# 60 YEARS
# OF
# ROLLING MILL
# TECHNOLOGY

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# PREFACE

Hot and cold metalworking between two or more rolls has been in existence since long before the industrial revolution. As a matter of fact, Leonardo da Vinci was credited for the metalworking mill prior to his death in 1519.

When most people think of a rolling mill, they visualize sizable machinery in ferrous (iron, carbon steel and stainless steels) and non-ferrous (copper, brass, lead, etc.) integrated or electric arc furnace (EAF) steel mill of today, to small manually cranked rolling devices used at jewelers to reduce the thickness of the precious metal or impart a pattern on the surface of the metal to be fabricated into a chain or ring.

Rolling mills have many functions. They can be used to reduce the thickness of material quite accurately (+/-.0001") or compress the material to create a uniform density throughout the strip or impart a surface finish on one or both sides of the material, just to name the most common methods.

Rolling mills are not a standard machine tool, nor are they built for stock. They are designed and built-to-order to specifically accomplish an end product or process.

At one point during the industrial revolution in America, the United States led the world in hot and cold rolling, plate mills, slabbing mills and blooming mills. Companies such as Mesta, United, Blaw-Knox, Lewis, Continental, and Bliss were attributed to building some of the largest rolling mills in the world before World War II. In fact, Mesta and United pioneered the rolling process to reduce very thick as cast slabs into plate, the plate into hot rolled coils and the hot rolled coil into cold rolled coil.

Many of these old mills are still running today as a result of upgraded electrical and hydraulic systems, including hydraulic screwdowns, hydraulic roll bend, and tension control.

This book does not focus on these specific rolling mill manufacturers and their various methods of manufacturing and patentability. My intent in this book is to show the modern rolling techniques that are employed today and how technology played a tremendous role in greater safety and improved production in the steel making process.

I have broken the book down into four specific chapters:

I. Materials That Can Be Rolled
II. Purposes and Products of Rolling Mills
III. Configurations and Types of Rolling Mills
IV. Advanced Rolling Mill Technology
V. Brief Calculations

*Note: All photos and drawings mentioned are at the back of this book.*

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# I. MATERIALS THAT CAN BE ROLLED

## Low Carbon Steels

There are many types of steel that vary in their carbon content. SAE 1006 to 1010 are low carbon steels that are extremely soft and ductile. See table;

300%

**STANDARD CARBON STEELS**
**Chemical Composition Ranges and Limits**

| SAE No. | C | Mn | P Max | S Max |
|---|---|---|---|---|
| 1005 | .06 max | .35 max | .040 | .050 |
| 1006 | .08 max | .25/.40 | .040 | .050 |
| 1008 | .10 max | .30/.50 | .040 | .050 |
| 1010 | .08/.13 | .30/.60 | .040 | .050 |
| 1011 | .08/.14 | .60/.90 | .040 | .050 |
| 1012 | .10/.15 | .30/.60 | .040 | .050 |
| 1013 | .11/.16 | .30/.60 | .030 | .050 |
| 1015 | .13/.18 | .30/.60 | .040 | .050 |
| 1016 | .13/.18 | .60/.90 | .040 | .050 |
| 1017 | .15/.20 | .30/.60 | .040 | .050 |
| 1018 | .15/.20 | .60/.90 | .040 | .050 |
| 1020 | .18/.23 | .30/.60 | .040 | .050 |
| 1021 | .18/.23 | .60/.90 | .040 | .050 |
| 1022 | .18/.23 | .70/1.00 | .040 | .050 |
| 1023 | .20/.25 | .30/.60 | .040 | .050 |
| 1025 | .22/.28 | .30/.60 | .040 | .050 |
| 1026 | .22/.28 | .60/.90 | .040 | .050 |
| 1029 | .25/.31 | .60/.90 | .040 | .050 |
| 1030 | .28/.34 | .60/.90 | .040 | .050 |
| 1035 | .32/.38 | .60/.90 | .040 | .050 |
| 1038 | .35/.42 | .60/.90 | .040 | .050 |
| 1039 | .37/.44 | .70/1.00 | .040 | .050 |
| 1040 | .37/.44 | .60/.90 | .040 | .050 |
| 1042 | .40/.47 | .60/.90 | .040 | .050 |
| 1043 | .40/.47 | .70/1.00 | .040 | .050 |
| 1044 | .43/.50 | .30/.60 | .040 | .050 |
| 1045 | .43/.50 | .60/.90 | .040 | .050 |
| 1046 | .43/.50 | .70/1.00 | .040 | .050 |
| 1049 | .46/.53 | .60/.90 | .040 | .050 |
| 1050 | .48/.55 | .60/.90 | .040 | .050 |
| 1053 | .48/.55 | .70/1.00 | .040 | .050 |
| 1055 | .50/.60 | .60/.90 | .040 | .050 |
| 1060 | .55/.65 | .60/.90 | .040 | .050 |
| 1065 | .60/.70 | .60/.90 | .040 | .050 |
| 1070 | .65/.75 | .60/.90 | .040 | .050 |
| 1074 | .70/.80 | .50/.80 | .040 | .050 |
| 1078 | .72/.85 | .30/.60 | .040 | .050 |
| 1080 | .75/.88 | .60/.90 | .040 | .050 |
| 1086 | .80/.93 | .30/.50 | .040 | .050 |
| 1090 | .85/.98 | .60/.90 | .040 | .050 |
| 1095 | .90/1.03 | .30/.50 | .040 | .050 |

