Coarser papers don't cut as well. I believe a metal surface is just too hard for them, and the maximum pressure that can be applied doesn't allow them to work. On the other hand, finer grits like 400 or 600 cut so slowly they can be a waste of time. If you want a better finish than you can get with 320A, polish it.

320A wet and dry paper is also useful to finish flat surfaces. Larger surfaces must be very fat or it will be easy for you to notice variations. The full size sheet of paper is laid on a flat surface and soaked with kerosene. The part is then dragged across the paper with little down pressure. This helps keep the part square to the flat surface. I always use a surface plate. Again, I have found I get better results by taking straight cuts from a variety of angles.

12.13 Powdered and liquid abrasive polishes

Most any abrasive powder can work, but diamond powder is by far the best and also the most expensive. Most any abrasive type polish will work as well. Automobile rubbing compounds will work and they should also be applied with a stick. The diamonds come mixed with an oil. A small amount is put on a clean stick and the stick is used like a polishing stone. The diamonds become imbedded in the stick and will keep cutting as long as a very small amount of kerosene is used. Of course, the diamonds will be eventually be worn and washed

A commercial "tumbler"uses abrasive particles to remove rough edges from machined parts.

away and more diamond compound will have to be added. You have to be careful you do not contaminate the sticks with any grit and the part has to be meticulously clean. You wouldn't polish a new Ferrari without washing it first. One little piece of coarse grit can make a polished surface look as though it had been attacked by a graffiti vandal.

12.14 Tumbled finishes

Production parts will be finished in a machine called a "tumbler". The parts are put into the drum of the tumbler along with a quantity of an abrasive medium, which comes in a variety of different shapes and sizes. When the machine is turned on, the random abrasion between part and abrasive medium will rub the tool marks off. For the home use, a small rotary tumbler used by the jewelry trade may be helpful and costs less than industrial models. It isn't a fast process, but the only labor is mixing the parts with the media and then adding water with a very small amount of detergent. The media should outweigh the parts by three times to keep the parts from damaging one another by contact. The detergent keeps the media from getting slippery from oil which would stop the cutting action. It will usually take several hours to get the desired results.

12.15 Sandblasted and beadblasted finishes

Sandblasting or beadblasling puts a soft, dull finish on metals. If you are modeling a part where you need to use machining but you want the finished part to look like a casting, sand- or beadblasting the part can give you the finish you are looking for. It's a pretty "low tech"process. All you need is a compressor, a sandblasting "gun a hopper and a bag of silica sand, but unless you plan to do a lot of it the mess it generates just isn't worth doing it yourself. It's not very expensive to send your parts out for sandblasting and is probably worth it not to have to deal with the very abrasive silica dust. However, taking a few small parts to a professional sandblaster is usually not practical. Their equipment is too large, and they are not really not set up to handle small parts. An automotive sand blaster that has an enclosed box for sandblasting small parts is probably your best bet.

If you do try and do it yourself, be sure to wear the proper eye protection and the correct type of respirator mask. The fine particles of silica are the same as what makes up glass, and getting them in your lungs can cause silicosis, which is similar to asbestosis.

Here's what M.H. Ellett's Chris Craft runabout looks like finished and in the water. The detailed and highly polished fittings make this model look like the real thing no matter how close you get.

Jerry Kieffer is seen here at a model exhibition with his 1/12 scale Brown & Sharpe Universal Milling Machine. He superdetailed his model based on photos in a reproduction of a Charles A. Strelinger & Co. machine-tool catalog from 1895. Jerry is in the process of outfitting a complete 1/12 scale overhead belt driven machine shop as it might have been found in the late 1800's. As is typical of Jerry's models, every detail is represented to exact scale. Shown below is the dividing head which sits on the mill's table.

Jerry's fingers give a sense of scale to the small size of the dividing head. The indexing plate has the correct pattern of 119 holes, each only .008"in diameter.

Глава 13

Chapter 6 — Cutting tools for metalworking

13.1 6.1— GENERAL NOTES ON CUTTING TOOLS

13.1.1 Tool Deflection

In machining, the cutting tools are the interfaces between the machine and the part. This is where the part is cut and shaped. Machines are built which are capable of incredibly accurate movements, but these accurate moves can't help the process if the cutter is deflecting by large amounts. A 1/2" (13 mm) end mill can deflect as much as .050" (1.25mm). The deflection is a function of the diameter of the tool compared to its length, plus the sharpness of the tool, the feed rate and the depth of cut all have to be considered. You must understand this fact to successfully make machined parts. It is not a business of just numbered movements. It is a process that requires a great deal of thought and planning to produce good parts. The better you get at anticipating these basic problems, the better you will become at machining metals.

A long, thin piece of stock will deflect away from the cutting tool. Overcoming the shortfalls of a process or *the quirks of a particular machine to make consistently good parts is what separates a hacker from a craftsman.*

A machinist will use every available skill to overcome these obstacles by "sneaking up" to final dimensions to make the first part good. If more identical parts are to be made, ways can then be found to speed up the process. Common sense should tell you that if a cutter deflects a large amount on heavy cuts, it will still deflect a small amount on light cuts. Tool or part deflection has to be considered in every case. Whether you are operating a machine the size of a locomotive or as small as a Sherline, the problems remain the same, but fortunately, the costs don't. A large part can have thousands of dollars worth of material and labor invested before a machinist touches it. How would you like to be the employee that has to tell his boss he had just bored a hole oversize in a twenty-thousand dollar forging?

The home machinist will have to learn these facts by trial and error. They don't usually have the advantage of having a skilled machinist nearby to rely on for information. I'll never understand why someone relatively new to the trade will resent a skilled craftsman suggesting a better method of doing the job. Information is being passed on that could be of tremendous help to them. I imagine they have never spent days of their own time trying to solve a problem that could have been solved in minutes by a skilled craftsman. The best and fastest way to teach yourself is by constantly checking the part as it is being machined. Learn how much the machine and tools deflect as they are being used.

13.1.2 Overcoming Problems on a Lathe

Lathes are easier to deal with than mills because the operations are straightforward. They are two dimensional machines, and diameters are easy to measure. The problems encountered with lathes usually involve the part bending. A perfectly aligned lathe will not cut absolutely straight unless the part is rigid enough to support itself. The shape of the cutting tool will influence the amount of deflection. A sharp pointed tool, with the cutting edge perpendicular to the diameter being machined, will have less deflection force than a tool with a large radius. Large radius lathe tools can be a loser if you are working on parts that are small or on a worn out machine because the forces are directed away from the headstock and towards the part. This can bend the part or load worn out slides. On a Sherline lathe a maximum tool radius shouldn't exceed .015". On high speed steel lathe tools, I will grind a small flat on the point rather than a radius to improve the finish. You can't grind the small radii required free hand, but you can grind a flat on a bench grinder which will work almost as well. Hand ground lathe tools are described completely in the section on "grinding your own tools" later in this chapter. They can be not only the fastest method of removing metal, but also the cheapest.

13.1.3 Electrical discharge machining or "EDM"

There is another way of cutting metal with which many home machinists are not familiar. I want you to know about this process, because I'm sure you may be curious about how a modem machine shop deals with hardened materials. It is called "Electrical Discharge Machining" or EDM. This is a slow process that does the seemingly impossible by using an electrode to remove metal. The electrode is made to the opposite shape you want to produce. (For example, a square electrode will produce a square hole.) When the electrode gets within .001" of the work, small sparks jump across the gap. The temperature of these sparks is hotter than the surface of the sun, and the metal actually disintegrates. In a sense, this happens one molecule at a time, which is why it is a slow process. It also takes place submerged in a special oil. The electrode, which is usually a pure form of graphite, has been shaped to burn a pocket into the hardened steel. The electrode also disintegrates during the process. EDM machines have controls that can be set to cut faster at the expense of the electrode; therefore, several identical electrodes are usually used to produce each shape. Each succeeding electrode makes the cut more and more accurate.

An EDM removes metal by actually vaporizing it with a high powered electrical discharge or spark. It is capable of great accuracy and of making shapes that would be impossible with other methods.

Debris is created as the EDM operates. This will "short out" the cutting action so the part must be flushed with oil to wash away the debris even though it is submerged in oil. Much of the skill in operating these machines is how you accomplish this. It is much more difficult than it sounds. I use an EDM machine to build plastic molds because the electrode is many times easier to shape than the cavity. Molds are built with materials which can be hard to machine.

13.1.4 Other special uses for EDM

A simple form of EDM machine has been developed just to remove broken taps from parts. The electrode is simply a tube that has a diameter which is less than the inside diameter of the hole in which the tap has broken off. Electrolyte is pumped down the tube and the simple EDM burns the center of the tap away. The broken tap can then be "picked out" and, if done correctly, the hole will not be damaged by the sparks. There is also a highly sophisticated EDM that cuts with a small diameter wire which is fed through the part like a bandsaw. They are used to make cutting tools like punches and dies and are amazingly accurate but very expensive — around $100,000. EDM machines have changed the way parts are designed and built. Many businesses have been started that take advantage of the capabilities of these machines which are expensive and have a limited use. I've even seen several designs for "homemade" EDM machines that will work as long as great deal of detail isn't required.

13.1.5 EDM, CNC, CAD/CAM and other acronyms of the computer age

Today, EDM electrodes are made on CNC mills which are controlled by computer programs that take information directly from the drawing that has also been produced on a computer. This type of work is where the term CAD/CAM (computer aided design/computer aided manufacturing) came from. These can be exciting times for the machinist who leams the new rules that govern this new way of doing things.

13.2 6.2 — CUTTING TOOLS FOR BOTH THE LATHE AND MILL

13.2.1 Using Center Drills

Center drills have been designed to drill a hole that a tailstock center will use to support the part. They have a short straight section at the end of a sixty-degree cutting edge. As the chart shows, numerous sizes are available to take care of any job. However, they do have a few problems you should be aware of. The straight section doesn't have any clearance on the sides like a drill. Without cutting oil the chips clog up the flutes and they can twist off. The reason they don't have clearance is to make them "find" the center of bar stock in a lathe. Drills that are flexible can start drilling off center without the help of a center drill to get them started. Even with cutting oil you can't drill to the required depth without backing out the center drill completely and adding cutting oil to it's tip. The straight part of the hole was to make a pocket to keep lubricants for lubricating the supporting sixty-degree tailstock dead center. A great deal of heat from friction can be generated at the center without proper lubrication. White lead was the preferred lubricant of its day because it didn't gall, but for obvious health reasons it isn't available any more. On lathes we now use live centers which rotate with the part to eliminate friction.

