Digital Manufacturing

CNC Machines

1. Manufacturing:

Manufacturing is the production of goods through the use of labor, machinery, tools and biological or chemical processing or formulation. Manufacturing can either mean transforming raw materials into finished goods on a large scale, or the creation of more complex items by selling basic goods to manufacturers for the production of items such as automobiles, aircraft, or household appliances.

Raw materials are transformed into finished products through manufacturing engineering or the manufacturing process. This process begins with product design and materials selection. The materials are modified during various manufacturing processes to create the finished product.

2. History of manufacturing:

Manufacturing has existed for centuries and was originally carried out by skilled artisans.

Then this early manufacturing system changed with the introduction of the factory system (industy0.1) in Britain at the beginning of the industrial revolution in the late 18th century. This system took advantage of technological advances and used machinery powered by water, steam and, later, electricity allowing for large-scale production.

A century later, a Second industrial revolution (industry0.2) appeared with the assembly line method of manufacture, it was described by Adam Smith in The Wealth of Nations, which introduced the concept of the division of labor. This meant that different people would each take just one part of a manufacturing process, for example cutting the wire for a pin, to create a more efficient and cost-effective process. Mechanization and later automation drew on this concept to create highly repeatable manufacturing.

Around 1970 the Third Industrial Revolution involved the use of electronics and IT (Information Technology) to further automation in production. Manufacturing and automation advanced considerably thanks to Internet access, connectivity and renewable energy. Industry 3.0 introduced more automated systems onto the assembly line to perform human tasks, i.e., using Programmable Logic Controllers (PLC). Although automated systems were in place, they still relied on human input and intervention.

The Fourth industrial Revolution is the era of smart machines, storage systems and production facilities that can autonomously exchange information, trigger actions and control each other without human intervention. This exchange of information is made possible with the Industrial Internet of things (IIoT) as we know it today.

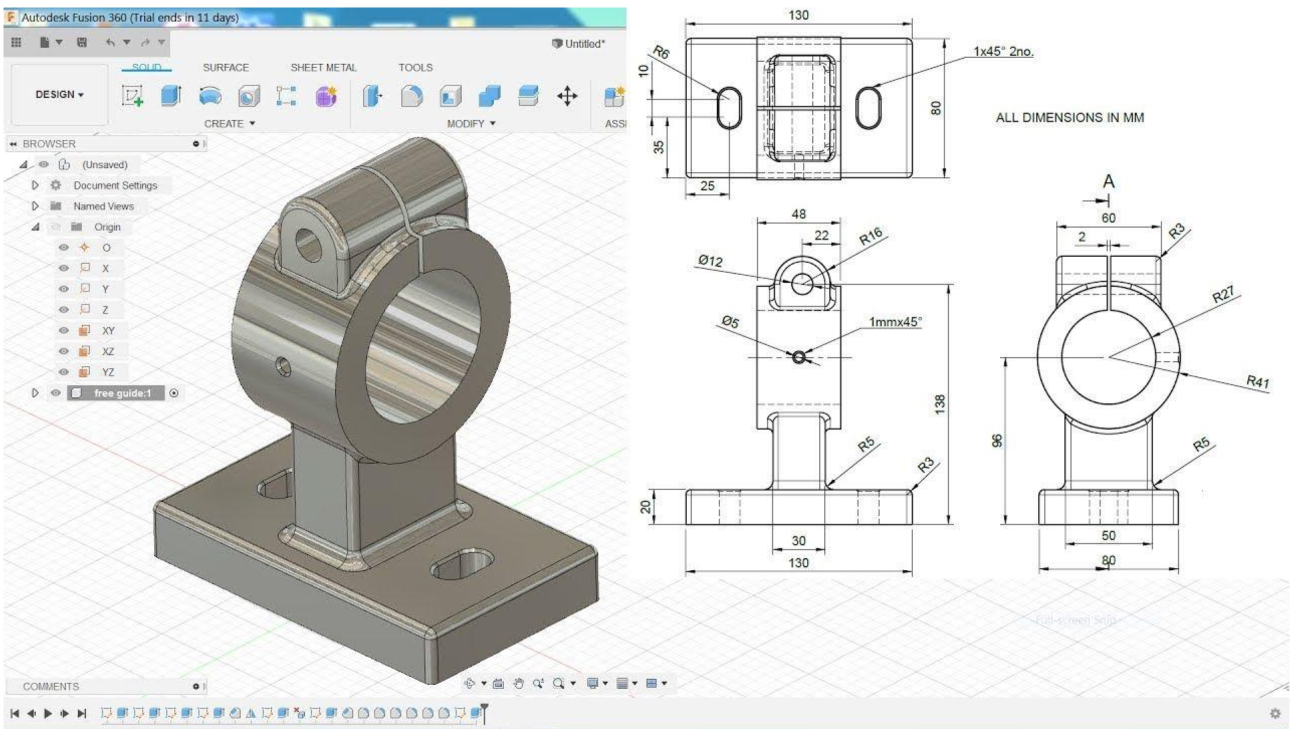
3. Digital Manufacturing:

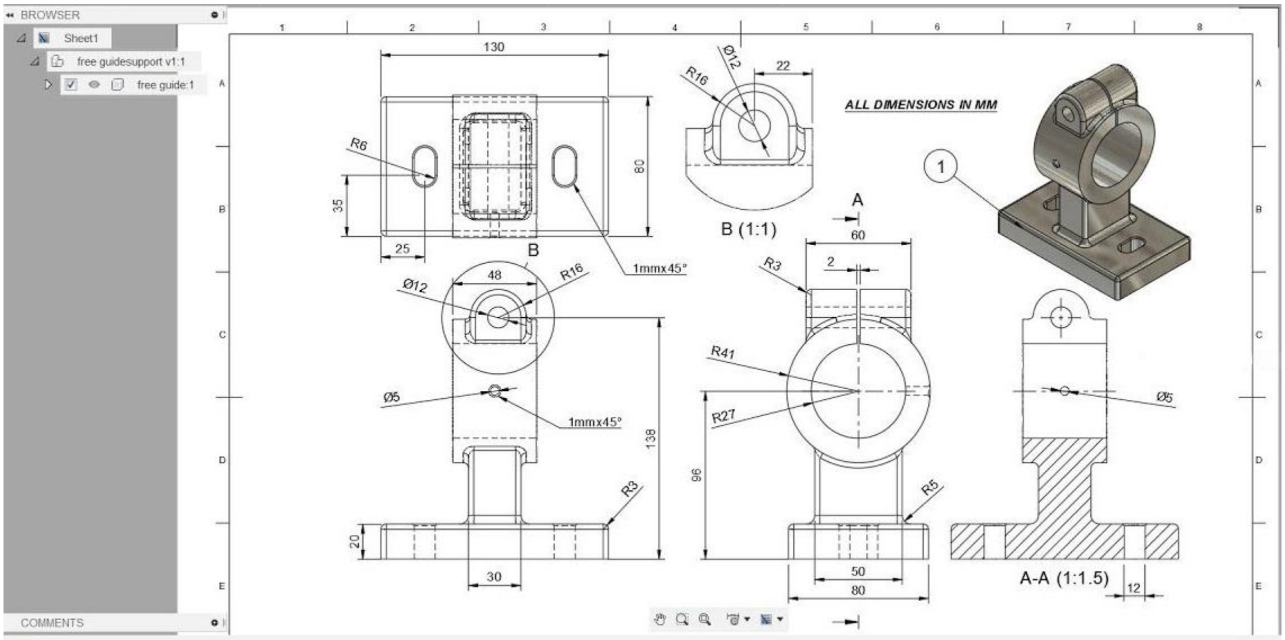
Digital manufacturing is the application of computer systems to manufacturing services, supply chains, products and processes. Digital manufacturing technologies link systems and processes across all areas of production to create an integrated approach to manufacturing, from design to production and on to the servicing of the final products.

4. Computer Aided Design (CAD):

Computer aided design (CAD) is the use of computers to aid in the creation, modification, analysis, or optimization of a 3D model design. This software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

