The Art of Manufacturing

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Draft- For Review

Foreword

This text is intended to be used in an introductory course in Manufacturing Engineering. The typical student will be a first year engineering student at a 4 year university. The course description listed in Figure 1 is the published description for the course offered at Worcester Polytechnic Institute, WPI, which this text was developed for.

*ME 1800 –M**anufacturing Science, Prototyping, and CNC Machining***

This course introduces students to manufacturing science and engineering and prototype part production. It emphasizes CNC (computer-controlled) machining. Students will learn how to go from a solid (CAD, computer-aided design) model to a machined part, using CAM software (computer-aided manufacturing) and CNC machining. They will also be exposed to associated issues in manufacturing process analysis, engineering design, material science, and in dimensional and surface metrology. Using machining as an example, the science of manufacturing processes is developed in a combination of class work and laboratory experience. The laboratory experience includes an experimental component that associates process variables in machining with performance and machined part quality. Students whose project work will necessitate fabrication of parts and those who want a background in manufacturing process science and engineering should take this course.

Figure 1 Course description published in WPI course catalog 2010-2011

Throughout the text I will draw on knowledge gained from over twenty years of experience researching and teaching about advanced manufacturing tools and technology combined with my experience consulting for both large and small manufacturing companies. We will deal with materials from well-established reference manuals as well as cutting edge research presented in new works in the scientific literature.

The text intends to introduce important concepts in Manufacturing, Manufacturing Engineering, and the Science of Manufacturing.

> A wise man once said "Engineers don't need to know anything; they just need to know what book to look in."

I'm not quite willing to admit that knowing which book to look in is the only thing an engineer needs to know, but it is certainly one of the most important things you will learn as you train to become and then work as an engineer. I have found that in addition to having access to a great library, the best engineers are the ones who have a grasp of the underlying physics of the problem they are trying to solve

If you stipulate that knowing which book to look in is important to solving many engineering problems the question you need to ask is:

> How you know what book to look in and how do you find the information that you need once you have found the book and finally how do you extrapolate or interpolate to find the answer to your question?

Throughout the text, a special emphasis will be placed on enabling the students to understand and use reference materials. Included in this Volume are:

- “Manufacturing Science and Engineering,”
- “A CNC Lab Manual for Engineers I,”
- “The CNC Quick Guide for Haas Mills,” and
- “The CNC Quick Guide for Haas Lathes.”

In addition to the included texts, we make use of the scientific and engineering literature and will examine examples from to the reference texts relying heavily on the "Machinery's Handbook (28^{th} Edition)", Industrial Press, 2008.

Students at most major universities are likely to have electronic access to the Machinery's Handbook through their library's web site. Whether you have "free" access to handbook you may wish to consider purchasing the hard copy to start your personal library.

Preface to the Art of Manufacturing

A couple of years ago I attended a graduation party for one of the most amazing students I've ever had the privilege to work with. He was wearing a t-shirt that said

> "College – the best 7 years of my life!"

I kidded him about it because I knew that he had not finished in the typical(?) four years and he admitted that it had indeed been seven. Not only that someone gave him the shirt his freshman year.

It made me think back to the end of August 1994 when I was about to begin my 6th year enrolled as an undergraduate engineering student.

I had plenty of excuses and rationalizations for the fact that I wasn't done but none of them mattered what mattered was that I had no intention of asking my parents for money to pay for this year – a year that should not be – and that I had used up all of the money I made during year four to pay for year five. (I took year four "off" and worked full time.)

With almost no cash and a full course load for two more semesters staring me in the face I signed up for the payment plan offered at the bursar's office and got a full time job driving a forklift in a warehouse attached to a plastic injection molding company. This was my first experience working directly for a manufacturing company and it was an eye opening experience.

It was also a tiring experience you see I was still taking a full course load and was working second shift five days a week plus taking all the weekend overtime they would give me. Amazingly enough I did not fail all of the classes I took that semester, but I failed enough of them to know that I needed a better plan for the spring.