COMMONLY AVAILABLE CENTER DRILL SIZES

13.2.2 The difference between a Center Drill and a Spotting Drill

Center drills are an important tool in machining and are used as much on a mill as a lathe. It is a simple fact of life that drills will "walk" when starting a hole that hasn't been started with a short, rigid drill. Center drills were the only tools available that could start holes without wandering. The only problem was, it took too long to drill a pocket for the lubricant that wasn't needed. Years ago, I saw this problem

A center drill (top) and a spotting drill (bottom).

and started making "spotting drills" for use in our own shop. We could save minutes of machine time on one part by not using center drills. They have finally brought to the market drills of this type called "spotting drills". When compared to the complexity of a standard drill, spotting drills cost more than they should, for they could be manufactured cheaper than a center drill.

A center drill being used to find the center of a piece of stock. The 60^o *angle will locate the point of the tailstock center for turning between centers. The smaller hole will serve as a reservoir for lubricant if a live center is not to be used.*

A drill press can be the most dangerous machine in a machine shop. They are so simple to use that operators don't give them the respect they deserve. New employees are often given drill press jobs to start their machining career. Never hold a part by hand when drilling into metal or similar types of materials. The drill can grab the part and start it spinning at the RPM the machine was set at. The greatest chance of this happening is when a hole is enlarged with a larger drill. The softer the material, the better the chance of this happening. The first part of this scenario is the where the drill screws into the part, lifting it off the table. When the drill jams in the part, the part will spin. If this happens. step away and try to safely shut down the spindle. Whatever you do, don"t be a hero and try to grab the part. You could end up looking like you have just been through a war in the 16th century. Also, when drills are broken off they may leave a very sharp point in either the spindle or the part that could cut to a depth that could result in permanent injury. Clamp your parts down firmly and cut down on injuries.

13.2.3 Who came up with these stupid drill sizes anyway?

Manufacturers of cutting tools sometimes have a strange way of applying logic. Take the standard drill indexes that are available today. They are still the same as sets from fifty years ago. If anyone could explain the logic of the sizes they manufacture I would love to know, They simply keep making the same old sizes they have always made without questioning the logic. Overseas manufactures aren't any better for they just copy what is available. (Obviously this is one of my pet peeves.) The quality of the better drills manufactured today is superb, but it is too bad they don't make them in the proper sizes. The better industrial suppliers may offer high and slow helix (flute twist), but I would recommend that you stick with the standard "jobber" drills. They are cheaper and work quite well. The hobbyist/machinist will want to buy a drill set for working with the miniature machine tools. My first choice would be a number 1 to 60 set. (Sizes .040" to .228".) This set will have the drills you need for drilling and tapping small holes. A miniature tool doesn't have the power or the size for large drills. On smaller machines, larger holes are bored rather than drilled.

The metal box holds a set of drill bits sized from number 1 through 60. The red plastic box holds a selection of very small bits from number 61 through 80. In the foreground are #1, #60 and #80 sizes.

There is a series of drills called "screw machine drills" that are shorter and better suited for small machines. They make them in both left and right hand. Only right hand drills will work on a Sherline because of the direction of rotation. Use high speed steel drills because of their low cost and long life when properly used. Stay away from carbide drills unless you have a particular need for them. They are very brittle and most small tools can't produce the spindle speeds needed for carbide to have an advantage. Printed circuit drilling machines, for example, may run carbide drills at over 60,000 RPM.

13.2.4 Using drill bits properly

Drills get more abuse than any other metal cutting tool made. Watching a home repair expert stick a drill back in a hole that they just drilled with a slight error and try to make the hole oblong by bending the drill should give a machinist the horrors. To begin with, the flutes on a drill were never designed to cut, but somehow they do when enough pressure is applied. They are designed to pull the chips out of the hole and a small amount of coolant is a must, especially for holes going more than two drill diameters deep. If you want accurately drilled holes, you can't abuse drills. Small diameter drills are usually discarded when dull to maintain accuracy. Hand-sharpened drills will normally drill oversize because the cutting lips are not exactly equal. To keep drills sharp, they have to be turned at a speed that is forty percent or less of the material cutting speed they are drilling. Exceeding this speed can instantly destroy the cutting edge. Dulling tools in this manner is foolish because speed is one of the easiest variables to control. Think about the way American Indians would start the campfire. They would turn a straight, dry stick back and forth with the palms of their hands until friction generated enough heat to start a fire on the wood where the stick point was rubbing. Now consider how fast they could have started that fire if they powered that stick with a five horsepower motor! Hopefully I have made my point.

With the centering hole drilled and the RPM set correctly it is time to drill the hole to size. The Sherline motor doesn't have the horsepower for large diameters and high feed rates, but that isn't a problem as long as you work within the capabilities of your tools. It just takes a little longer. The real problem is keeping a constant feed rate and knowing how deep the drill can go without "pulling" the drill.

The drill point must be lubricated and the chips must be removed from the drill flutes. With automatic production machinery, the drill can go as much as three and a half times the drill diameter into the hole before it is backed out to clear the chips. From that point on, I usually program depth of cut in one drill diameter increments. Using manual machines I would recommend two times the drill diameter for the first cut and one diameter beyond that point. When using small drills, the amount that can be drilled without clearing the drill is as small as the drill diameter. This is very important and the reason I am emphasizing it. A drill that has been broken off in a part will usually result in "scrap. To make matters worse, when you start over again, unless you have a spare bit, the one you need is now broken. Good drilling technique makes this one problem that is avoidable.

13.2.5 Should a hole be drilled in stepped sires or directly to size?

I have found that once the part is center drilled, drilling a hole to size with a single drill will give better results than enlarging a smaller hole with a series of larger drills. Every time a different tool enters a part it can pick up off center, because the drill before it may have left a sharp burred edge in the hole. If this method must be used, make sure the spotting or center drill will cut to a diameter that includes all the sizes you will be using and has a ninety or sixty degree tip. Brass is a difficult material in which to enlarge a drilled hole. In fact, it can be downright dangerous, because a standard drill can be pulled into a pre-drilled hole and lock up. Machinists often put a slight flat on the cutting lip of drills used to enlarge a hole in brass to avoid this problem.

13.2.6 Drilling stainless steel

First-time machinists will discover it's a whole new ball game the first time they attempt to drill a hole in a piece of stainless steel. It is called "work hardening" and it is just as the name implies. I'm sure everyone has taken a wire and bent it back and forth until it broke. What was done was the metal kept getting harder at the bend until it became so brittle it fractured. Stainless steel as well as many other exotic metals can surface harden while being machined. Small drills will make this fact even more apparent. If a drill is allowed to rub the surface without cutting, it will work harden the surface it is trying to drill. This happens at the bottom of a hole that is being drilled. The cause can be a dull drill or not using a sufficient feed rate to keep the drill cutting. This will work harden the surface, which will dull the drill, which will work harden the surface even more until the drill will not cut at all. To work around this problem, the spindle has to be turning slow enough to have a feed rate that allows the drill tip to maintain a constant, uninterrupted cut. The calculated spindle speed may be much faster, but the machinist can't keep up with the higher RPM. Also, don't leave the drill at the bottom of a hole when it isn't cutting. Raise it immediately. If a hole gets work hardened, check the drill for sharpness and start drilling again with a slight "tap". This will sometimes allow the drill point to break through the hardened surface and start drilling again.

13.2.7 A Note on very large drill bits

Drill bits at the large end of the size scale usually have a tapered shank and could never be used on a Sherline, for they are as big as the machine. However, there is still something to be learned from large diameter drills. In many cases, larger drills have a tapered shank with a "tang". A tang is a rectangular shape on the small end of the taper that engages with a holder designed to accept it so the drill cannot spin. The added cost for manufacturing this type of drill is worth every penny if it keeps the drill from spinning, as this will ruin the shank. The way standard twist drills are kept from spinning is by tightening the drill chuck with a key to create enough friction to lock them in place. If they are not tightened enough, they will spin in the chuck, and you simply can't tighten the chuck enough by hand without a key. Many machinists never learn this fact and the results of their carelessness can be found in tool cribs around the world.

A large drill bit with a tapered shank. On larger machine tools where cutting forces are higher the flat tang keeps the drill bit from spinning in the chuck. Miniature machine tools don 7 have enough power to require this kind of holding force, but you still need to tighten your chuck with a key so the drill can 7 be ruined by spinning in the chuck.

Additional information on large drills is not included because it isn't very useful for small machines like the Sherline. *Machinery's Handbook* will be the best source of information for large drills. I have also learned much information from catalogs on cutting tools printed by mail order suppliers. I would also suggest you inspect a small drill under a magnifying glass some time to appreciate the level of perfection to which these tools have been made. Their very reasonable cost will be appreciated even more once you get a really close look.

13.2.8 Countersinks

The countersinks I prefer to use have only one cutting lip, and they will cause you very few problems with chatter. Countersinking tools are used to chamfer the sharp edge left after a hole has been drilled. A wide variety of angles are available. They are also used to allow flat-headed screws to fit flush with the part surface. They should be run at a very low rpm when used in manual machines. You can instantly destroy these tools in stainless steel by using excessive speed with a hand drill. If the hand drill you are working with doesn't have a speed control, keep the RPM low by pulsing the trigger switch. The speed should be such that you can see the tool cutting. If the tool is not perpendicular to the hole, the chamfer will be uneven.

13.2.9 Step drills

Step drills have one or more diameters and are made to eliminate changing tools to save time in machining operations. Only consider the step drill's smallest diameter for feeds and its largest diameter for speeds. It is easy to twist the tip off if not enough cutting oil is used. They are expensive, and because of the limited sizes available will usually be custom-made by local toolmakers. Only use them when the cost is justified by the time saved.

13.2.10 Counterbores

Counterbores are used to enlarge existing holes. They have a "pilot" shaft which can be changed to different sizes on larger diameters counterbores. One of the most common uses for these tools today would be counterboring a clearance screw hole for a socket head cap screw. (Many times these screws are referred to as "Allen cap screws".) Spot facing rough or curved castings so bolts can be pulled down on a

Top: a 1/4" short shank counterbore of high speed steel. Above: a longer style counterbore is well suited for screw heads and spring pockets. There are many more styles and shapes, A pilot sized to the drilled hole goes in

the front of each counterbore. They are normally sold separately and are held in place with a set screw.

flat surface is another common use. If the pilot is the right size it keeps the tool from wandering, Counterbores will usually have three flutes and a very slow helix, making their diameters difficult to measure, They have to be turned at low RPM with a moderate amount of pressure similar to using a countersink. They are expensive.

13.2.11 Reamers

Reamers are available in more sizes than drills. A reamed hole will have more accurate diameters and better finishes than a drilled hole. However, if they are not used properly, a good drilled hole may be better than a reamed hole. They come with straight and spiral flutes. In theory, straight flutes will work better if the hole goes all the way through the part because a lot of chips get in front of the cutting edge. Spiral flutes will help pull the chips from the bottom of a "blind" hole. A right-hand cut, left-hand spiral will push the chips forward and should never be used in a blind hole. I always order straight flutes for general use. A feed rate of .001" per tooth is recommended, so the RPM must be slow enough to maintain this feed. Ample cutting oil must be applied, and the reamer must be pulled out of the hole often so chips can't build up in the flutes. The reamer must be located directly over the center of the hole to work properly.