Low carbon steels are used for deep draw stampings where the material must elongate, such as when making an automobile fender. These are sometimes referred to as Deep Draw Quality (DDQ). This type of steel starts off with a very low yield strength of 30,000 PSI. As soon as it is cold reduced, and depending upon the amount of reduction, the yield strength can go as high as 100,000 PSI as the material under the work roll hardens. However, as further reduction increases the yield and tensile become about the same and the material will become extremely hard or brittle. This material has now reached its ultimate tensile strength and if bend upon itself, the material will perhaps break, even though the low carbon steel started out very soft prior to reducing. As a rule of thumb, the more carbon content in the steel, that harder it is prior to any cold reduction in a rolling mill.

Some low carbon steel is galvanized (coated with zinc). There are various types of galvanized steel that all have various amounts or weights of galvanized coatings that protect the base metal from corrosion. The thickness of the zinc can be applied very accurately at the coil coater so overall thickness of the coated steel has not increased in gauge very much. Coating weights are measured in grams per meter, one side or both side of the steel coil. So a specified coating weight of 60G/60G would represent a coating weight on both sides of 60 grams per square meter. This type of coating is predominately found in a garbage can or a metal bucket or pail found at the hardware store. Low carbon, galvanized material of the highest possible quality is produced for making products such as automobile panels.

Light gauge (.017") steel studs and steel framing are also made from low carbon steel. These products are commonly found in walls of commercial buildings and have now found their way into home production as a way to reduce the amount of wooden members previously used over the years. The absence of wood in a home reduces the likelihood of bug infestation and increases the speed of erection as the steel stud and framing member is much lighter that of wood. An industry was developed around the light gauge steel stud because steel mills were unable to produce high quality galvanized steel from .020" to .035" thick on a consistent basis off their rolling mills. As a result, much of this low carbon galvanized steel was sold on the secondary market for products such as steel studs, corrugated steel containers, and mailboxes. Cauffiel built the first rolling mill for reducing secondary galvanized steel from .032" to .017" thick on a high production, continuous basis so that it could be roll formed into a C-section or stud to replace wooden two-by-fours, which ultimately revolutionized the construction industry as we now know it. By reducing material from .032" thick and then down to .017" thick, the material became very strong through work hardening (80,000 to 100,000 PSI yield strength). This makes an excellent stud material for non-load bearing walls due to its stiffness. In fact, the use of steel studs in most commercial buildings became law in many states due to hurricane and NFPA fire codes.

**High Carbon Steels**

By increasing the carbon content, steel can be made hot at temperatures above 1200°F. Normally, high carbon steel is further heat treated, such as quenched and tempered, to increase the yield and tensile strengths. Because of the high carbon content, when you quench steel in water, as an example, the steel becomes very hard, (i.e. the Rockwell can increase substantially). In fact, if it becomes too hard, the material is quenched in oil or salt instead of water, which allows it to be very tough and still allows it to be reduced because the yield strength is less than the tensile strength. Expensive, high carbon steels are found in agricultural products such as plows, cultivator disks, lawnmower blades, cutting blades, etc. Of course, high carbon steels can be annealed to bring down to a very low yield strength or heat treated to a tough product of 150,000 PSI yield strength.