I still use some of the credit cards I applied for that winter and finished the spring semester passing 12 classes with all As and Bs and almost $35,000 in credit card debit that I was very adept at moving from card to card in rotation.

In one sense, looking back, I can see that I manufactured both my failure that first semester and my success the second. During the first semester I misused my resources my time and my focus. One of the only classes I passed that semester was a class I now teach at that same university and I often wonder if the C that I got was actually a gift from the instructor.

In the spring of 1995 on the other hand success was my only acceptable result and I was able to focus on the things required to pass my classes and manufacture my success.

Contents

Chapter 1 The world's oldest profession

> it's how we make things
> it's built our society
> manufacturing

Look around yourself right now. Look around and take note of the things you see. Look especially closely at the things you use every day. Even though I'm not sitting with you at this moment I know something about almost all of those things, they were manufactured!

Our entire society is built with manufactured goods. Society as we know it could not even exist without manufacturing and it is the profession – manufacturer - that began it all.

I would argue that it was the first hunter gatherer who traded finely crafted arrow heads or spear tips for a share of the hunt who was the first professional. Making manufacturing the world's oldest profession, despite the ravings of Rudyard Kipling.

What is manufacturing?

A Google search for the phrase "define manufacture" returns upwards of 70 million responses in about a half of a second (at least id did just now as I'm writing this chapter.) Merriam-Webster lists the first definition as

> "to make a product suitable for use"

, and the Oxford English Dictionary says

> "The making of articles on a large scale using machinery"

Both dictionaries state that if you manufacture you must make something. All manufacturing engineers and companies know that the use of machinery is optional and the companies that succeed know that the word ***product*** is key when we manufacture. You see ***product*** implies customer and without customers there is no point in manufacturing.

Merriam-Webster, but not the OED, goes on to indicate manufacturing requires ***raw materials***. This may be one of the reasons that we won the

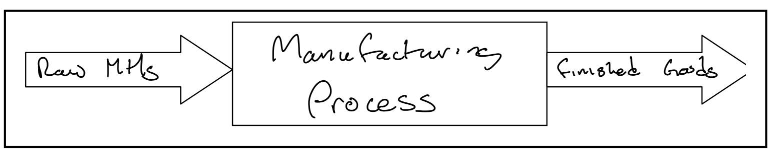
Revolutionary War, a better understanding of raw materials and manufacturing…

For this text we will consider manufacturing to be:

> The process or processes used to transform raw materials into something somebody else wants

Without a customer there is really no point manufacturing anything, because manufacturing is done by companies and companies have expenses. If they don't pay their expenses either the bank or the government will close them down and they will lock the doors for them too.

In this most basic sense manufacturing is really any activity where raw materials are transformed



into finished goods, goods that someone else wants. The way we know that someone else, our customer, wants the goods that we have manufactured is that they pay us for them. Viewed in the abstract this makes any manufacturing process like a transfer function with an input and an output.

In most instances the raw materials have gone through some previous process and the finished goods or the product of the current process will move to another process as raw materials. The Big Mac® for example was assembled (assembly being a manufacturing process) from previously processed materials:

- beef,
- sauce,
- lettuce,
- cheese,
- pickles,
- onions, and a
- bun.

The previous process for the raw material lettuce was washing and cutting. The beef, well that was butchered, ground, formed in to patties, flash frozen, shipped to your local "restaurant", warehoused in the freezer, and finally heated, then stored again before being assembled into that famous burger that was served to you.

It's possible the process has changed since I had direct experience as a poor college student working for beer money but I doubt it has changed much.

Mac Donald's is probably one of the most successful manufacturing companies in the world. Mostly because they understand their customer and the customer's "needs."

Manufacturing processes can range from assembly, simply putting components together, to innovative new processes where materials are printed in 3D or even microscopic processes involved in making MEMS Devices and today's computer chips. There are literally tens of thousands of processes in the world that can be considered manufacturing processes. In this test we will only consider a handful of these processes but we will look at some of the processes which are the most important in the world today and into the foreseeable future.