The safest way is to ream the hole to size immediately after drilling. I usually allow less than .008" (.2mm) on sizes less than 5/16" (8mm) and for over this diameter I allow 1/64" (.4mm) for clean-up with a reamer. A reamer can start cutting off-center if the drilled hole has chips lying on the hole edge; in fact on CNC machines, we occasionally put a program stop to allow the operator time to blow the chips out with an air hose. What happens is the chip will start rotating with the reamer, shutting down the cutting action on one side. The reamer will cut oversize until the chip is forced from its location. It will then start cutting on-size leaving the hole with a "bell-mouthed" entrance. Fractional inch sizes are quite a bit cheaper than decimal size reamers. Try to design your parts to have finish diameters that take advantage of this fact.

13.2.12 Taps

Taps are cutting tools to cut screw threads in holes (see thread cutting instructions for thread definitions) and are made in many sizes and shapes. Taps cut several thread shapes and the sixty-degree thread is standard. The "acme"and "square" threads are not available in diameters under one half inch and will very seldom be used by the hobbyist. For the type of work done in miniature machining, I would not consider large taps. If needed, you can usually get the information from most industrial supply catalogs.

The same rules should be applied to large and small taps. Taps are defined by their diameter first, which may be a wire gauge size, and followed by the number of threads per inch. Metric taps will be defined by diameter and actual pitch. Drill and tap charts will give the information to cut 75Engineers have discovered long ago that a full thread isn't necessary. A 75thread is almost as strong and the difficulty in cutting a full thread just isn't worth the extra effort and cost.

To tap a high quality thread, you need to start with a proper hole size and use a lubricating cutting fluid. A chamfered hole will start the tap better and will not raise the surface where the hole is being tapped; however, thin parts may require no chamfer in order to have the maximum number of threads for a given thickness.

13.2.13 Why cheap taps are a poor investment

If you have a choice as to the size you can use, look at a tool catalog and pick out a size that is readily available. The savings in cost will be worth the effort. Remember also that just because the size may be listed doesn't mean you can buy it at every industrial supplier, never mind a local hardware store. Buy taps before you start the job, and it would be wise to buy an extra one. They are very easy to break. If possible, I get my tapping done early on complex parts. If a tap does break and ruins the part, you are not scrapping a lot of labor. If you are having a problems tapping holes, the first question to be asked is about the quality of the taps you are using. Inexpensive tap sets can be so bad they wouldn't cut butter. They usually are found in department stores. Stay away from them no matter how tempting they may look. Tap sets sold by industrial suppliers are better, but I still advise buying only what you need, when you need it. Buy quality taps and save hours of grief.

Taps are made in a variety of styles, and my favorite are the "spiral point gun taps". In smaller sizes they have two flutes and are the strongest series of taps available. "Spiral pointed" means that the chip is pushed ahead of the tap. This eliminates the need to back up a tap to break the chip as four-fluted hand taps require. These taps are made with two choices for the cutting tip: "plug"and "bottoming". Use the plug style for general use. Spiral point taps have been designed to push the chips out the bottom of the hole that is being tapped. In blind holes, the chips will pile up at the bottom and could cause a problem.

SPIRAL POINT TAP
SPIRAL FLUTE TAP

13.2.14 Spiral pointed taps vs. spiral fluted taps

Don't confuse spiral pointed taps with spiral fluted taps. Spiral fluted taps pull the chips out of the hole, which may seem like an excellent idea until the strength of the tap is considered. They break easily, because under load they "unwind" and jam in the hole. The problem eliminated by these taps can be canceled out by their inherent weakness. If possible, drill the hole deeper than it will be threaded to make room for these chips. After tapping, the chips can be removed from the hole with tweezers.

A problem can arise when a tap is reversed. The chips can jam the tip in a blind hole, breaking the tap, but tap breakage is less with two-fluted than with four-fluted "hand taps" because of the extra strength of these fine cutting tools. In small sizes, the four-fluted hand taps should be avoided but some sizes are only available in that form. "Starting" taps have a shallow cutting angle mat will cover many threads. Each cutting tooth will form a small amount of the thread. While this may seem like a good idea, it does not always work well. With many threads cutting at the same time, the torque required to drive them may be higher than a plug style spiral pointed gun tap, but they do start the tap straight down the hole with less effort.

13.2.15 Tapered pipe thread taps and dies

Pipes used in plumbing use a National Pipe Thread (NPT) standard which is a tapered thread. Tightening the parts together seals them as the tapers meet, making a tight joint. When tapping a hole for a tapered thread, measure the part you will be threading into it to make sure you don't run the tap too deep. NPT threads start at 1/16-27 and go up to over 3 inches. You might use some of the smallest sizes on miniature plumbing fittings for steam engine models or pipe fittings in small engine blocks.

13.2.16 Hand tapping a hole

When tapping holes by hand, the tap must be perpendicular to the hole. I recommend having the part clamped down so the tap will be pointed towards the center of the earth. It is easier to line up when the tap and handle are square to its surroundings. The quickest way to break a tap is casually holding the part in your hand and a tap in the other. If the tap is not "square" it will not follow the hole and will progressively start to cut one side more than the other. This will quickly reach the point of no return when the cut exceeds die strength of the tap. It is very difficult to straighten a tapped hole. Again, you must use a cutting fluid. It not only keeps chips from sticking to the cutting edge, it also keeps the tap from sticking to the cut thread. Remember that "like" materials will gall and stick together, and this is one reason taps break at a alarming rate.

NOTE: Broken taps can be dangerous! Pieces of the tap can be thrown at a very high speed and easily do eye damage, Always wear eye protection. The broken tap can leave a sharp cutting edge where it has broken and give a nasty, deep cut that could require stitches.

13.2.17 Tapping stainless sleel

Hand tapping a small diameter screw thread of 75% may seem impossible if the material is stainless steel. The tip of the tool will twist' to the point of almost breaking before the tap will even start to cut. Dull or poor quality taps will not stand a chance in stainless. A 65% thread may help, but a change such as this must be authorized if the part isn't for your own use, and considered if it is for your own use. Don't use a tap until it breaks. They are disposable tools and have a life-span that can be short with exotic materials.

13.2.18 Tap wrenches

The tap wrenches for holding taps used by amateurs will usually be the standard hand tap holder. Buy the size that just goes to one-quarter inch and, if you can locate a smaller size, buy it too. It will be useful to have a very small tap wrench for the small sizes that you will encounter while working on very small parts. When you work with equipment that is too big for the job, you lose that "feel" that keeps taps from breaking. A tap wrench has a chuck similar to a drill chuck but it has only two jaws. The jaws allow the tap to be held by the square, machined end on the tap. Good quality tap wrenches will clamp the tap in line with the tap wrench body, making it easier to get the tap square with the part. When working with full size mills, I will use the spindle to line the tap over the hole. Some tap wrenches have a sliding shaft protruding from the handle. Using this shaft, the holder can then be held in a collet or drill chuck and be supported so that the holder is always square and directly over the hole. To cut successfully, taps must start square while cutting the first threads.

A standard "T" handle tap wrench and a tap wrench with a pilot shaft for holding in a collet or drill chuck.

13.2.19 Tapping threads on big CNC machines

Automatic tapping on a modern CNC milling machine is accomplished by reversing the spindle. The tap is held in rigid holders and the spindle is electronically synchronized with the feed to turn in relation to pitch of the tap. It does this so accurately, a "floating" holder is not necessary. It is amazing to see a part being tapped at 2000 rpm! Metal will cut better at a higher rpm and the quality of the tapped holes will be better. Of course, you can't do this on inexpensive equipment, but I thought you might find it interesting.

13.2.20 Tapping heads for manual mills and drill presses

What you may be able to afford some day is a small tapping head. They can be used with manual drill presses and mills. A good quality tapping head costs about $400 (1998). They are designed to turn in one direction when the pressure is applied to drive the tap into the part and in the opposite direction to unscrew the tap when the tapping head is raised. The tapping head is usually geared to turn the tap at twice the input rpm when backing the tap out of the work. This makes the process more efficient. They make several models, and for small taps I prefer a cone clutch design over the dog clutch. Dog clutches engage with a "snap" which has a tendency to break small taps. Also, they cannot tap left-handed threads. Cone clutches operate more smoothly.

When a tapping head is used, the operator must put enough pressure on it to start the threading process. The tap will then be screwed into the hole at the rate of its pitch. If the feed rate, controlled by the operator, does not equal the pitch of the tap, the clutch will disengage. On a drill press, the depth of the tapped hole will be controlled by the "depth control stop". When you are tapping blind holes, you set the stop to make sure the tap will not go all the way to the bottom. Measure the distance to go and reset the stop to eliminate any error. A tap will go deeper than the stop is set because it has to disengage the clutch. When the tap is unscrewed, a slight withdrawal pressure is needed to operate the opposite clutch and any excess pressure will "tear" the thread as the tap leaves the now-threaded hole. A definite feel for the process is needed to operate these labor saving devices effectively.

13.2.21 Tricks of the trade... A tapping tip from Bob Shores

I have read many tips on tapping holes — some good, some not. Five years ago I dreamed up a tapping method for small holes. I tap a lot of holes with 0-80 and 2-56 threads, and since I have been using this method, I have not broken a tap in five years.

After drilling the hole in your part to the proper size, the drill bit is removed from the chuck without disturbing the work, A 2" aluminum disk, knurled on the outside and drilled and tapped for a 4-40 hex bolt grips the tap just above the flutes. The end of the tap is gripped in the drill chuck and lowered until it just touches the work. The chuck is then loosened to allow the tap to turn freely. The disk holding the tap is turned with your thumb and forefinger. The drill chuck acts as a guide to keep the tap running true, and your fingers are very sensitive to the amount of torque being applied. To break a tap you would have to apply a lot of force.

— Bob Shores

HOLE SLIGHTLY LARGER THAN TAP
2" DIA × 1/4" KNURLED ALUMINUM DISK
4-40 × 1" HEX BOLT
DRILL CHUCK
7" KNURLED ALUMINUM DISK
TAP

13.3 6.3 LATHE CUTTING TOOLS

13.3.1 Right- and left-hand tool shapes

Again, the difference between a lathe and a mill is that the work turns on a lathe and the tool turns on a mill. Before we get into grinding lathe tools let's define this type of cutting tool as a single point tool that is fixed (doesn't cut by rotating) and held in a tool block on the crosslide of a lathe. By the way, lathe tools can be cut as "right-hand" or "left-hand" shapes. The reason we call a tool a "right-handed" tool when the cutting edge is on the left is because it is designated by which way the chip leaves the cutting tool. A left-handed tool is designated as such because the chip will go to the left as it cuts. The cutting edge will be on the right. The standard tool is a right-hand tool, and a right-hand ground tool bit is included with each Sherline lathe to help get a novice started. Scissors or sheet metal shears are also defined this way, because the cutoff falls to the left or right. Right-handed people will usually prefer "left-hand" shears.