**Alloy Carbon Steels**

One of the purposes of alloy carbon steel is to improve the quality and physical properties of carbon steel. Many carbon steels have other alloys mixed in such as chrome, molybdenum, vanadium, manganese, silicon, and many other elements. The purpose of alloy carbon steel can be many. However, it is exceedingly difficult to weld high carbon alloy steels because when the weld cools, the carbon steel near the weld becomes very hard, making the steel under the weld unsatisfactory. The only way to weld high carbon steel is to preheat the steel before welding however, this destroys the integrity of the steel. The mill must add columbium or niobium in the steel so that it is strong and welds quickly without becoming brittle. Many ships, tanks, towers, etc. are welded with alloy carbon steels.

Before a product is designed with carbon steels or alloy carbon steels, extensive research is done to not only look at the best consistent quality of available steel, but to look at the cost of each carbon steel product. Seeking the advice of a welding expert to specify, and how the material should be welded, such as ERW, TIG, MIG, etc. All alloy carbons steels become harder (100,000 to 300,000 PSI yield strength) after being rolled or reduced and annealed for further rolling and reducing.

Carbon steels and stainless steels can be made into almost any alloy. An alloy is the mixture of almost any element. The most common high strength, high yield alloy is a chrome moly alloy such as AISI 4140 or 4340. These alloys are commonly used in steel plate and are quenched and tempered. To reduce these steels, cold working or work hardening is a factor to consider because, like stainless and high carbon steels, the material increases substantially in yield strength when reducing.

One of the most useful purposes of alloy steels is in springs or any application where the material has to flex on a continuous basis without breaking. Most steels will crystalize in time even though they are not bent beyond the yield point. As an example, that is why a lot of machinery shafts that take a side load are made from alloy steel. As an example, AISI 4340 is used to prevent fatigue, and the maximum stress the shaft may be under is 16,000 PSI however, the actual yield point of the material is 150,000 PSI. Fatigue and flexing is considered when the material is used in bridge or machinery building. The material, type of construction, welding, machining, etc. must all be considered in the final cost.

**Stainless and Stainless Alloys**

There are many stainless alloys. The most common is 300 series. The most important purpose is to have a metal that will not rust or corrode. Many stainless steels can be surface polished or brushed to make a product that will last indefinitely around mixtures of water. Stainless comes from the mill with a yield strength as low as 50,000 PSI, but as soon as you reduce, say 10%, the surface becomes as high as 300,000 PSI yield strength. As mentioned, stainless and many other alloys, including high carbon steels, increase in yield strength and tensile strength when reduced. Most stainless is easily annealed because once it is heated and cooled down, it becomes soft again. Stainless steel has many corrosion applications. Stainless is used to hold an appearance without painting such as on the outside of buildings and automobiles. In fact, most stainless steels will hold its finish under all types of atmospheric conditions. A considerable amount of automobile trim is made from stainless steel as well as boat hardware, chemical equipment, tanks, condensers, etc. In fact, much of the food industry requires stainless steel products such as vessels and piping. Certain industrial atmospheres prefer stainless steel because of the corrosive atmospheres. Many industrial washrooms are equipped with stainless steel.

There are many specific types of stainless steels. Stainless generally has chrome and nickel and other alloys. Stainless is not magnetic, which in some applications, such as electronics, has advantages. The most common stainless alloys are 302, 303, 304, and 305 series.

In the last 20 years, there has been a growth in 400 series, which can also be used to prevent corrosion, but the big advantage is that it has a lower cost. 400 series is also generally easier to weld. 400 series is used for exhaust manifolds, exhaust pipes, mufflers, etc.

All types of stainless steels increase in yield strength and become harder after reducing or forming operations.

**High Temperature Alloys**

Reducing and bending high temperature alloys is similar to stainless steels. High temperature alloys are used for resistance type electrical heating (toasters, heaters, furnaces, etc.). High temperature alloys are a mixture of any element that has a high temperature melting point, including chrome, nickel, and titanium. Rolling and reducing high temperature alloys is the same or similar to stainless alloys.

**Aluminum and Aluminum Alloys**

Aluminum has many advantages. The first advantage is that it is light weight or has a low specific gravity. Steel weighs 0.28 pounds per cubic inch. Aluminum weighs one third of steel. If you take the weight of steel and divide by three, you will have the approximate weight of aluminum. Of course, this has a large advantage in the aircraft industry and has made inroads in the automobile industry, such as lightweight aluminum wheels, which reduces the kinetic energy required to accelerate or decelerate. Many other innovations in aluminum have been made in the automotive and truck industries. For example, many trailers and railroad cars are made of aluminum. By reducing the weight of any vehicle, the energy for acceleration and deceleration is reduced making more load possible.