No matter what you are making, manufacturing requires:

- raw materials
- a transformation process, and
- a customer.

Manufacturing is almost always conducted by companies, these companies may employ tens or even hundreds of thousands or people, or may operate as sole proprietorships, but they all have one thing in common.

> If for any extended period of time the total cost of the raw materials and the operation of the transformation process exceeds the revenue from sales they will fail.

At the time of this writing 17% of the GDP of the Commonwealth of Massachusetts, my home state, is produced by manufacturing companies. Not only that, most of those companies have fewer than 50 employees.

Some of these companies operate at the edge of failure and others generate millions of dollars of net cash to their owners. It often comes down to management, systems, and a fundamental understanding of manufacturing science and engineering to determine which fail and which prosper. Throughout this text I intend to give you, the tools and understanding it will take to make sure the companies you work for or own will be among the latter.

Lean Manufacturing

Every manufactured item must have things about it that the customer values more than they valued the original raw materials. When a manufacturing company transforms raw materials into a finished part we say that they have added value to the raw materials. In life we measure value in many different ways but we most often express the value of physical things by associating them with some monetary unit. We may say for example that a Haas MiniMill is worth or valued at $34,995. We know in fact that that is the value of the MiniMill to Haas automation because its the selling price of that particular machine tool at the time of this writing. We also know that Haas's customers value the machine tool at least this much, they tell us so every time they buy one.

> It may be, that the manufacturer or reseller of an item sets its price but the customer always sets its value. They do so every time they make a purchase.

For us to succeed as manufacturing engineers we need to work for successful companies. For companies to succeed they need to be profitable. Profit for the sale of a manufactured item is defined as:

$$\text{Profit} = \text{Value} - \text{Cost}$$

Where the cost is typically calculated as the cost of purchasing the raw materials, and the cost of performing the manufacturing process. It is important to note that the sale of an item can be profitable while the company itself is not. Accountants refer to the cost detailed above as the cost of goods sold where the overall profitability of the company also includes company's overhead expenses.

Overhead expenses include things like:

- rent and or real estate taxes

- maintenance of the facilities
- lights
- people answering the phone
- sales people, and
- of course us, the engineers.

As manufacturing engineers if we intend to be successful then we need to ensure that we work for profitable companies. There are two ways we can significantly impact the profitability of any company we work for:

1. increase value to the customer, and
2. reduce the cost of manufacturing.

Lean Manufacturing is a system that allows companies to identify and characterize the costs of manufacturing processes with the intent to drive those costs to zero. The system is really set of management tools that help manufacturing companies better understand costs relative to value, identifying wasteful [processes and process steps minimizing their impact while maintaining the value the customers expect.

> The objective of lean manufacturing is to reduce cost while maintaining and improving value.

The term “Lean Manufacturing” was coined by James Womack in 1990 in the book “The Machine that Changed the World” but the principles have been used in manufacturing for centuries.

Much of what we refer to today as lean manufacturing and many of the lean tools we use today are based on the Toyoda Production System, TPS. Interestingly enough Sakichi Toyoda, who created the foundations of the TPS, credits much of the beginnings of this system that has revolutionized modern industry to principles learned when he read Henry Ford’s book and visited the Ford manufacturing Facility in Highland Park Michigan.

Lean Tools

I stated earlier that lean manufacturing is at one level a collection of tools, mainly management tools, tools that help manufacturing companies increase their profits.

> It is more than simply a collection of tools though; it's a philosophy, a style of management, a way of life even.

Lean manufacturing promotes the principles of:

- teamwork
- communication
- efficient use of resources and the elimination of waste, coupled with
- continuous improvement.

Using the lean principles and the understanding that the people who actually make the parts companies sell often understand best what is good and bad about the manufacturing processes that make the parts.

In this short introduction it would be a mistake to try to cover all of the lean manufacturing tools available to manufacturing engineers and managers but below we will look at a few of the most often discussed lean tools.