CHUCK
TAILSTOCK
LEFT-HAND TOOL
RIGHT-HAND TOOL

A tool is called a "left-hand tool" because the chip comes off to the left even though the cutting face is on the right. On a right-hand tool the chip comes off to the right.

13.3.2 Why you should ovoid cheap carbon steel tools

The Sherline lathe has been designed to use 1/4" square tool bits. You don't have many choices when it comes to grinding your own lathe tools. The shapes you will need to produce special parts can't be made with standard cutting tools. If you read an old book on machining, it may have mentioned carbon steel tools, and these are case hardened tools. The only way you might find these inferior tools would be in cheap imported sets.

Today, the labor and machine cost to produce a good cutting tool exceeds the material cost by so much that it just doesn't make sense to use cheap steels.

A selection of 1/4" high speed steel and carbide tipped cutting tools for miniature machining. Shown are left to right: A high speed steel boring tool, right-and left-hand cutting tools, right- and left-hand carbide tools and a carbide 60^o *threading tool.*

13.3.3 High speed steel tools

For the average machinist, "high speed steel" will always have a use in a machine shop. It is inexpensive and easy to grind and shape. High speed steels comes in a variety of grades. For the average work done in a home shop, M-2 tool steel is more than adequate. M-5 would be considered top-of-the-line. Some tool steels contain several other metals to add to their life. Cobalt is a common additive that makes the cutting edge less prone to "chipping" and is effective in adding life to a tool. Usually, the more high speed tool steel costs, the harder it will be to grind and the longer it will hold an edge. You will find the answers to all engineering problems are a trade-off, just as this one is.

13.3.4 Brazed carbide and diamond tipped tools

Sherline offers brazed carbide tools in left, right, and 60^o threading. Brazed carbide tools have a shorter life than inserted tip carbide tools because the carbide has been brazed to the holder and their different expansion rates can causes problems. The left-hand brazed carbide tool works well with the flycutter and is included with its purchase. They can be useful but you need a diamond wheel to resharpen them. One thing you must realize is that some materials can only be cut with carbide. You don't have a choice. These materials usually have an abrasive nature and are not that "hard". In general, hard materials (heat treated tool steels) can't be successfully machined. You can't chuck up an end mill in a lathe and machine its shank down with carbide or diamond cutting tools. Diamond cutting tools are used to get beautiful finishes on nonferrous materials and shouldn't be used on steels. The carbon in the diamond will weld to the carbon in the steel and destroy the diamond.

Heat treated tool steels are shaped by grinding, not by turning. Cutting the silver and copper material used in the armature of an electric motor would be a good application for a diamond tipped tool.

INSERT TIP
TOOL
TOOL POST (P/N 7600)
SPECIAL TORX DRIVER FOR TIGHTENING INSERT HOLD DOW SCREW (INCLUDED)

Carbide insert tool and tool post

13.3.5 Inserted tip carbide tools

I would first like to emphasize that I believe the prime method for cutting metal on a miniature lathe should be high speed steel cutting tools. They are inexpensive, easy to sharpen and can be ground to make "form" tools. On the other hand, insert tools are expensive and can't be resharpened or shaped, but there are times they can be a lifesaver. In some applications they are the perfect tool for the job.

The obvious difference between brazed carbide tools and inserted carbide tools is that the tip is held on with a screw rather than brazed onto a piece of steel. This fact has a lot to do with the success of insert tools in recent years. Steel and carbide have slightly different expansion rates which can cause premature failure of the carbide tip. It is surprising that a small screw will hold these inserts tight enough to accurately cut metal, but it does. We run 20 horsepower computer controlled lathes at Sherline that can remove metal at a rate of 2 pounds (1 kg.) a minute with these tools and have few failures.

The reasons I believe insert tools should have a place in your shop is they are ready to use, they hold their cutting edge when cutting exotic metals or abrasive materials and they can speed up the cutting process.

13.3.6 The rules on cutting speeds are different for inserted tip tools

Normal cutting speed rules don't apply to the same extent as when using high speed steel. Stainless steel can be cut at triple the rate with these tools compared to high speed steel tools. This higher RPM also puts you in a better horsepower range on a small motor. Another interesting fact is that you can get a better finish on some steels, such as cold rolled, by turning up the RPM. Insert tools don't need cutting oils to work well, but I still use a few drops now and then. The lack of messy cutting oil can be an important factor when working on your kitchen table, as it keeps the work area cleaner.

13.3.7 Positive and negative rake tools

I experimented with various tools before making a choice. I wanted a cutting tool that had a positive rake. I don't believe the tools we manufacture are rigid enough for the normal negative rake tools which cost less and are far more popular.* These tools are designed for machines that weigh hundreds of times more than a Sherline Lathe. Positive rake tools have to be sharpened at the time of manufacture which adds to their cost, but also adds to their performance on a Sherline lathe. You can't use any insert in these holders unless it has a positive cutting edge.

*NOTE: Sherline also offers a negative rake tool holder designed especially for use on the Sherline lathe which allows the use of a 55^o negative rake tip. Because of the design of the holder, this tool cuts like a positive rake cutter. This gives you the best of both worlds. A description of that tool can be found on the next page.

CUTTING EDGE
NEGATIVE RAKE TIP
CUTTING EDGE
POSITIVE RAKE TIP

Negative and Positive Rake Carbide Cutting Tips. Negative Rake tips can be held upside down giving 4 cutting edges. Positive Rake tips cut from one side only, but cut better.

Another choice I made was the .015" (4mm) radius on the tip. A large tool radius can give good finishes on a full size machine, but it can cause havoc on small diameter parts or miniature machines. Large radius tools create high tool loads because of their large cutting surface. On the other hand, a radius smaller than .015" will chip too easily.

The difference between the 80^o and 55^o tools is that the 80^o tool is a little stronger at the tip, but the 55^o tool can get into corners better. If you plan to only purchase one, buy the 55^o. The 80^o tool is a good choice to use for rough cuts.

13.3.8 Reading the chips

To get maximum life out of these tools be sure to increase the "feed" as you increase the RPM. The chip should have a tight curl to it and break off into short lengths. These chips can be very HOT, Remember, your hands are closer to the cutting edge when using miniature machine tools, so use caution.

13.3.9 Cutting harder surfaces

Another plus for insert tools is their ability to cut hard or abrasive materials. Don't plan on machining hardened tool steel with them, but you can cut through a work-hardened surface on stainless steel with ease.

Carbide tools can simplify many machining operations, but will never solve problems caused by poor machining practices. As with all machining operations, WEAR EYE PROTECTION.

The negative rake tool holder is shown with a box of spare carbide tips and the tightening wrench. The insert is angled down slightly which provides clearance and is supported all the way down to the table, which provides support for stiffness.

13.3.10 The 3/8" IC 55^o negative rake tool holders

I believe Sherline's 3/8" IC 55^o negative rake indexable holder will bring a lot of enjoyment to your machining, particularly if you have trouble grinding good tools or if you choose to turn difficult materials such as stainless steel. The indexable carbide insert sits on the tool holder at a 5^o negative angle. This gives the sides of the cutter clearance even though the insert has square sides. By having square sides, both the top and bottom of the insert can be used as cutting edges. This gives you front and back, top and bottom of both sides for a total of four cutting edges on each insert. Though not inexpensive, when you consider you are getting four cutting tools in one, it is really a pretty good deal.

Remember that carbide cutting tools are a little more brittle than high speed steel and take care not to break the insert. If you break a chip out of one surface, I don't recommend that you use the cutting surface on the other side. The insert would not be properly supported on the tool holder with material missing from the lower surface which should be resting solidly on the tool holder. Damage to the tool holder can occur if you use a broken insert in this fashion.

13.3.11 Precautions for making deep cuts

Keep in mind also that it is not good machining practice to feed a tool straight into a part any further than necessary. Parting-off tools are designed for this task, but regular cutting tools are not. Going straight in puts two cutting surfaces to work at once, and as you get deeper and deeper into the part, you can overload the cutting capacity of the machine and cause it to jam. If you must feed straight in to cut a groove, for example, go a short distance and then open up the slot side to side, using only one cutting surface of the tool at a time. Then go a little deeper and repeat the side to side cuts.

13.3.12 Don't be afraid to crank up the RPM a bit

An advantage of this tool is that it will cut in either direction. It can also give good finishes on hard-to-machine materials such as cold rolled steel. (Note: the best finishes on soft materials such as aluminum, brass or leaded steels will still be achieved using a good, sharp high speed steel tool. However the carbide insert tool will still do a very good job and will last almost forever on these materials.) A good finish on harder materials using a carbide tool is accomplished by turning up the RPM of the spindle about three times faster than if you were using a high speed steel tool. In fact, when making most cuts with this tool, don't be afraid to turn up the RPM and feed the tool rapidly. Of course, you must have the part you are machining held in a setup sufficiently secure to accomplish this.

13.3.13 Design of the negative rake tool holder

The holder is manufactured from 7075 Aluminum, which is approximately twice as hard as regular aluminum in a T6 condition. This material also costs approximately twice as much, but I felt it would be money well spent to insure a long life for the holder.

13.3.14 Design of the insert cutter

The carbide insert is designed in such a way that it cuts like a positive rake cutter. Positive rake cutters don't require as much rigidity as negative rake cutters. This type of design allows the advantages of a negative rake cutter (four cutting edges per insert) without requiring the rigidity that can't be found in bench type machines.

Replacement inserts for this holder are available both from Sherline and from a number of tool manufacturers. They are usually designated DNMG-331.

NOTE: ALWAYS USE CUTTING OIL WHEN USING THE CUTOFF TOOL

13.3.15 The cutoff or "parting" tool

After completing a part in the lathe it is frequently necessary to separate the part from the excess material used for chucking. This operation is best accomplished with the use of a cutoff tool or "parting tool" as it is sometimes called. The Sherline cutoff tool and holder consists of a very slender high speed tool steel cutting blade mounted in a special tool holder. The thinness of the blade (.040") enables it to feed into the part quite easily and at the same time minimizes the amount of waste material. One word of caution; never use a parting tool on a part mounted between centers. The part may bind on the cutter and result in a scrapped part or a broken cutting tool.

13.3.16 The proper way to cut off a part

Always try to lay work out so the cutoff tool is used as close to the spindle as possible. Set blade height by sliding the blade in its slot in the tool holder. It should be set so the tip is at the same height as the centerline of the part being cut. An unusual part diameter may require a shim to be placed under the front or rear of the holder to accomplish this.

NOTE: ALWAYS USE CUTTING OIL WHEN USING THE CUTOFF TOOL. The cut will be made much smoother, easier and cooler.