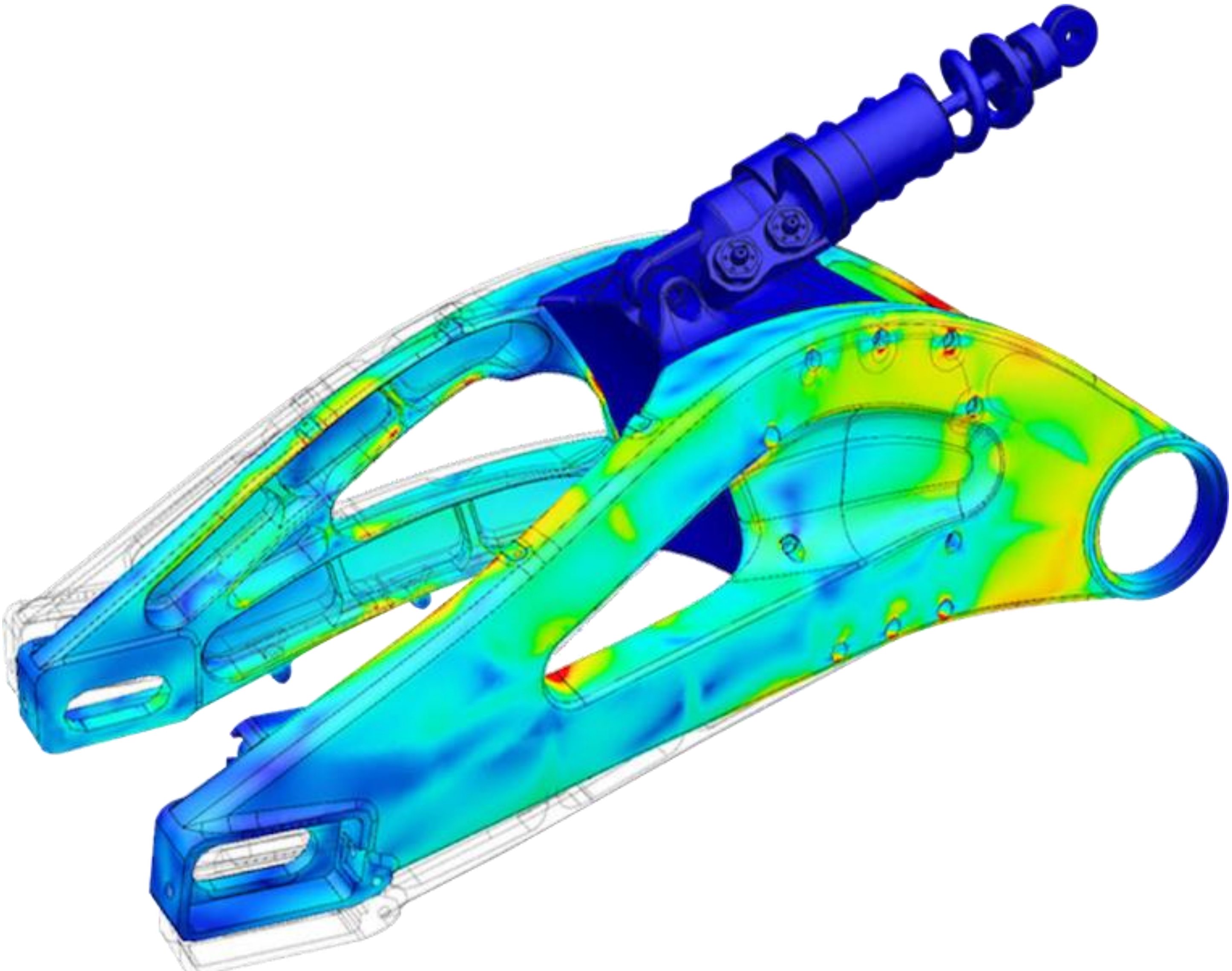
For example, in some environments, designers may be responsible for creating the initial design in a CAD program, while analysis and release engineers will review and analyze it to make sure there are no errors.





5. Computer Aided Engineering (CAE):

Computer-aided engineering (CAE) is the use of computer software to simulate performance in order to improve product designs or assist in the resolution of engineering problems for a wide range of industries. This includes simulation, validation and optimization of products, processes, and manufacturing tools. This saves companies significant time and money in product development while often yielding higher quality designs that meet multi-disciplinary and multi-functional requirements.



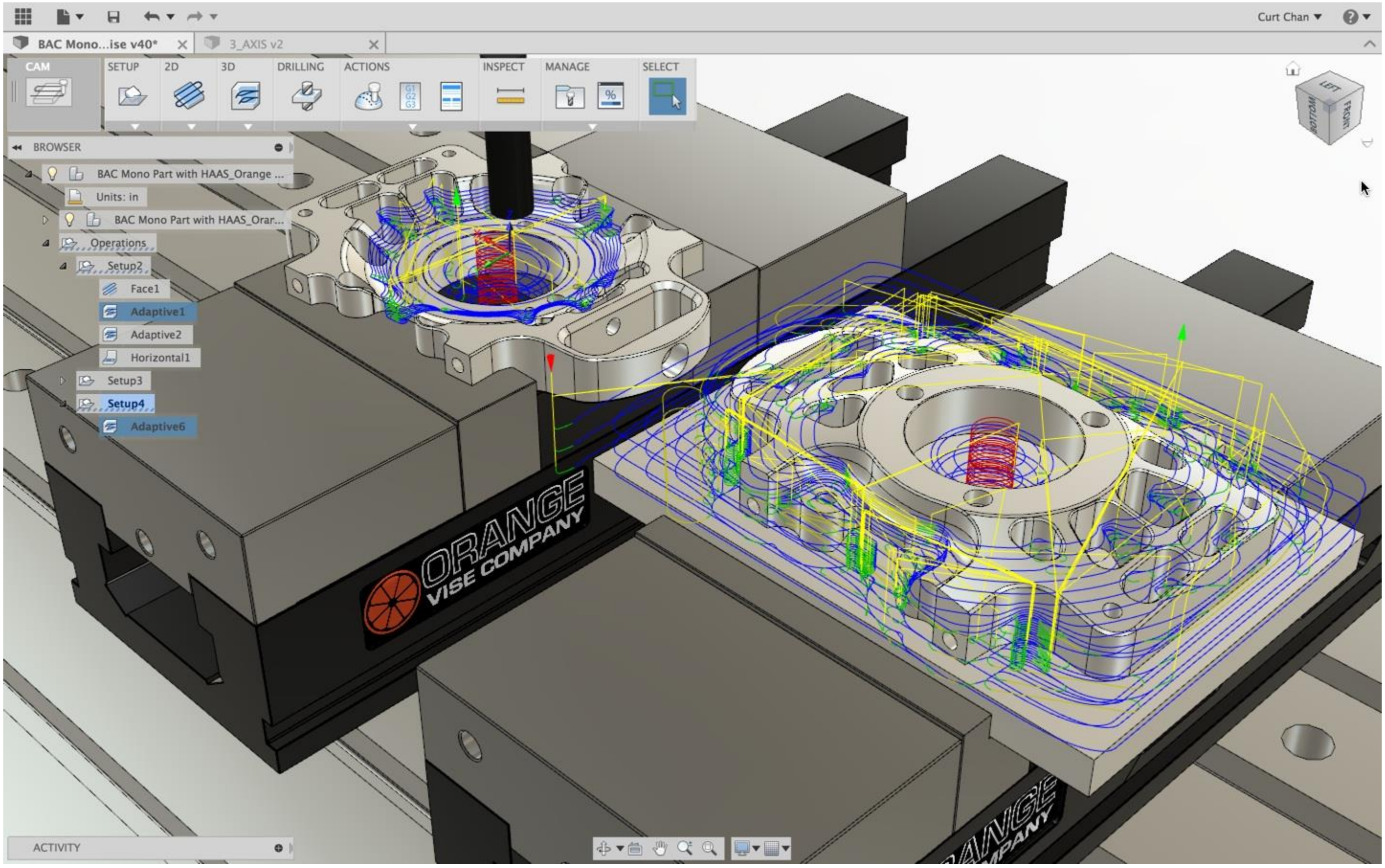
6. Computer Aided Manufacturing (CAM):