I was first introduced to lean concepts while a graduate student at WPI in the late 1990s. At the time I had had some industry experience, owned and operated my own business, and was working as a consultant. I attended a seminar series hosted by the Society of Manufacturing Engineers SME. I still remember my initial reaction. I thought “this is just a bunch of buzz words created to talk about things that are commonsense.” Then I remembered two important things: commonsense is not that common, and I had never seen all of this particular commonsense grouped together before.

Below we will look at some of the most often talked about lean tools and why they are important so that you as manufacturing engineers will at least know some of the buzz words and be able to talk about them as an expert.

5s

Although not considered to be one of the original pillars of the TPS the concepts of 5s are likely the most important of the lean tools, they are really the foundation on which the rest of the tools are allowed to function. The Ss after translated to English are as follows:

- Sort
- Straighten
- Shine
- Standardize and
- Sustain

The ultimate goal of the 5ses is to give everyone doing work a clean organized work area that they know how to use. If you have ever been in a hurry to get something done, something really important, and not been able to find one of the things you need to do the job you know how important that can be. Wasted time is one of the largest unnecessary costs of most companies seeking to increase profits.

Below we give a quick description of how to use the 5s to create such a workspace in an existing scenario.

Sort

A wise man once said "where you is - is where you is" the corollary in examining a workplace is "what you've got is what you've got. The first thing you need to do is know what you have to work with.

Sort out the "stuff" in the space into logical groupings, tools, stock material, finished parts, and unneeded "junk" frequently referred to as crap. (add or remove categories as needed)

Until you have done this sorting, until you know what you have you will not be able to do the next steps.

Straighten

Once you know what you have, you need to organize it. As you do this you should think not only about what you found during the sorting but consider any thing that the operator needs and was missing. I was once working for a company as a lean consultant. One of the things they wanted me to do was observe the process they used to setup CNC machine tools and identify any waste. Then they wanted me to suggest how it could be eliminated.

The company had one employee qualified to do this work and he also happened to be the shift supervisor with several machine tool operators reporting to him. I watched him for one 8 hour shift taking notes and shooting video. In that one shift he set up one job. Setting up a job on a CNC Machine tool requires several unique steps and mistakes can cost anything form a few dollars to tens of thousands of dollars.

While he set up the job he was interrupted 24 times. Nine times he was interrupted by one of the operators asking what they should do next. Eleven times he was interrupted to walk to his tool box and get a tool that he needed to use to perform the step he was working on. Four times he was interrupted when he had to stop the program because he realized the tool room had given him the wrong tool.

Each time he walked away from the machine to get a tool from his tool box other things he had to take care of came up. If he had stayed at the machine during those eleven interruptions I estimate he would have completed the setup in three to four hours instead of the seven and a half it took.

One of the things we do during the sort phase of completing a 5s upgrade to our facility should be logically organizing all of the tools needed to complete a task at the location the task will be completed.

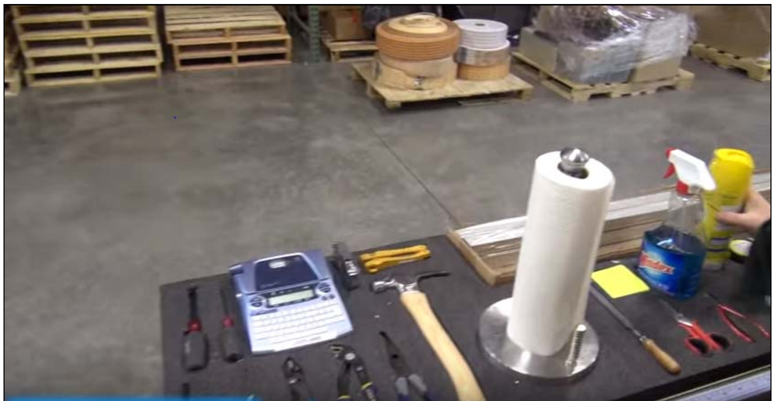


Figure 3 an example of a manufacturing cell at FastCap, LLC

Shine

Once you have sorted and organized your work area. You need to clean it. A clean workspace is a safe workplace and nothing is more wasteful in manufacturing than not finishing a job because the operator that knows how to complete the job is out because of an injury that could have been prevented.