Aluminum has other great characteristics. Cost should be considered because if steel costs .40 cents/pounds and aluminum being one third the weight of steel, you could pay three times more per pound for aluminum and receive the same volume. However, most aluminum is not as strong as steel. Depending upon its alloy, it has less yield and tensile strength than carbon alloys. However, by adding chrome and other alloys to aluminum, aluminum can approach the strength of steel. This is very common on aircraft landing gears.

As with carbon steels, aluminum has many alloys. Pure aluminum is very soft with a low yield strength, which has many advantages, such as deep drawing when making beverage cans, bearing material, foils, etc. Aluminum forgings can be very strong, approaching the strength of many steels, as used in the structural parts of a vehicle.

Aluminum has other possibilities. It can be used for electrical components, including bus bars because it has a high degree of electrical conductivity. Certain aluminum is corrosion resistant and used in the chemical industry. It is common in cooking utensils because it has a high conductivity of heat transfer. A lot of food packaging is done with aluminum foil.

Aluminum can be extruded so it is used for all type of shapes, such an angle, flat bar, etc. It is certainly used in the furniture industry because of its light weight. Aluminum can be polished, anodized or coated, so it holds a reflective surface for a long period of time. This is common with concentrated solar collectors.

Since aluminum carries a high price per pound, it is collected and recycled. Most aluminum cans are re-melted and made again into aluminum strip. The aluminum strip can be painted so you have a painted sign or light weight building material. In Africa, there are many buildings made from painted aluminum strip that was melted from recycled aluminum beverage cans, which are ideal near a salt water coast.

Aluminum foil from a rolling mill is used to make all types of capacitors. Aluminum foil is used in the tobacco and the food industries. Foil is made from hot rolled strip up to .250" thick and is rolled to .008" to .0002" thick by up to 72" wide, but generally 48" to 60" wide. Aluminum can corrode, however, but with the low cost of anodizing, corrosion can be minimized. This type of rolling mill sometimes operates at over 3,000 FPM.

Scrap aluminum is easily melted and made into aluminum foil, strip, or plate. All kinds of aluminum alloys are made to increase strength or to make soft for substantial cold working without heat treating. Aluminum alloys can be soft and cladded to steel as used in connecting rods and main automobile bearings instead of using Babbitt, a lead alloy which is a pollution concern. Many aircraft bearings are made from aluminum alloys, including high strength aluminum alloys such as aluminum bronze. There are many paints that can used to paint aluminum any color, which is useful in light weight appliances, as well as automobiles and buildings.

**Copper and Copper Alloys**

Pure copper is very ductile, which means it has a high elongation. Pure copper can be annealed at 12,000 to 15,000 PSI yield strength, and when reduced or cold worked substantially, can go to 45,000 PSI yield strength. Copper at elevated temperatures can be 6,000 to 15,000 PSI yield strength. Pure copper can be made into slab and further reduced into copper plate or hot rolled coils. Copper can also be continuous cast and usually milled (to remove the imperfect surface) and cold reduced all in line. It can be made into light gauge coils, sheet, rod, and wire.

Copper can also be extruded. A lot of air conditioning and refrigeration tubing is extruded into large diameter tubes and further reduced into small diameter tubes, ¼" or less. Pure copper is difficult to weld because it takes the heat away from the weld quickly. Some copper is made round, but is rolled into a flat shape. Copper is rolled into a flat wire for electric motors and transformers. This allows more windings on a transformer motor without increasing the diameter or size. Copper has good corrosion characteristics under certain acids and alkalis. One of the most important aspects of copper is that it has a high electrical conductivity. Certain copper alloys have high fatigue characteristics. Beryllium copper, as an example, is used to make ignition points and springs where continuous bending is necessary.

Another important characteristic of copper is that it has a very good heat transfer. That is why it is very common in condensers and heat exchangers as used in air conditioners and refrigerators. When copper is made into a tube, sometimes it has internal spiral grooves which doubles the surface area inside the tube and allows for better turbulence. This improves the heat exchanger affect for air conditioning and refrigeration and reduces the cost of the product.