Computer-aided manufacturing is the use of software and computer-controlled machinery (CNC) to automate the manufacturing process. CAM itself stands for computer-aided manufacturing and usually works in tandem with CAD (computer-aided design) to allow machines to create objects directly from computer designs and software rather than engineers having to set up machines and processes manually.

Three components for a CAM system to function:

- Software that tells a machine how to make a product by generating toolpaths (CAD software).

- Machinery that can turn raw material into a finished product (ex, CNC).
- Post Processing converts toolpaths into a language machine can understand (G-code).

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N100 G1 X0.0026 Y0.0593 Z-0.0815
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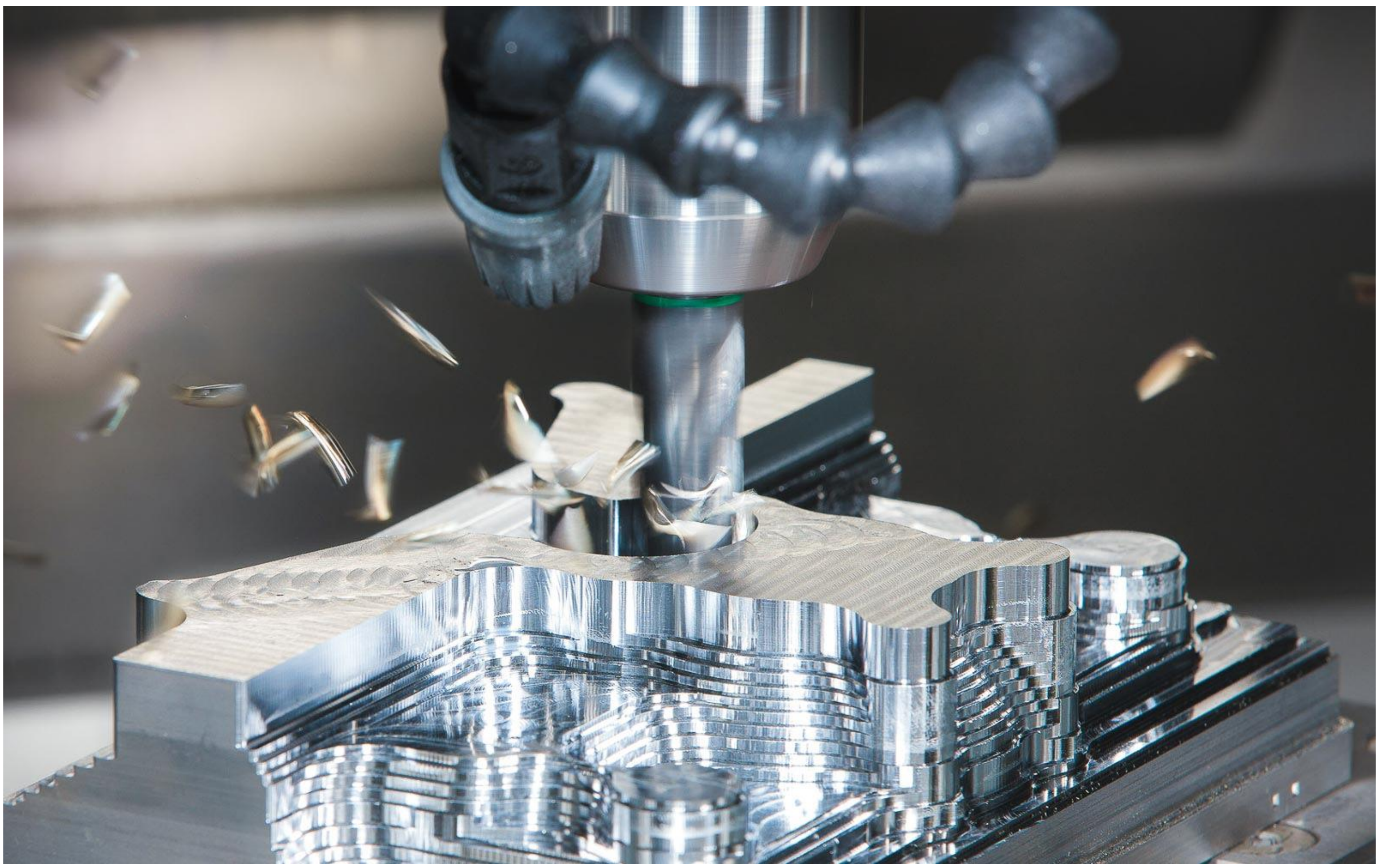
7. CNC machines (computer numerical control):