Standardize

When you've got a clean organized work area that only contains the things your operators need to do their job you will need to standardize your system. If you have two, three, or three hundred work cells that are for the same activity they should all be identical. The operator from one should be able to transition to another with no training.

Figure 4 Machine tool setup shadow boards in the WPI Haas Technical Education Center

Although the three machine tools pictured in Figure 4 are within a few feet of each other they are all supplied with identical tools and shadow boards. Any operator familiar with the system can operate any of the machines and all three can be operated and setup at the same instant, no waiting for your colleague to compete a task so you can use the tool you need.

Sustain

Many people and companies find that this can be the most difficult step in the implementation of any new system.

In order to sustain this system or any other for that matter you and your company will need to rely on the first two Lean manufacturing principles – teamwork and communication. You will need buy-in from the entire management team and the shop floor employees. As I said earlier lean is more than a set of tools and buzz words it is a philosophy and everyone needs to believe and participate.

5s Case Study

A great example of a company that has implemented the 5ses and many other lean tools is FastCAP LLC. They have an excellent video presentation that I encourage you to review.

https://youtu.be/jYby_HczyDA

Other Lean Tools and Examples – An Exercise for the Reader.

There are literally thousands of books and courses on lean manufacturing and it would be outside the scope of this text to attempt to cover any number of lean manufacturing tools in any detail, so as an exercise for you the reader I would like you to put down my text and reach out to other resources to find descriptions and examples of other lean manufacturing tools and techniques.

Before moving on to the next section of this book search for information about and write a one paragraph description of at least 5 additional lean manufacturing tools and concepts.

A good place to start might be the video:

https://youtu.be/zUUVy59J_54

When you are researching look for things like:

- Single part flow
- Pokiyoke
- Value stream mapping
- Just in time manufacturing, and
- Six sigma

Lean is not just for manufacturing

Lean manufacturing is not just for manufacturing. People around the world have been applying the lean principles and using lean tools for years in other area.

The class that this book was written for was designed using lean principles,

Hospitals and insurance companies have been working to transform the US medical industry for years by applying lean principles and using lean tools, specifically reducing waste processes and mistake proofing procedures and work areas.

And the bestselling book "The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses" by Eric Ries has been changing the face of entrepreneurship and starting companies.

Art to Part, FRs, DPs, and PVs

Throughout this text and working together with the associated lab manual and reference guides we will paint a picture of the process of taking our concepts from simple art to finished parts that we will hold in our hands and use to perform tasks. This process has many steps and can be confusing to the uninitiated but when it is boiled down to nuts and bolts it is really a simple process.

The Art

The art that we talk about when we look taking our concepts from art to part is the design. It includes:

- drawings,
- solid models, and
- specifications.

The art must contain enough information so that the manufacturer can make parts that satisfy the needs of the customer. The process of developing the art involves understanding these Customer Needs, CNs, and transforming them into a set of Functional Requirements, FRs, which are then met with Specific Design Parameters, DPs, represented by the drawings, solid models, and specifications.

This step of understanding the CNs and forming FRs is critical and often overlooked because as engineers we tend to be introverts who are often kept away from the company's customers.

There is a fabulous scene in the movie "Office Space" where the character Tom, who is about to be laid off, shouts at the consultants, Bob and Bob. He says

> "But I have people skills! I talk to the God damned customers so the engineers don't have to!"

Shouting at the management consultants didn't work for Tom and it probably won't work for you.

Regardless of who talks to the customer, the step of understanding and documenting the customer's needs and then producing the design of the part or assembly that meets them is the job of the designer or design team.

The best designers understand how the parts will be manufactured and the best design teams include manufacturing engineers so even if you don't see yourself being a manufacturing engineer when you "grow up" being a design engineer that understands manufacturing will make extremely valuable to your company.