The turning speed for parting should be approximately one half the normal turning speed for any given material, and the feed rate should be a little heavy so the chip will not break up in the slot. If speed and feed are correct, there will not be any chatter, and the chip will come out as if it were being unrolled. Coolant (cutting oil) plays a major roll in this occurring properly.

HEIGHT OF TOOL TIP SHOULD BE SET TO CUT AT CENTERLINE OF PART

A parting tool is used to separate a completed part from its raw material workpiece.

If the tool chatters, first check to see if the work is being held properly. Then decrease speed (RPM) or increase feed rate or both. Once the blade has chattered, it leaves a serrated finish which causes more chatter.

Sometimes a serrated finish can be eliminated by stopping the spindle, adding a liberal amount of cutting oil, bringing the blade up so there is a slight pressure on it without the spindle turning. and then turning by hand or as slowly as possible with the speed control.

Very small work may be completely cut off when held in a chuck and allowed to fall onto the crosslide. It is too small and light to cause any damage. Hollow articles such as rings may be caught on a piece of wire whose end is held in a suitable position.

13.3.17 SHARPENING INSTRUCTIONS

To sharpen the blade, use the tool support on the grinder set in such a way that it will produce a 7^o to 10^o angle on the blade (lop to bottom). (See Figure 1 below.)

FIGURE 1 — Side view of blade.
7^o to 10^o
FIGURE — Top view of blade (enlarged) when ground for "parting off"
SIDE VIEW
TOP VIEW

If you are sharpening the blade to "part off, the blade should have an additional angle of approximately 5o when viewed from the top with the point on the right. (See Figure 2.) Normally the angle would be as high as 15o but the .040" thickness of the blade would not be rigid enough and the blade could bend. If you want to cut grooves, don't put any angle on the blade when seen from the top.

13.3.18 Mounting the cutoff tool using o rear mounting block

The rear mounting block is a simple spacer block that allows you to mount the cutoff tool and holder to the table on the back side of the part. Because the part is rotating "up" on the back side, the tool must be flipped over in the holder. The mounting block raises the tool holder the amount needed to put the tip of the tool back at the right cutting height. This will save you time by being able to leave the cutoff tool holder mounted to the table while you use the regular tool post in its normal position on the front side of the part.

USE LONGER 10-32 × 1-3/4" SOCKET HEAD SCREW PROVIDED
P/N 3002 CUTOFF TOOL AND HOLDER
PART
STANDARD TOOLPOST AND CUTTING TOOL
LATHE CROSSLIDE

FIGURE 3 — Seen looking from headstock toward tailstock. (Arrow shows direction of part rotation.) The rear mounting block is shown in position under the cutoff tool holder and mounted to the "back" side of crosslide table. The cutoff tool holder can now be left mounted to the table, ready for a parting operation at any time. There is no need to remove the standard tool post in order to "part off the work.

The mounting block is placed between the standard cutoff tool holder (P/N 3002) and the lathe crosslide. It is mounted on the back side of the part, or me side away from the crosslide handwheel, The longer 10-32 x 1 -3/4" socket head screw provided with the rear mounting block is used to attach the unit to the crosslide table. (Use the T-nut that came with the cutoff tool holder.) Note that the hole in the mounting block is not in the center. Rotate the block to find the position where the sides line up with the sides of the cutoff tool holder.

Loosen the two clamping screws which hold the cutoff tool blade in place. Turn the blade over so the cutting tip is facing down and mount it as shown in Figure 3. Adjust the tip of the tool to the desired height by sliding it back and forth in its slot. Lock it in position with the two clamping screws.

Even though the tool is upside down, all the same rules about its use still apply. The only difference is that the crosslide table is now cranked toward the operator to cut off a part.

A parting tool is held upside down in the tool holder which is mounted to the rear mounting block. This simple accessory is helpful if you are doing repeated cutoff operations and don t want to keep switching toolposts.

13.4 GRINDING YOUR OWN LATHE TOOLS

As a home shop machinist you are going to have to shape tools the old fashioned way, and that means you need a grinder. A bench grinder doesn't have to be expensive to work well, but it does require good "wheels" for high speed steels. Try to find a source for grinding wheels from an industrial supplier. Some of the wheels that come with inexpensive grinders wouldn't sharpen a butter knife. Sixty grit is a good place to start. A wheel dresser is also a necessity. They cost less than $10 and are readily available from good hardware stores.

13.4.1 Using a wheel dresser to keep your wheel sharp

Grinding wheels should be considered cutting tools and have to be sharpened. A wheel dresser sharpens by "breaking off the outer layer of abrasive grit from the wheel with star shaped rotating cutters which also have to be replaced from time to time. This leaves the cutting edges of the grit sharp and clean.

A wheel dressing tool and spare "star" cutter

A sharp wheel will cut quickly with a "hissing" sound and with very little heat by comparison to a dull wheel. A dull wheel produces a "rapping" sound created by a "loaded up" area on the cutting surface. In a way, you can compare what happens to grinding wheels to a piece of sandpaper that is being used to sand a painted surface; the paper loads up, stops cutting, and has to be replaced.

13.4.2 Setting up your grinder and tool rest

For safety, a bench grinder should be mounted to something heavy enough so it will not move while being used. The tool support must be used and should be set at approximately 7^o. Few people have the skill to make tools without a tool support and in essence it's wasted effort. Tool supports are usually made up of two pieces that allow you to set your tool rest above or below center. It really doesn't matter whether it's above or below as long as the support is at 7^o.

The reason tool supports are designed like this is so they can be used for a variety of uses, not just tool bits. What this means is that if the tool support is above or below center, it must be adjusted as the wheel diameter changes.

GRINDING WHEEL
TOOL REST

FIGURE 4 – Set tool rest at any height, but at 7° angle from centerline of wheel.

13.4.3 Getting started on making a toot

Now it's time to make a tool, and whether you turn the job into a major project is up to you!

CAUTION!
When working around grinders it is an absolute necessity to wear EYE PROTECTION. Grinding debris is thrown out at high velocities and can damage not only eyes, but also expensive glasses. Wear safety glasses or a full face shield.

If you've never sharpened a tool, take a close look at how ours are sharpened. Let's duplicate the right hand tool on the opposite end of the blank. Be careful you don't cut yourself on the blank or the sharpened end while working with it.

First dress the wheel by taking the dresser and setting it on the tool support square with the wheel and while applying a light pressure move the dresser back and forth with the grinder running. Unless the wheel is in bad shape, it should be ready to use in a few passes.

13.4.4 Grinding side 1 of the tool

Turn off the grinder and set the tool support for approximately 7^o if you haven't done it yet. If you're not good at guessing at angles use a presharpened SHERLINE tool to set the angle. Metal cutting tools are very tolerant on angles. I've always found wood cutting tools more difficult to sharpen. Too little angle and the "heel" of the tool will rub, loo much angle will cause the tool to "dig in" and chatter.

TIP
HEEL

FIGURE 5 – Heel of tool
Have a cup of water handy to cool the tool with, set the blank on the tool rest and start grinding side I.

WINDING WHEEL
TOOL REST

FIGURE 6 – Grinding Side 1 of the tool

NOTE: Became of T angle on laol rest, side of tool is actually cur first.
TOP OF TOOL

FIGURE 7 – Properly ground side I

Move the blank, back and forth across the face of the wheel until you have ground a 10^o angle on approximately 3/16" (4mm) of side 1.

This is where the "positive approach" comes in. Unless you push the tool into the wheel with enough pressure, the tool will bounce around and you'll never get a good flat cutting surface. It isn't necessary to worry about getting the tool too hot. Modem day tool steels don't anneal and a little discoloration doesn't affect the tool life in tool room use. What you should worry about is not burning yourself or grinding the tips of your fingers off! Concentrate on holding the 10^o angle while moving back and forth. We'll give this edge a final sharpening later, but now it's time for side 2.

TOP OFTOOL
LESS THEN 90^o

FIGURE 8 – Grinding side 2 of the tool

PART
TOOL

FIGURE 9 – Properly ground tool cutting into a corner.

13.4.5 Grinding tide 2 of the lool

The reason angle B is ground less than 90^o is to allow the tool to get into corners.

Side 2 is ground the same way as side 1. moving the tool back and forth until you have a point. After you get side 2 ground, cool the tool in the cup of water.

Now 1 want you to learn another aspect of tool grinding. It is important to know when you have ground the surface up to the cutting edge, especially when resharpening lathe tools. Take the tool you just ground and bring it up to the wheel at a slightly different angle than you just ground for this experiment. Watch the point that touches the wheel first and you will notice that the sparks will bounce off the cutting edge only where the wheel has ground from top to bottom.

SPARKS
TIP
SPARKS AT TIP OF TOOL

FIGURES 10A — Tip not yet ground flat and 10B, Tool ground flat all the way to the tip.

This tells you when the tool has been sharpened without taking it away to look which allows you to grind flat and true surfaces. If you sharpen a tool for a Sherline lathe, use a 1/4" square tool blank and keep the cutting edge up to the top of the blank; the tool will come out on center without shims. You will have to be precise grinding the third side to accomplish this.

13.4.6 Grinding side 3

ROTATE TOOL
APPROX 15^o
GRIND UNTIL SPARKS JUST REACH TIP OF TOOL

FIGURE 11 — Grinding the "Hook" into side 3

Now you will use the skill you have developed grinding the second side. Set the blank on the support with the 10^o (side 1) up. The tool has to be brought up to the grinding wheel with a slight angle so you don't grind the tip below center. With the tool setting on the rest, move the tool in and grind until you see sparks bouncing off the cutting edge where the corner of the wheel is lined up with the back part of the 10^o face. When this happens, slowly decrease the angle without pushing the tool in any more until sparks bounce all the way to the tip. Stop as soon as this happens. You may inspect it, and the surface should be entirely ground. The recommended way is to put more "hook" on the tool than I have suggested, but I have found that the slight increase in performance is offset by the problems encountered resharpening these tools.

SIDE
FRONT

FIGURES 12A — Normally recommended "hook" ground into tool and 12B, Simpler method suggested for Sherline tools.

To put the finishing touches on your tool, you have to "kiss off" sides 1 and 2 again. You must carefully line up side 1 with the wheel and bring it to the wheel in a positive manner with very little pressure. Then watch for the sparks on the cutting edge. What you're trying to accomplish is to make the tool set against the wheel on the same plane as when you first ground side 1. If the tool is held too rigid, it will not align itself, too loose and it will bounce around.

13.4.7 "Breaking" the point

Use the same method on side 2. The tool should be ready to use except for the point. I always put about a .010" (.2mm) "break" on the point by holding the tool with the point aimed at the wheel face. Because two angles converge at the point, the angle in relation to the sides is greater. Think about it!