CNC stands for computer numerical control and these machines play an important role in the manufacturing industries including automotive, aerospace, construction, and agriculture, and they are able to produce a range of products, such as automobile frames, surgical equipment, airplane engines, gears, and hand and garden tools. These complex machines are controlled by a computer and provide a level of efficiency, accuracy and consistency that would be impossible to achieve through a manual process.

CNC is an automated control of machining tools such as drills, lathes, mills, grinders, routers and 3D printers by means of a computer. These machines process a piece of material such as metal, plastic, wood, ceramic, or composite, to meet specifications by following coded programmed instructions (G-code) and without a manual operator directly controlling the machining operation.

CNC machining is a manufacturing process which utilizes computerized controls to operate and manipulate machine and cutting tools such as to shape stock material into custom parts and designs. While the CNC machining process offers various capabilities and operations, the fundamental principles of the process remain largely the same throughout all of them. The basic CNC machining process includes the following stages:

- Designing the CAD model
- Converting the CAD file to a CNC program
- Preparing the CNC machine
- Executing the machining operation



8. CAD Model Design:

The CNC machining process begins with the creation of a 2D vector or 3D solid part CAD design, Computer-aided design (CAD) software allows designers and manufacturers to produce a model or rendering of their parts and products along with the necessary technical specifications, such as dimensions and geometries, for producing the part or product.

Designs for CNC machined parts are restricted by the capabilities (or inabilities) of the CNC machine and tooling. For example, most CNC machine tooling is cylindrical therefore the part geometries possible via the CNC machining process are limited as the tooling creates curved corner sections. Additionally, the properties of the material being machined, tooling design, and work holding capabilities of the machine further restrict the design possibilities, such as the minimum part thicknesses, maximum part size, and inclusion and complexity of internal cavities and features.

Once the CAD design is completed, the designer exports it to a CNC-compatible file format, such as STEP or IGES.

9. CNC Machine Tolerances:

When specifying parts to a machine shop, it's important to include any necessary tolerances. Though CNC machines are very accurate, they still leave some slight variation between duplicates of the same part, generally around + or - .005 in (.127 mm), which is roughly twice the width of a human hair. To save on costs, buyers should only specify tolerances in areas of the part that will need to be especially accurate because they will come into contact with other parts. While there are standard tolerances for different levels of machining (as shown in the tables below), not all tolerances are equal. If, for example, a part absolutely cannot be larger than the measurement, it might have a specified tolerance of +0.0/-0.5 to show it can be slightly smaller, but no larger in that area.

Table 1: Linear Tolerances in CNC Machining

Dimension Range (mm)	Fine (F) +/-	Medium (M) +/-	Coarse (C) +/-	Very Coarse (V) +/-
.5-3	.05	.1	.2	--
3-6	.05	.1	.3	.5
6-30	.1	.2	.5	1.0
30-120	.15	.3	.8	1.5
120-400	.2	.5	1.2	2.5
400-1000	.3	.8	2.0	4.0
1000-2000	.5	1.2	3.0	6.0
2000-4000	--	2.0	4.0	8.0

Table 2: Angle Tolerances in CNC Machining

Dimension Range (mm)	Fine (F) +/-	Medium (M) +/-	Coarse (C) +/-	Very Coarse (V) +/-
0-10	1º	1º	1º 30′	3º
10-50	0 º 30′	0 º 30′	1º	2º
50-120	0 º 20′	0 º 20′	0 º 30′	1º
120-400	0 º 10′	0 º 10′	0 º 15′	0 º 30′
400	0 º 5′	0 º 5′	0 º 10′	0 º 20′

Table 3: Radius and Chamfer Tolerances in CNC Machining

Dimension Range (mm)	Fine (F) +/-	Medium (M) +/-	Coarse (C) +/-	Very Coarse (V) +/-
.5-3	.2	.2	.4	.4
3-6	.5	.5	1	1
6	1	1	2	2