The Part

In the manufacturing lab where I've spent the last ten years teaching we have a policy that requires anyone who wants to enter the facility to pick up a phone in the lobby and call the Lab Monitor who is responsible for the fact that the lab is open. As the most senior manager working in the facility I frequently answer the lab monitor's phone and have often heard something like this

> "So I heard like if I had my SolidWorks done I could like come here and you could like print my part. I really need it for a meeting with my advisor this afternoon, so could you like hurry up."

Unless it is very close to the end of the school year we all try really hard not to laugh until after those students have left the facility.

Granted some of the components the students ask for can be printed with today's technology but most of them cannot be printed on a printer costing much less than a million dollars and, almost all of those parts will need some kind of finish machining to create the features specified in the students' "designs."

Once the design is completed, even assuming the designer understood something about manufacturing, there are still several steps to complete before you ship the finished part to your customer.

Even if you were the designer, even if you are the customer at this point in the process you must become the manufacturing engineer if you are the one who will make the part(s).

As the manufacturing engineer

- You will need to select the process or processes that will be used to make your part(s).
- You will need to select the stock material that the part(s) will be made from.
- You will need to determine for each workpiece, and each process how it will be fixtured.
- You will need to select the tools and tooling to use.
- You will need to determine the Process Variables, PVs for the tools used.
- You will need to determine how you will check the quality of your finished parts.

Processes

There are thousands or possibly tens of thousands of individual manufacturing processes that can be used to make finished parts for any number of customers. In this text we will look primarily at material removal processes, specifically CNC Milling and CNC Turning.

Both of these processes use cutting tools to remove material from a piece of stock, also known as a workpiece, until the workpiece looks like the part designed by the designer. The Primary difference between turning and milling is that in a turning operation the workpiece spins and in milling the tool spins.

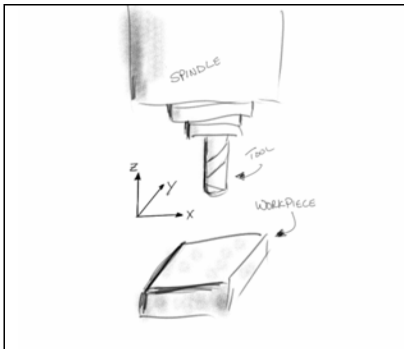


Figure 5 Typical mill spindle and workpiece showing x y z (Note: the machine tool table and fixturing are not shown)

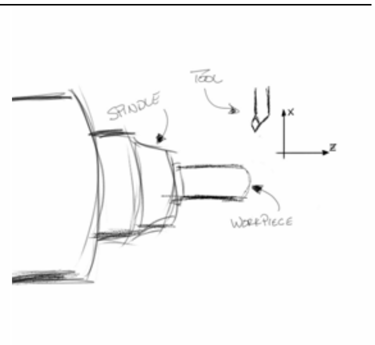


Figure 6 Typical Lathe spindle and workpiece showing x z. (Note: the typical lathe does not have a y axis.)

For a more in-depth description of milling and turning and the types of features you can make on your workpiece with each look at the Intro to Milling and Turning Section of "Manufacturing 101 for Engineers."

Stock Material

The material the finished part is made from is almost always specified by the designer as a DP. The particular piece of material that the part will be cut from on the other hand must be chosen by the manufacturing engineer. We as manufacturing engineers must decide if we will cut the part from a prismatic block of material or a cylindrical piece, or perhaps we will use a near net process like casting or 3d printing to create our stock material before we complete the milling and or turning operations that make it in to the particular finished part our customer wants.

If the part will be cut from cylindrical or prismatic stock pieces we typically get the stock material form a supplier that ships it to us as long bars of material. The stock used in the labs at WPI is almost always purchased in 12 foot lengths.

Since none of the CNC machine tools at WPI can accommodate 12 foot long bars of stock (easily) we cut the bars to length with a saw before performing CNC operations on them in a mill or a lathe. Before you can begin programming your part or setting up the machine tool to make your part you will need to know what your stock material is made of and its shape.