ANGLES APPROX EQUAL
TOP OF TOOL

FIGURE 13 — Putting a .010" "Break" on the tip of the fool.

This means that if you set the tool flat on the tool rest, the tool rest angle would have to be increased to get an even flat. This wouldn't be worth the effort. so the easy way is to freehand it. 1 always start by touching the heel of the tool first, and then change the angle until a slight flat is put on the tip. Of course, the angle you're holding it at has to be close when starling to get desired results.

FIGURE 14 — Hand holding the tool to "Break" the point saves resetting the angle on the tool rest.

The purpose of this flat is to improve finish and tool life. I don't recommend a large radius on the tip of tools used on small machines. These machines are not rigid enough to get the desired results from this practice and cause "chatter"problems.

13.4.8 Some final tips

The finished product should be a right handed tool, have flat cutting surfaces (except for the radius caused by the wheel), have a slight flat on the tip, and a tip angle of less than 90^o. Tools used on lathes such as the Sherline will do all their cutting at the tip of the tool because they don't have the horsepower for 1/4" (6mm) cuts.

I don't recommend using oil stones to improve the edges. After a few minutes use with an occasional dab of cutting oil a properly sharpened tool will hone itself in.

I always believe the final sharpening to a tool should take place with the wheel cutting the cutting edge of the tool from the top of the tool to the bottom when using bench grinders.

I realize I've given a great deal of information on how to do what I call a "simple operation but these are very difficult instructions to write because I'm trying to tell you how to control your hands, not a simple machine.

SIDE VIEW
BOTTOM VIEW

A typical boring tool

13.4.9 Grinding boring tools

Boring tools are the most difficult tools to grind. They should always be made as rigid as possible. Tool angles around the "tip" can be the same as any cutting tool, but clearances of the tool body have to be considered carefully. A tool ground with enough clearance for a finished hole may not have enough clearance to start with when the hole has a smaller diameter. If you have to bore a hole in a part that has a lot of work in it, have a tool ready to use that's been checked out on a piece of scrap.

13.4.10 Grinding "form" tools

Form tools are used to create a shape that is a mirror image of the shape of the tool. To grind form tools, a pattern of the finished shape should be at hand and you should have a workable design for the tool in mind. You must be able to achieve the shape you want with the tools you have to work with. For example, you can't grind a 1/8" (3mm) groove 1/4" (6mm) deep into your tool with a 1/2"(12mm) wide grinding wheel.

Intricate form tools are usually made by tool and cutter specialists who have expensive shop rates and use precision grinders, diamond dressers and the large variety of wheels available to them. However, all is not lost if we have a good pair of hands with a good mind driving them! We can use the grinding wheel corners on our $50 grinder and generate the shape one half at a time on each side of the tool and still get our job done.

SHAPE OF PART DESIRED
STEP 1
STEP 2
FORM TOOL

Drawing A shows a Typical Form Tool made by a custom toolmaking shop. Drawing B shows a home shop method of achieving the same finished shape in two steps with a tool that can be ground on a bench grinder.

Form tools don't need any top relief (hook) to work. Use low spindle RPM and steady feed rates to prevent chatter. The width of a form tool should never exceed three times the smallest diameter of the finished part.

Like any skill, tool grinding is one that has to develop with time. It is also the skill that allows you to go one step beyond the average "hacker". Working with sharp tools makes machining much more pleasant too, so this is a skill worth spending some time developing. In the long run you will also save a lot of money by not having to continually buy new cutting tools or pay someone to sharpen them for you.

Sparks fly as the finishing touches are put on a lathe tool using a grinding wheel. Learning to grind good cutting tools is a key to getting good finishes on your parts.

13.5 6.4 CUTTERS FOR MILLING

13.5.1 Fly cutters

A fly cutter is a inexpensive way to machine flat surfaces. All machining operations should be done using eye protection and it is an absolute must for fly cutting. As the term implies, the chips "fly". The chips can be very hot and care should be taken to protect yourself. In a sense these are dangerous tools that can send an improperly clamped part flying. The cutting portion of the tool is a left-hand lathe tool which is inexpensive and easily sharpened. Sherline supplies a left-hand carbide lathe tool with a new fly cutter, but you can also use high speed steel and achieve excellent results. Even with a small milling machine such as the Sherline, the width of the cut can exceed two inches. They produce a good finish similar to a lathe and only need a small amount of coolant to keep the material from sticking to the cutter. The depth of cut is somewhat limited, and if the cutter makes a "rapping" sound, lighter cuts should be taken. They work best when the tool starts the cut from one side and exits the part on the opposite side rather than being lowered into the surface. This eliminates the "crushing" action it takes to start a cut when the cutter comes in from the top rather than the side of the part.

If a fly cutter is lowered directly into a flat surface. a circle would be cut at the edge but not in the middle. You have to understand that fly cutters do not cut to center. The work must be moved under the spindle to cut a flat surface. As you move the part under the spindle, the cutter will start cutting on the outside, and the inside of the cutter will start cutting after the work has been moved under the spindle equal to the diameter the fly cutter is set at. Of course, the milling machine spindle must be square with the table for a fly cutter to work properly. but machinists are often tricked into believing their spindle isn't square when the cutter takes a second cut on the "back" side as the part is fed under the spindle. This second cut happens because the inside cutting edge remains sharp longer and the machine isn't "loaded" as much. When fly cutters are cutting correctly, a small spiral chip will be thrown from the part. A fly cutter is a very useful tool that can remove metal quickly, saving time and eliminating the use of costly end mills.

Regular fly cutter and inserted tip fly cutters

13.5.2 Inserted tip fly cutter

For those who prefer the advantages of working with inserted carbide tip tools. Sherline offers an inserted tip fly cutter. It uses replaceable carbide cutting inserts which last longer than steel tools without sharpening, plus they provide an excellent finish on hard-to-machine materials like cold rolled and stainless steels. The cutter shape allows it to cut a straight shoulder on a part, something not possible with a standard fly cutter. It comes with the toolholder. a drawbolt, a 2-edged insert, a Torx T-15 driver and mounting screws. Additional inserts are available.

13.5.3 End mills

2-FLUTE, SINGLE ENDED
4-FLUTE, SINGLE ENDED
2-FLUTE, DOUBLE ENDED

Some common types of end mills. The flat on the side is where the set screw is to he tightened to hold them in place when using an end mill holder.

End mills are used to shape metal parts on a milling machine. The first thing you should realize about end mills is they can cut the "meat" off your hands faster than they cut metal. They are sharp! They arc not just flat ended drills. Unlike drills which cut only at the tip, the sides of the flutes on an end mill have a cutting edge as well. Don't ever touch a turning end mill! The next thing to consider is that end mills can bend or "deflect" while cutting, and the direction of the bend will be determined by the direction of the cut. The terms, "conventional milling" and "climb milling" must be thoroughly understood before doing any mill work.

More detail on end mills can be found on page 201 in the instructions for milling. Also included there is a chart showing recommended cutting speeds for various diameter cutters in typical materials.

A ball end mill has a round end and will put a radius in the comers of your cuts.

13.5.4 Special shaped milling cutters

Milling cutters that cut angles and shapes are available. Ball end mills are a good example of one type of shaped cutting tools, Ball end mills require very light cuts because they have a greater cutter contact area. This causes even more cutter deflection. Cuts should be taken that are so light that the feed rate doesn't have a great effect on the cutter deflection.

This section has been one of the most difficult of all the instructions I have ever written over the years. What I have tried to accomplish was to make you aware of problems that don't always have good solutions. I didn't want to scare a potential home machinist away by attempting to explain all of the intricacies of machining, however, I also want a novice to spend little time fixing mistakes. Many of the mistakes I made as I taught myself to be a machinist could have been avoided if someone had just told me some of the simple things about cutting tools that I have passed on to you.

13.5.5 CUTTING TOOL HOLDERS FOR MILLING

End mill holders

Sherline's 3/8" End null holder. Holders like this are also available in other sizes.

The 3/8" end mill holder makes it easy to use the popular (and less expensive) 3/8" end mills. Using double-ended end mills is economical and easy with this holder as tools are changed by simply loosening a set screw and changing the tool. The holder is also available in 3/16" and 1/4" sizes to hold smaller size tools in the same manner.

Milling collets

The main purpose of the mill collet set is to hold end mills. The spindle nose has an internal Morse No. 1 taper, which closes the collet as the drawbolt is tightened. Morse tapers are approximately 5/8" per foot and are self-locking. Therefore, to loosen a collet, the drawbolt must be loosened a few turns and given a few light taps with a hammer.

Mill collet set

Boring head and boring tools

The main purpose of the boring head is to eliminate the need for a large inventory of drills and reamers. A small milling machine would not have the power or rigidity to turn a one-inch diameter drill even if one could be obtained that would fit. However, holes of even larger diameters can be accurately bored to size with a little patience and care.

Sherline's boring head and a boring tool. The bottom half of the boring head is offset to achieve the size hole you need.

Boring heads work on the same cutting principle as lathe boring, except that the cutting tool turns while the work remains stationary. (When boring on the lathe, the work turns and the cutter remains stationary.) The boring head is designed to employ cutting tools with a 3/8" shank. Sherline offers two boring tools with lengths appropriate for the Sherline mill. It is sometimes advisable to remove excessive tool shank length from standard (non-Sherline) 3/8" boring tools in order to improve rigidity. (See page 198 for a drawing of a boring tool in use.)

Tool sizes are listed indicating the smallest diameter hole that can be bored and the maximum depth that can be cut. For best results, use the largest diameter possible with the shortest lengths. A .010" cut represents a good starting point.

If boring a hole where a flat bottom is required, it is advisable to stop the down feed at about .002" above the desired depth, turn off the motor and cut the remaining distance by hand turning the spindle to eliminate any possibility of chatter.

13.5.6 USING MILLING CUTTERS

ROTATION
FEED
CONVENTIONAL MILLING
CLIMB MILLING

Conventional milling vs. climb milling. For purposes of explaination, imagine the part is fixed and (he cutter is moving.

Comparing "Conventional" and "Climb" milling

To explain the difference, the best analogy 1 can come up with would be using a shovel to dig a ditch. Consider the shovel a cutter and yourself the spindle, and you are digging a ditch that has already been started. If you dig the shovel in at the bottom of the ditch and push the shovel away and lift, the force will push you back and down. This action is the same as conventional milling. When you start the shovel at the top of the ditch and pull it towards yourself and down, you will be pulled towards the shovel and upward. Consider this action the same as climb milling. Now consider how a powered ditch digger works, They have a series of small buckets (cutters) that are attached to a round frame in a fashion similar to a "Ferris wheel". When the cutters are lowered into the ground, the forces push the machine backwards and these forces are counteracted by the tires. The feed of the machine down the ditch will never exceed the traction of these tires and the machine is doing "conventional milling". If the ditch digger were designed to have its cutters turn in the opposite direction, the cutters would climb up on the surface, pull the machine forward and the operator would be chasing the machine around the field. This represents the basic problem with climb milling. It can be downright dangerous with machines that have loose slides or excessive backlash because it pulls the work into the cutters.