The number one use for copper is copper wire. There are various copper alloys used for many other different products. Copper aluminum alloys have a special advantage in phosphoric acid, which is a very difficult acid to contain. As an example, copper alloys are used for making beer and sulfuric acid. It is also used in transporting sea water. One of the great uses for copper alloys is bearing applications. Copper nickel alloys have advantages in high load bearing material. Copper nickel magnesium alloys are used in radio resistors. In rolling mill applications, much of the copper is continuous cast and reduced on a rolling mill. Many square and rectangular bus bars are made from copper because of the high electrical conductivity used to transport high amps or continuous power throughout a building. All of these products are rolled on a rolling mill. This may be a tandem rolling mill where each rolling mill runs a little faster depending upon the reduction from one rolling mill to another.

Another use for copper, because of its heat transfer characteristics, is continuous casting of steel. By water cooling the copper mold, high temperature steel can be poured through a mold on a continuous cast basis and made into a slab or ingot. Also, copper foil is used in electronics and is sometime cladded to plastic for printed circuits. There are many copper rolling mill applications.

**Other Metals**

Refer to Photo #760. Gold and silver are rolled on a rolling mill. All coins made from copper zinc coils are made on a rolling mill. In fact, almost any metal can be rolled on a rolling mill. This includes lithium for batteries and uranium for atomic energy. Tantalum and niobium are also reduced on a rolling mill with heavy duty, stand-alone rolling mills with substantial reduction to make what is called a target for the electronics and sputtering industries. Tantalum, not titanium, is a corrosion resistant inert metal. It will withstand almost any acid and is used in heat exchangers for hot hydrochloric acid. Niobium is mixed with steel to make special weldable ductile steel alloys. Titanium alloys are used in the aviation industry and corrosion resistant heat exchangers and other corrosion resistant chemical systems. Lead and lead alloys are still used in large quantities today. They are sometimes made in wide sheets and are in every x-ray room. Lead is used at airports and seaports for radiation shielding.

All internal combustion engine bearings are made from an aluminum tin copper alloy. The aluminum tin copper alloy is made into a strip and cladded to steel to make bearing inserts for connecting rods and main bearings for gasoline and diesel engines.

There are many other mixtures of metal alloys, including brasses and bronzes for valves, bearings, etc. All of these materials are sometimes rolled into a strip, sheet or rod.

Rolling alloys is very important and can provide a good or excellent grain structure. All of the material mentioned can be cast, but a casting is porous so it is not dependable. When reducing a cast product, sometimes heat treating the rolled product will give an excellent grain structure. The rolling and heat treating of any metal alloy can be very important in producing a consistent, high quality product.

Highly complicated formulas for cold rolling mills have been developed by some of the greatest mathematicians and engineers. Cauffiel has developed its own formulas and calculations by actually testing and experimenting with cold reducing. These formulas give data such as separating force, torque, horsepower, and deflection of rolls and housings. Also, Cauffiel has developed yield data to show what hardness yield and tensile can be expected from different types of metals, especially high strength, low alloy steel, copper alloys, and stainless alloys.

Cauffiel has cold rolling mills at their facility as part of their research and development to actually run a customer's product or material. This can determine for the customer if it is economically feasible to invest in a cold rolling mill.

Flexible cold rolling mills that are placed in line with existing processing lines will be common place in America as the world metals working industry of America becomes more quality conscious and competitive.

**Powdered Metals**

There are many methods of producing metal into powder. This is a technology that is becoming more common today. Some high strength, high temperature alloys are made from powder. After rolling into a strip, the powder is put through a furnace and brought up to a eutectic temperature where the chemical reaction causes the elements to mix without melting. This is why powdered metal technology can produce any type of alloy from any metal. It is impossible to mix aluminum with chrome because of the vast change in melting temperatures, but it can be done with powder. High strength gears today are made from powdered metal. Certain alloys are very difficult to mix because they do not form a chemical reaction at the melting point and can have a wide variety of melting points. As an example, aircraft landing gears can be very strong, but very light because the aluminum is mixed with chrome and other elements. The powder is mixed mechanically and taken up to a eutectic temperature where a chemical reaction between the metals can occur without making the metal into a liquid. Aluminum and chrome, as an example, form a chemical reaction and mix into a process called a sintering furnace. The part is then rolled or forged to improve its grain structure and fully tested to make a high quality part. This is very common when making parts such as gears and screw machine parts. The benefit of powdered metal is the fact that it is put into a mold, compressed, and sintered before it reaches its liquid state. This makes a very strong alloy. A considerable amount of scrap is eliminated with this process, as the parts can be molded and forged accurately to size. Titanium can be made into powder and rolled into strip to make into sheet. The sheet can be very light gauge and strong as used in bullet proof vests. In fact, thin strip can be made from powdered metal without reducing from a slab or heavy gauge coils. Many high temperature alloys are made from powdered metals.