In prototype manufacturing we often cut parts from stock pieces that we have rather than purchasing pieces specific for the part we are making. This means that our stock material is not always the optimum shape or size. It can add considerable manufacturing time to the making of the first part but is often better than waiting for stock pieces to be ordered and delivered.

Fixturing

Once you have decided which process(es) will be used to make your customer's finished part and picked the stock material you will use you must figure out what is going to keep the workpiece (stock material) in the machine tool while you are cutting it.

The servo motors that control the x, y, z motion of CNC machine tools and that controlling the rotation of the spindle are capable of generating thousands of pounds of thrust and cutting forces respectively. If your workpiece is not held securely in the machine it will become a projectile the instant the cutting tool touches it.

I've visited machine shops around the world in almost every one I've been to I've seen evidence of damage to one of the machines that was caused by a part that came free from its fixture. And as the operations Manager of Manufacturing Laboratories at WPI I've spent thousands of dollars to repair machines damaged because of insufficient clamping force being applied to parts being cut.

In chapter 4 of this text we will look at fixturing and fixture design in depth. At this point it is sufficient for you to understand that parts must be fixtured in the machine when they are cut and unless you know how you will fixture the part you will not be able to safely create tool paths that will make the part your customer wants.

Tools and Tooling

The tools and tooling that we as manufacturing engineers need to select are

- the particular machine tools that will be used to cut the part,

- the cutting tools that will engage with the workpiece to remove the material, and
- the tool holders that will hold the cutting tools in the Machine.

Selecting a Machine Tool

When selecting a machine tool the manufacturing engineer needs to consider the availability of the machine and operator as well as the machine tools capabilities.

The first step in the process of taking concepts from art to part described above was to select the process(es) needed to create the finished part desired by our customer. Once we have done that we know if we need a milling machine, a turning machine (lathe) or a mill-turn machine.

Once you know what type of machine you will use you will need to consider the particular machine that will be used. You may need to get up from your cubical and walk around the shop floor if you haven't' done it in a while and see what is there. Once you know what machine tools are available you should consider the following characteristics:

- the work envelope of the machine,

- the work holding (fixturing) available for the machine, and
- the power available for cutting.

You may also need to consider the availability of the machine. If a particular machine tool is scheduled for a long on-going production run it may not be available for your part(s).

If, instead of machining prototype parts or contract machining as that type of work is sometimes called, you are establishing a production line for a new product you may be in a position to specify the machine tools that you (your company) will purchase to make the parts.

As an exercise

Before moving on to the next section of this book search for 4 machine tool manufacturers that make a milling machine capable of machining a 25 inch by 6 inch by 4 inch workpiece. Once you have identified the manufacturers not the model number(s) of the equipment they sell that can make the part and any pricing information you can find for purchasing the machine tools.

Selecting Tooling

Once you have picked your machine tool you will need to choose the cutting tools that will be used to make your part.

Milling Tools

The most common milling tools you will use as manufacturing engineers are:

- End mills,
- Face mills,
- Drills,
- Taps, and

End mills

Figure 7 Various Kennametal solid carbide end mills

End mills typically have cutting edges on the sides and bottom. The edges are called flutes or teeth. An end mill may have as few as one flute or as many as 8, 10, or more. Most , though, like those pictured in Figure 7 have two three or four flutes.

The number of flutes or cutting edges on an end mill will impact it strength and its ability to clear chips by removing them from the cutting area. As a rule end mills with more flutes will be stronger and end mills with fewer flutes will be better at clearing chips.

End mills can be used to remove material from the top of a workpiece (facing operations) as well its sides (contouring operations) and from the interior of the workpiece (pocketing operations)

Face mills

Figure 8 Kennametal Dodeka™ Series Face Mills

Face mills are used to remove material from the top of the workpiece (facing operations.) Those pictured in Figure 8 above have a steel body that holds carbide inserts that are fixed in place with screws.

Drills

Drills are intended to plunge in the Z direction in both milling and turning operations and when used in a two axis lathe must plunge I the center of the spinning part.