Then why would you do it? Sometimes the part configuration forces cuts in this direction, or you may decide to climb mill by choice. Lets go back to the ditch and try to understand the forces in more detail again. When conventional milling, we started with the shovel in the bottom of the trench and pushed as the shovel was lifted to remove dirt from the ditch. The lifting action also has to be considered. The first part of the cutting action is getting the shovel (cutter) to start the cutting action by taking a cut that gets progressively heavier. At the end of the cut, the cut is the greatest, which in turn, adds weight to the person using the shovel, which makes them sink deeper into the dirt at the bottom of the trench. This is just the opposite of climb milling where the lightest (depth) part of the cut is at the end. (Note that the same forces must be considered whether the cutter is vertical or horizontal. The forces involved are so much greater than gravity that it is not a consideration.)

Despite its drawbacks, climb milling can give a better finish

Climb milling can create a better finish in two ways. First, the lightest part of the cut is at the end of the cut. Second, the chips are tossed from the cutting area and do not affect the finish. Climb milling will deflect the cutter away from the cut. It is called climb milling because the end mill wants to climb up on the work. The major problem with machining in this direction is that the cutter may actually do just that— climb up on the part and break. Also, when a climb cut is first started the work has to be pushed into the cutter. Then the cutting action pulls the backlash out of the table leadscrew and a heavier cut is taken than planned. Look at the diagram in the previous column as it will be very useful in helping you to understand the interaction between cutter and part.

An example of a climb milling cut

As an example, we will consider using an end mill to cut a 1 /16" (.062" or 1.5mm) wide slot 1 /8" deep (.125" or 3mm) in a piece of aluminum. A novice might attempt to cut the slot to its final depth in one pass. The end mill would break even if the depth of the cut were halved. Next you try a .010" (,25mm) cut and lower the cutter into the part .010" at the start of each pass. This is still a heavy cut but chips are coming out and you continue on. When the cut is finally completed you measure it and find the slot is .070" (1.8mm) wide. It also has a finish that resembles a stone wall. Cuts that deflect end mills, big or small, have these problems and you must deal with them. The shorter the end mill, the more rigid the cutting surface will be. Short end mills can eliminate some problems and speed up the process, but the basic problem will always be there.

I would start by taking a cut of only .0015" (.04mm) to start on the slot we are using as an example. It is more of an engraving process to cut narrow slots and, when possible, a slitting saw is quicker. The problem with thin slitting saws is that they don't always track well because the teeth may be sharper on one side of the cutter than the other. On larger slots, an undersize end mill may be used to "rough cut" the slot. The "on size" end mill can then be used to bring the slot to size, but there is another problem that occurs at the end of the slot if the slot doesn't go through the side of the part. When the cutter reaches the blind end of the slot, the cutting load changes considerably and the cutter may "chatter" and cut oversize. A drill will chatter only at the bottom of a hole and is supported by the outside diameter, but an end mill is designed to cut on the sides as well as the end and can really make a mess of a good part when this happens. If the slot is critical, after rough cutting the slot, I will "plunge cut" (feeding the end mill straight down) each end before cutting the slot to size. What can cause grief with this method is when the cutter starts cutting to its full diameter at the bottom of the hole which upsets the cutting loads causing the cutter to wobble and cut the hole or slot oversize. As long as you anticipate these potential problems, this is a method that can be used on any inside corner that you want perfect.

A fly cutter is a good way to machine flat surfaces. It gives an excellent surface finish and makes cuts up to 2 inches wide on a Sherline mill, but cutting forces are high so parts must be held very firmly. Watch out for the chips. . . they are HOT, and eye protection is a must!

13.6 Chapter 7 — Measuring and measurement tools

13.6.1 Measurement throughout history

No one knows who was the first to actually measure something, but at some point in history, craftsmanship reached a point where doing things "by eye" just wasn't good enough any more. For example, the builders of the pyramids would start the job out with a gage carved in stone. From this, each worker would mark his own measuring stick. The punishment for having a stick that wasn't correctly calibrated was *death*. Common sense tells me that they quickly arrived at only one stone for a standard and that the craftsmen were pretty careful about marking their measuring sticks. It could ruin your whole day to have to kill your best stone mason because he got his sticks mixed up. They must have had a number of jobs going on at the same time, and I'm sure some enterprising Egyptian did good business selling calibrated sticks, saving everyone in the building trades a lot of trouble.

13.6.2 The modem stick and stone

Things today really haven't changed all that much. We still need standards for measurement and we keep coming up with ways to divide the "stick" into smaller and smaller parts. The "stone" is now a gas that is measured to the atom electronically, whether you use the inch or the metric system. The "sticks" of today are the rulers, tapes, scales and electronic readouts we use daily.

13.6.3 Measurement increments had a human touch

You might find it interesting to note that most of the dimensions we are familiar with in the inch system came from parts of the human body. The inch was once based on the length of the last joint of the thumb. A yard was the distance from the tip of the nose to the end of the fingers with the arm outstretched. (A seamstress measures "yards of cloth" by pulling from nose to fingertips to this day.) A fathom is two yards, or the distance from outstretched fingertip to fingertip. The ancient Egyptians also used cubits (elbow to fingertips), digits (one finger width), palms (four digits) and hands (five digits). The height of a horse's shoulder is still often measured in "hands".

Time also figured into some early measurements of distance as in the acre which was the amount of land a team of oxen could plow in a day. The length of the furrow in that acre was called a furlong. A journey was measured in hours (much as it is on the L.A. freeway system today), days or moons.

The tools used for measuring and checking parts in a machine shop stand ready for use on a ground granite surface plate. The parts you make will be no more accurate than your ability to measure them.

The foot is also a common unit of measurement, although deciding whose fool was to be the standard was a problem that plagued standardization throughout the ages. It would vary from place to place and time to time as each ruler declared his foot to be the standard for all. The earliest preserved standard for length comes from 2575 B.C. and is the length of the foot of a statue of Gudea, the governor of Lagash in Mesopotamia. It was about 10.41 modern inches long (they had smaller feet back then) and was divided into 16 parts. Later the Romans subdivided their version of the foot into 12 unciae, hence our inches. A Roman pace was 5 feet, and 1000 paces made up a Roman mile.

Despite the current movement to standardize the world on the metric system, my own preference is the inch system. Mere's why. When working in metal, .001" (one thousandth of an inch) is a tolerance that can be achieved with cutting tools, and .0001" (one ten thousandth of an inch) is a tolerance that can be achieved by grinding. The numbers don't come out quite so neatly in the metric system. 1 mm equals .03937 .1 mm equals .0039" and .01 mm equals .0004". The tolerance of $\pm$.1 mm (.004") is too coarse for most work, and $\pm$.01 mm (.0004") is too fine. Therefore, you end up with tolerances too tight or too loose because the draftsman usually calls out a tolerance of $\pm$.01 mm when it should be $\pm$.025mm. In addition, the basic unit of distance measure, the meter, is unrelated to any human increment, unless you are a basketball player who can stretch his fingertips out to 39.37 inches from his nose. On the plus side for the metric system, of course, is the fact that it is based on units of 10, and many conversions can be done in your head. In the end it will be interesting to see if the pure logic of the metric system can finally erase the human side of measurement in the inch system.

13.6.4 Then or now, skill with your tools is still a part of accurate measurement

Egyptian builders had only simple plumb lines, wood squares and rulers, but they obviously used them with great skill, because their measurements were amazingly accurate. The dimensions of the Great Pyramid of Gizeh, built by thousands of workers, boasts sides that vary no more than 0.05 percent from the mean length, That means a deviation of only 4.5 inches over a span of 755 feet. Some construction workers of today might find it hard to duplicate that accuracy. When Sherline's factory was being built, a laser level was set up in the middle of the foundation to lay out the building. I noticed a workman accidentally kick one of the legs of the level and stick it back in place by hand. If I hadn't brought it to the attention of the foreman who releveled the laser sight, our building might have resembled the leaning tower of Pisa today. This is a good lesson that skill and technique can overcome some of the faults of poor measurement tools, but carelessness or improper technique can render even the most sophisticated tools useless.

A large coordinate measuring machine makes accurate part measurement easier for the factory that can afford one. Unfortunately their price takes them out of the reach of the home shop machinist.

13.6.5 Machine shop measurement today

Until a few years ago, most factory and machine shop measuring was done with a micrometer, height gage, squares and surface plates. In the past few years many new methods to measure your work have been added that take advantage of the calculating power of the computer. The most important of these new measuring systems would be the "coordinate measuring machine". It is built on a surface plate and can read all three axes of movement: "X "Y"and "Z". What is interesting about them is the methods used to come up with dimensions. They have a small probe that very accurately informs the computer when it touches the part. To read the diameter of a hole, the probe has to touch three points in that hole which don't have to be equally spaced. The computer will triangulate these points and produce a diameter within .0001"(.0025mm) and note where the center of the hole is located on the part. The part doesn't even have to be located square with the machine, yet it can be checked accurately. The programs that run these machines can be as complicated as the programs that make the part. The cost of these marvelous machines can be several hundred thousand dollars, but they are well worth it to companies that purchase and manufacture millions of dollars worth of precision machined parts.

13.6.6 Modern scrap is more costly than ever

This technology allows aerospace companies to build more perfect products, but it has also filled salvage yards across the world with some very expensive scrap parts. The problem in many cases is that manufacturer of these parts doesn't have measuring equipment that is as good as their customer's. Who can afford $100,000 measuring tools to measure $10 parts? Contract machine shops can go broke overnight when they find out an expensive, high quantity part has been rejected. When making machined parts for other people you have to be able to prove your parts are correct.

When making parts for yourself, you can fit one part to another and lighten the tolerances in the process. This is a very important difference, and if you work at fitting and matching parts together you become a modelmaker. Modelmakers develop a special skill to make and fit parts together so the assembly works in unison, while the machinist will produce close tolerance parts that are within the tolerance of the part drawing. In most cases, he doesn't have the luxury of test fitting it to the part it will eventually be assembled to. When you make parts for other people the drawing is "king". A machinist shouldn't have to worry about problems someone may encounter assembling parts they manufacture. They have enough problems making a part within the tolerances given. Toolmakers are the best at both skills because they usually make the parts they fit together. If you build and fit parts together you are closer to a toolmaker than a machinist. Even though your tabletop machines are small, the processes you will use in making your parts are the same as any machinist must deal with.