10. CNC Programming:

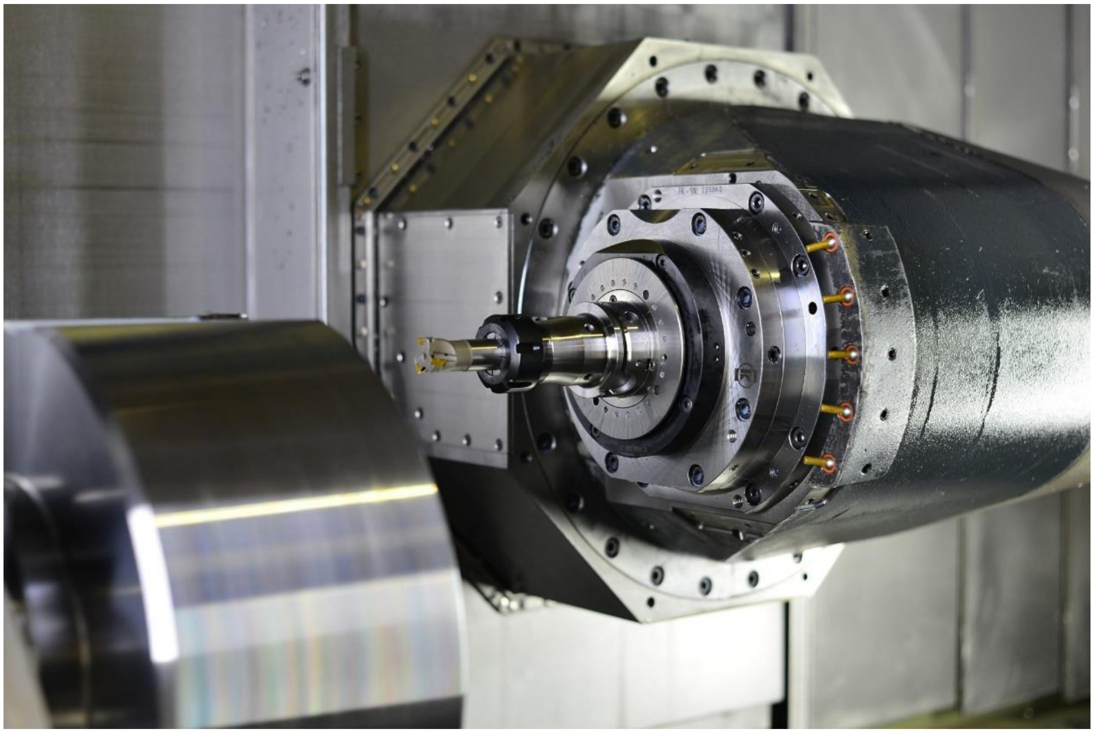
The formatted CAD design file runs through a program, typically computer-aided manufacturing (CAM) software, to extract the part geometry and generates the digital programming code which will control the CNC machine and manipulate the tooling to produce the custom-designed part.

CNC machines used several programming languages, including G-code and M-code. The most well-known of the CNC programming languages, general or geometric code, referred to as G-code, controls when, where, and how the machine tools move (e.g., when to turn on or off, how fast to travel to a particular location, what paths to take, etc..). Across the workpiece. Miscellaneous function code referred to as M-code controls the auxiliary functions of the machine, such as automating the removal and replacement of the machine cover at the start and end of production, respectively.

Once the CNC program is generated, the operator loads it to the CNC machine.

11. Machine Setup:

Before the operator runs the CNC program, they must prepare the CNC machine for operation. These preparations include affixing the workpiece directly into the machine onto machinery spindles or into machine vises or similar work holding devices and attaching the required tooling such as drill bits and end mills to the proper machine components. Once the machine is fully set up, the operator can run the CNC program.



workholding: CNC spindle machine

workholding: Vice mailing machine

12. Machine Operation execution:

The CNC program acts as instructions for the CNC machine it submits machine commands dictating the tooling's actions and movements to the machine's integrated computer, which operates and manipulates the machine tooling. Initiating the program prompts the CNC machine to begin the CNC machining process, and the program guides the machine throughout the process as it executes the necessary machine operations to produce a custom-designed part or product.

13. Types of CNC machines:

In this paper we will explore some of the most common mechanical CNC machining operations including:

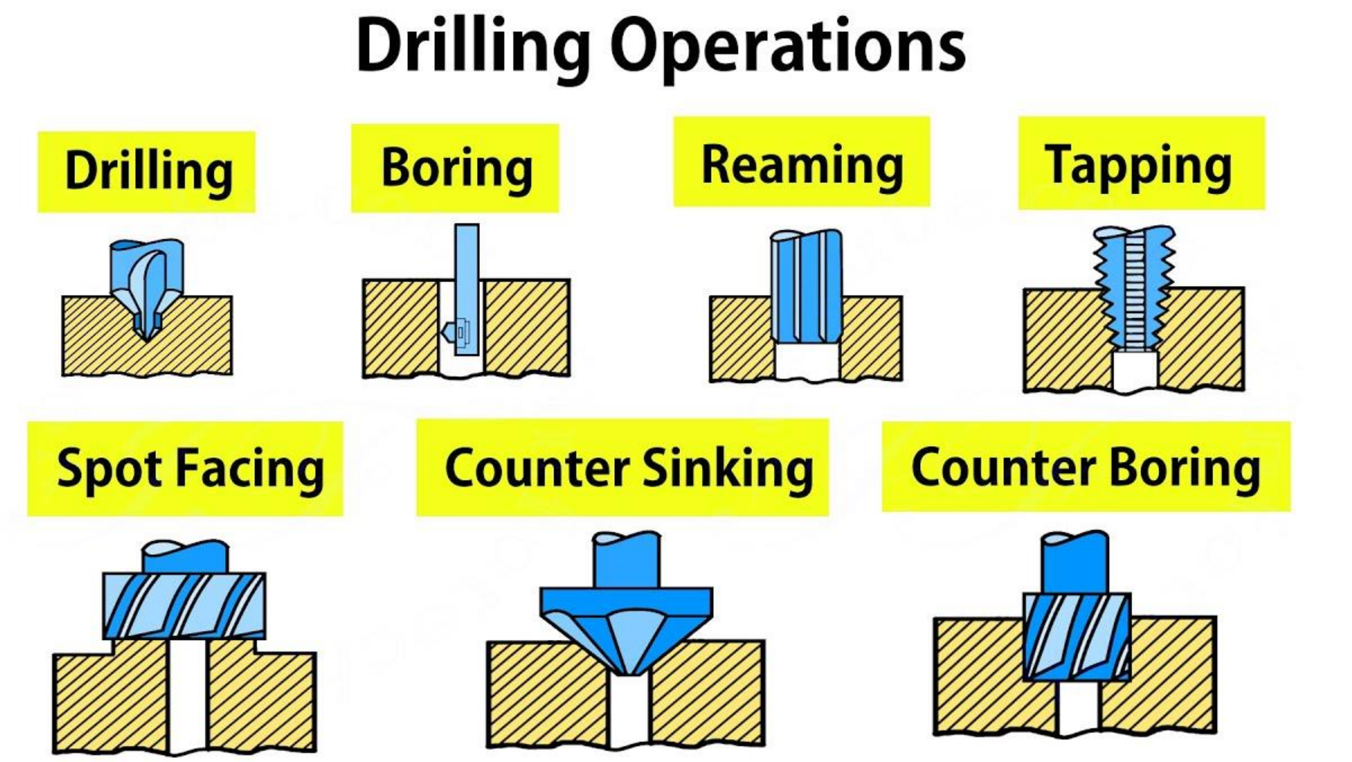
- Drilling
- Milling
- Turning

Note that there are other machining processes such as chemical, electrical and thermal machining process. And they will not be covered in this paper.

a) CNC Drilling:

Drilling is a machining process which employs multi-point drill bits to produce cylindrical holes in the workpiece. In CNC drilling, typically the CNC machine feeds the rotating drill bit perpendicularly to the plane of the workpiece's surface, which produces vertically-aligned holes with diameters equal to the diameter of the drill bit employed for the drilling operation. However, angular drilling operations can also be performed through

the use of specialized machine configurations and workholding devices. Operational capabilities of the drilling process include counterboring, countersinking, reaming, and tapping and spot facing.



b) CNC Milling:

Milling is a machining process which employs rotating multi-point cutting tools to remove material from the workpiece. In CNC milling, the CNC machine typically feeds the workpiece to the cutting tool in the same direction as the cutting tool's rotation, whereas in manual milling the machine feeds the workpiece in the

opposite direction to the cutting tool's rotation. Operational capabilities of the milling process include face milling, cutting shallow, flat surfaces and flat-bottomed cavities into the workpiece, and peripheral milling, cutting deep cavities, such as slots and threads, into the workpiece.

c) CNC Turning: (Lathe)

Turning is a machining process which employs single-point cutting tools to remove material from the rotating workpiece. In CNC turning, the machine, typically a CNC lathe machine feeds the cutting tool in a linear motion along the surface of the rotating workpiece, removing material around the circumference until the desired diameter is achieved, to produce cylindrical parts with external and internal features, such as slots, tapers, and threads. Operational capabilities of the turning process include boring, facing, grooving, and thread cutting.

d) Different between Milling, Drilling and Lathe CNC machines

When it comes down to a CNC mill vs. lathe, milling, with its rotating cutting tools, works better for more complex parts. However, lathes, with rotating workpieces and stationary cutting tools, work best for faster, more accurate creation of round parts.