Drills are never intended to be feed in the x or y direction when in contact with the workpiece and will break if used in such a manner.

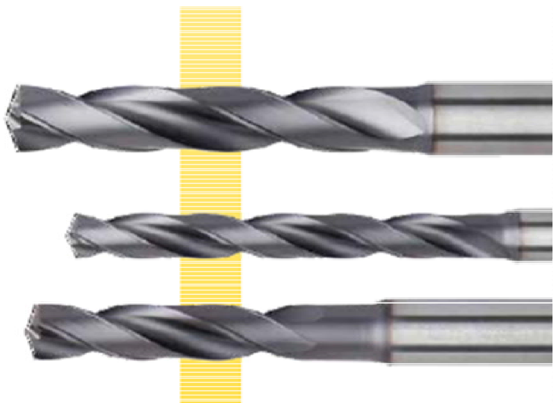


Figure 9 Kennametal Kenna Universal™ Drills

Taps

Taps are used to cut or form threads in holes that were previously drilled. These threaded holes can then be used to thread in fasteners that were either purchased or manufactured.

Side Note:

The figures in the section above come mostly from the Kennametal FIRST CHOICE Program Catalog available at:

http://www.kennametal.com/en/resources/catalogs-and-literature.html#mw

Turning Tools

Turning tools unlike milling tools do not spin when they are interacting with the workpiece. In

Figure 10 Sandvik Coromant - T-Max P Negative basic-shape inserts for high performance turning (http://www.sandvik.coromant.com/)

turning operations remember that the workpiece is rotated and the tool is fead into it in the x and z directions. In CNC Operations these tools may work on the front of the part (the face), on the outside diameter (OD) of the part, and on the inside diameter (ID) of the part.

Selecting Tool Holders

The tool holders you use will primarily be determined by the selection of the machine tool and the tooling that will be used. As a rule tool holders should be as short and rigid as possible to reduce vibrations and deflection during the cutting process.

As an exercises

There are amazing resources available for manufacturing engineers online and it would be a mistake for me to try to duplicate that knowledge here.

As an exercise look at the information provided by the tooling manufacturers

- Sandvik Coromant and
- Kennametal,

And make note of the resources they provide to help engineers choose the appropriate tools for particular cutting operations and data they provide to help you choose the appropriate process variables (PVs) for using the tools.

PVs

The process variables in any manufacturing operation are the things that the manufacturing engineer, the setup technician, and the operator choose and control. They include the items listed in the previous sections like selecting operations, tools, tooling, fixtures, stock material, and tool holders. They also include other things like the temperature in the room, the time of day that the operation is performed and the concentration of the coolant or cutting fluid that is used (if any.) But, when we as manufacturing engineers talk about the PVs that control cutting we are almost always most concerned with

- the feed
- the speed, and
- the depth of cut (DoC.)

There is an introduction to these parameters in the "Process Variable Selection" section of "Manufacturing 101 for Engineers," and we will cover these topics in depth in Chapter 3 of this text.

Quality Inspection

In in-depth discussions of lean manufacturing we are often able to conclude that the step of quality inspection in any manufacturing process is a waste step. (The exception being when the customer is willing to pay more because the part comes with an inspection report.) But, quality inspection is what keeps us from shipping crap to the customer so it is often a waste step that cannot be eliminated and it is our job as manufacturing engineers to setup the quality inspection steps that will be carried out in any process.

These quality steps can *include in process inspection and control* and or *final inspection before shipment*. We will look in detail at these and other quality issues in Chapter 2.

Chapter 2 Manufacturing Science and Metrology

Chapter 3 Modeling of Manufacturing Processes

Chapter 4 Fixturing and Fixture Design

Chapter 5 Design for Manufacturing

Chapter 6 Design of Safety Systems

Chapter 7 Manufacturing Economics

Weather we are looking at the profit from the sale of individual items manufactured or the profitability of the company as a whole, one of the most important things we will consider is the time it takes to make a profit.