13.6.7 Watch those divisions

If you are making parts for your own enjoyment there is nothing wrong with changing a dimension here and there to save a part that may be a few thousandths (.lmm) undersize. Of course, if it affects the strength or integrity of the assembly, I would not do it. When building small metal parts they have yet to come up with a good "putting on tool"* so you have to get used to the idea of starting over. You can't work with dimensions all day without making an occasional error. The only people who don't make mistakes are those who do nothing. I've

* NOTE: A long-standing joke in machining, a"pulting-on"lool is what you send the new apprentice to the tool crib for when he makes his first undersize part.

found many mistakes are accurate to a very close tolerance, but off by a division. When taking a reading, always read every dimension, not just the dimension you are correcting. A good example would be when you are using a lathe and getting close to the final cut. The diameter you are reading may need a very close tolerance and you are concentrating on the thousandths of an inch or tenths of a millimeter located on the barrel of a micrometer. When you start looking only at this part of your micrometer you could screw up and get the diameter off by one full turn which would be twenty-five thousandths (.5mm). Mistakes of this magnitude will usually create scrap.

13.6.8 Good measurement tools are one of the pleasures of machining

I enjoy buying measuring tools. Most people treat these tools with great respect and take pride in them. A good toolbox full of high quality measuring tools in your workshop has the same owner's sense of satisfaction as a china cabinet full of figurines has for your wife. I don't know if you will convince her of this fact, but it's worth trying. I have always been a fan of the Starrett company located in Athol, Massachusetts. Their measuring tools have set the example for the rest of the world to follow, and they are still reasonably priced. The truth is that you can get by with far fewer measuring tools than you will buy. Again, I want you to understand that I'm referring to people working at this trade to please themselves, not to please a customer.

Every machinist's tool box eventually collects a number of favorite measuring tools.

Measuring tools don't have to be expensive to work well. Due to the number of imports on the market there is a great selection of measuring tools available that all work quite well. People seem to think tools like this are a lot more valuable than they are. I have seen people trying to sell a beat up one-inch micrometer at a swap meet that I wouldn't even use as a welding clamp. They may be asking more money than you could buy a set of three new ones at today's prices.

The cost of measuring does go up considerably when you buy specialized tools. A good one-inch micrometer could be purchased for around thirty dollars (1997), but a thread micrometer could cost three hundred dollars. As soon as you get away from the basic "mikes"you are in the hundred-dollar range.

13.6.9 Working with tolerances

Before getting into measuring, there is one more concept I want you to understand and that is the concept of tolerances. Tolerances are the limits placed on any dimension by the designer of the part. They are designed to make the part price as low as possible while still making the part useable in every combination with other parts of a given assembly. Almost any engineer can design parts that will work if tight tolerances are held. These parts are almost impossible to build and can increase the cost by a factor often. It takes a good engineer to design parts within practical limits. The tolerances are always given on commercial drawings, in fact, we would refuse to bid a job unless every dimension had a tolerance when we did contract machining. You can't be arguing with a customer about how they assumed you would know that the part you made for them had to fit another part for which you had never seen the drawing. Making parts that don't work can be a financial tragedy when the quantities are high and costs are in the thousands of dollars. Before starting on any part, review the drawing and convince yourself the part will work. When in doubt, tighten the tolerance so you know it will work.

Tolerances should be thought of as a percentage of the dimension. For example, .001"(.025mm) may seem like a very tight tolerance when you are turning or boring a diameter of three inches, but it would be a two percent error on a diameter of .050"(1.27mm). If you had the same limits for a three inch part, a two percent tolerance would allow you a range of .013"(.33mm). These are boilermaker's tolerances. Obviously, small parts can't be manufactured to the same tolerances as large parts and still work. Most hobby drawings don't have tolerances listed, and you have to decide which parts are good or bad. Don't forget that a dimension taken on a part that doesn't have the proper surface finish will come out undersize after it is polished. Allow for this fact.

13.6.10 Technique and "feel"in using measuring tools

A delicate "feel"must be developed to measure the small parts manufactured on tabletop machine tools. Just because your micrometer has lines on it that represent one ten thousandth of an inch (.0025mm) it does not mean you can measure to that degree of accurately without that special "feel To develop this feel you should start measuring things of known dimension to see if you come up with the same answer. If you have a friend that is skilled in taking measurements, have them give you a lesson. Machinists usually own their own measuring tools. They develop confidence in these instruments and, along with that "feel they are sure their dimensions are correct. You can't hold your head high in the metal cutting trades until you can make parts to size.

13.6.11 Gage readouts

The actual readout on a measuring gage uses one of three methods to come up with an accurate dimension: The screw thread on a micrometer, the Vernier scale on height gages, calipers and angle reading devices or the new digital readouts found on all types of modem measuring tools.

The digital readout of a modern caliper makes life easy for a machinist. Readings in inches or millimeters can be taken and translated back and forth eliminating many of the math errors associated with dimension conversions.

The screw thread on a micrometer is forty threads per inch or has a pitch of .025"and a calibrated movement of one inch. The metric micrometer has a .5mm pitch and 25mm total calibrated movement. One of the reasons I don't like the metric system is the way micrometers are calibrated. When you're using a inch model micrometer, all you have to do to get a reading is add the reading to the size of the gage. With metric models you have to add the range of the micrometer to the reading. The problem is the range isn't a simple number like the inch system; It is 25 millimeters. If you are using a micrometer with a range of 75mm to 100mm you can't add your reading to the number one. You have to add it to 75. This gives you an excellent way to introduce mistakes into your calculations.

Pitch is the amount of movement the screw or nut will move in one revolution. These threads have to be precise and are usually made with a precision thread roller. [1] Expensive micrometers will also have a screw that has been ground. The same type of measuring assembly is used on all micrometers. They are mounted on different gages to make a very large range of sizes. Micrometers are available that have a range that can be expanded by changing a spacer at the anvil end. They can be somewhat awkward to use because they feel out of balance.

13.6.12 Getting consistent readings with a micrometer

Micrometers also have a locking lever and a ratchet thimble at the end of the barrel to allow you to apply the same pressure each time when measuring. It is still up to the user to determine if the reading is correct. You can misread a micrometer by trying to measure the surface of a part that isn't in line and parallel with the anvil. If your mike is twisted on the part or if the part is twisted, you can't get an accurate measurement. Surface finish has to be considered when measuring. To read to four places you can mentally interpolate between the lines or use the vernier scale that is engraved opposite the barrel, assuming your micrometer has this scale. I have never understood why they don't manufacture a micrometer with two inches of movement (50 mm), particularly in

[1] A paint of interest: Although the lead screws on Sherline tools are not ground, a precision thread roller is used to make them. They are accurate to within 99.97%.

larger sizes. This would certainly cut down on the number of micrometers needed. (Maybe I just answered my own question. . .)

Sherline machinists will need at least a zero-to-one-inch mike (0-25mm) to start. Calipers can take care of the larger dimensions you will come up with. As you get more interested in machining, you will find needs for these lovely tools, but I wouldn't purchase too many until I had decided that cutting metal can be fun.

13.6.13 Reading Vernier scales

The Vernier scale, named after its inventor, is used on all kinds of products that measure lengths and angles. They are quite simple to use and can be read to .001"(.025mm). The method they use to break a scale into so many divisions without having a line for each division is clever. For this example, let's use a height gage that reads to one thousandth of one inch (.025mm). The basic scale is fixed and divided into 20 parts per inch (25mm). They can be manufactured as long as needed. Eighteen inches or 400mm would be common scales used on height gages. Opposite this scale on the inch model is a Vernier scale that has been divided into fifty parts mounted on the movable slide. The reason 50 divisions are used is because 1/20"(the units into which the basic scale has been divided) equals fifty thousandths of an inch. This provides an accuracy of one thousandth of an inch. The Vernier scale will have only one line on its scale that lines up with a line on the basic scale for each one thousandth inch movement unless the setting is zero. If you set the Vernier scale at zero, you will find that the length of fifty equally spaced marks on the Vernier scale is equal to exactly one division less than fifty divisions on the basic scale. On the inch model used in this example it would work out to be two inches and four hundred fifty thousandths of an inch on

Vernier scales use a clever method to come up with a scale that reads to high levels of accuracy without requiring a division on the main scale for every increment. The reading on this scale is .867

the basic scale. As the slide is raised, the two lines that line up with each other keep getting higher in value until you get to fifty. At this time, the zero line will also be lined up with a line on the basic scale to start the process again. This is the only time two sets of lines will line up at the same time.

The rules for reading Vernier scales are as follows: First you read the basic scale where the zero line on the Vernier lies on the basic scale in whole divisions. Then add the amount on the Vernier, which is the line on the Vernier scale that lines up with a line on the basic scale. Remember the lines on the Vernier scale only use the basic scales lines to line up with. You don't consider what these lines represent on the basic scale. To accurately read a Vernier scale you should view the lines at an angle that clearly

MAIN SCALE
VERNIER SCALE

EXAMPLE 1 – Here is a very simple Vernier scale and the key to how it works. In this example, divsions on the main scale correspond to tenths, divisions on the Vernier scale indicate hundredths. Ten divisions on the Vernier scale are the same length as nine divisions on the main scale, so that at any position other than zero, only one of the pairs of lines will line up exactly. The zero of the Vernier scale is past . 2 on the main scale. The seventh line on the Vernier scale (.07) lines up with a line on the main scale. Therefore the reading is .2 + .07 or .27.

EXAMPLE 2 – Above is an example like the one mentioned in the text. Each division on the main scale represents 1/20"or .050". The small divisions on the Vernier scale each represent. 001". The zero is just past. 45 "on the main scale. The 22nd line of the Vernier scale or. 022 "most exactly lines up with a line on the main scale. Therefore the reading is .450 + .022 or .472".

shows which single line falls on the basic scale. I start by looking where the zero on the Vernier scale is and make a guess where I should start. For example, if the zero falls about half way between the divisions, I start with the twenty-five on the Vernier. I try to look at more than one line at a time. If you stare at a scale too long, your eyes may start playing tricks on you. This usually happens right after you have found the part you have been working on for the last two hours is undersize.

13.6.14 Thinking about measurement in the planning stages of your project

Before starting any complex part you should consider how you will measure it to assure its accuracy. Sometimes the calibrated machine you are using will be more accurate than your measuring tools, but few of us have that much faith. We know that the only thing worse than making a bad part is sending the defective part out or using it ourselves, so it must be checked. Once the part has been produced it is too late if it doesn't pass inspection.

SHAFT
BARREL

EXAMPLE 3 – A simple micrometer barrel. Each whole number on the shaft is .100 (inches or millimeters). Each increment between the whole numbers on the shaft is . 025. Each number on the rotating barrel is .001. This example reads .2 + .025 + .014 which equals a reading of .239.

EXAMPLE 4 – A Vernier micrometer barrel. Each whole number on the shaft is .100 (inches or millimeters). Each increment between the whole numbers on the shaft is .025. Each number on the rotating barrel is .001. Each number on the Vernier scale is .0001. The reading shown here is .3 + .075 + .008 + . 0008 which equals a reading of 0.3838.