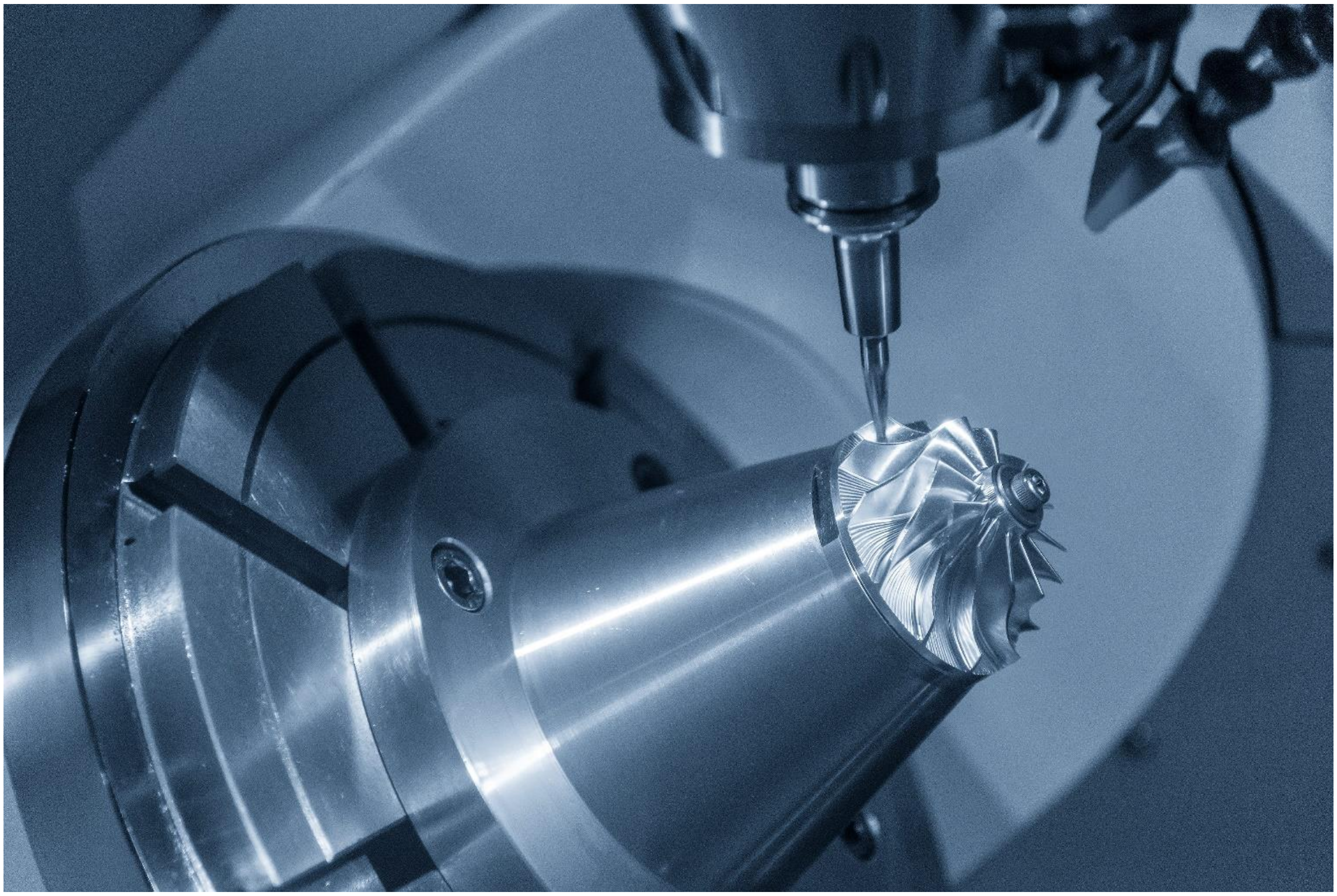
Table 1 – Characteristics of Common CNC Machining Operations

Machining Operation	Characteristics
Drilling	• Employs rotating multi-point drill bits • Drill bit fed perpendicular or angularly to workpiece • Produces cylindrical holes in workpiece
Milling	• Employs rotating multi-point cutting tools • Workpiece fed in same direction as cutting tool rotation • Removes material from workpiece • Produces broader range of shapes
Turning	• Employs single-point cutting tools • Rotates workpiece • Cutting tool fed along the surface of the workpiece • Removes material from the workpiece • Produces round or cylindrical parts

14. 5 Axis CNC Machine:

5 axis CNC machining describes a numerically-controlled computerized manufacturing system that adds to the traditional machine tool's 3-axis linear motions (X, Y, Z) two rotational axes to provide the machine tool access to five out of six-part sides in a single operation. By adding a tilting, rotating work holding fixture (or trunnion) to the work table, the mill becomes what is called a 3+2, or an indexed or positional, machine, enabling the milling cutter to approach five out of six sides of a prismatic workpiece at 90° without an operator having to reset the workpiece.

It is not quite a 5-axis mill, however, because the fourth and fifth axes do not move during machining operations. Adding servomotors to the additional axes, plus the computerized control for them – the CNC part –would make it one. Such a machine- which is capable of full simultaneous contouring- is sometimes called a "continuous" or "simultaneous" 5-axis CNC mill. The two additional axes can also be incorporated at the machining head, or split – one axis on the table and one on the head.



CNC Machine: 5 Axis

Fusion 360 software:

Fusion 360 is a cloud-based 3D modeling, CAD, CAM, CAE, and PCB software platform for professional product design and manufacturing. It helps on:

- Create and Design engineering products from scratch.
- Simulating and testing the engineering performance of the 3D model.
- Simulating the manufacturing prosses on the stock part.
- Extracting the G-code for CNC machine operation.

Note:

On my projects I'm using Fusion 360 cloud-based software for Design, Drawing, Engineering and Manufacturing processes.