Refer to Photos #734 and #7000, which show horizontal mills with hydraulic screwdowns for powdered metal. Once the powder is compressed, the material is put through a sintering furnace

**Plastics and Rubbers**

Many plastics and rubbers are made on a rolling mill. This is sometimes referred to as a calendar mill. Many plastics used in automotive brake pads are rolled on a rolling mill. There are many types of plastics that are rolled, such as polyurethane and polypropylene. The rubber is mixed in the rolling mill. The rubber can be pure rubber or any polyurethane type of rubber. Because polyurethane rubber can be in a non-liquid state, it is best to mix it with a rolling mill or calendar mill with many passes.

**Ceramics**

Ceramic can be used for many purposes such as corrosion resistant, high tensile products. Ceramic is made into a powder and sometimes put through a rolling mill to make a ceramic sheet or product. Ceramic can handle considerably higher temperatures than metal. Sometimes ceramic is mixed with metals and plastics where heat and strength are needed. Fiberglass plastics, as an example, are a mixture of glass fiber and plastic resin. This type of material is made in many different forms, depending upon the purpose, which could be acid resistant, heat resistant, light weight, and low cost. Many ceramics are molded, but some are put through a rolling mill to make a sheet.

Ceramic may even include pure powder carbon. Cauffiel has been successful in rolling powdered carbon for the electronic industry. Powdered carbon strip is used in electronics as a high temperature conductor of electrons. Carbon strip is rolled down to a thickness of .001” with a tolerance of ± .00008”.

**Secondary Steels and Metals**

America’s steel industry produces a vast tonnage of secondary steel. Some of this steel is off gauge or slightly off chemistry. Secondary steel can be purchased at a low price and can be cold rolled to compete with very expensive steels. Surface defect, such as coil breaks can be removed by cold rolling.

When a cold rolling mill reduces the thickness of any material, whether it is plastic or metal, the material elongates in proportion to the reduction in thickness. In other words, if the thickness is reduced by 10%, the material will grow 10% in elongation. In turn, this means the parts or product manufacturer can expect a 10% higher yield for the same amount of material before it is reduced. Ten percent more product or parts from the same material means 10% more profit.

This can be significant because, as an example, some prime hot rolled pickled and oiled steels can have a thickness tolerance of ± .004”. This means if you are purchasing steel by weight, you will probably obtain the material at the maximum thickness instead of the minimum thickness tolerance and you will produce 10% less parts or product than you would if the mill were able to hold very close minimum tolerances. This is one of the reasons why higher quality steel products obtained from some rolling mills have made great inroads into the metal working industry.

Cold rolled stainless and other expensive alloys can have a quick payback. This is because there is a wide difference between the cost of the raw material and the finished precision cold rolled product.

Cauffiel has developed many cold rolling mills that can be placed in any coil processing line. These cold rolling mills assure an exact gauge, generally with tolerances of ± .0005” in thickness, thereby reducing and elongating the material. The strip camber can be removed and edging rolls can be placed in front of the cold rolling mill to produce burr free edges or any kind of rounded edge that may be required. Also, by cold rolling, the material can be increased in yield strength and tensile strength for structural purposes such as racks and building products.

# II. PURPOSES AND PRODUCTS OF ROLLING MILLS

## Reducing Metals

Refer to Drawings #D-5757. There are many large rolling mills, including rolling mills that roll hot steel slabs 16" thick x 160" wide down to steel plate. When we think of reducing, we think of at least 20% thickness reduction per pass or many passes. In all cases, by reducing hot or cold metals, you improve its grain structure. As an example, if you start with a casting or cast slab, and reduce the casting at ambient elevated temperatures, you will improve or change the grain structure. Casting does not always have the best grain structure required for the end product. By reducing a casting, the grain structure is improved or changed. Reducing is sometimes done after the material has been annealed. The softness obtained from annealing is for a substantial reduction. Reducing can also be done to hold an accurate tolerance in thickness. As an example, steel slab up to 6" thick in any width can be reduced 4" in a single pass. This assures a good grain surface. To do this, it is necessary to have a rolling mill with a large diameter roll. With a small diameter roll, the material will slip and not move through the mill. Roll bite can be calculated with total reduction coefficient of friction between the material being rolled, the roll diameter, and other factors. When the roll bite percentage becomes too large, the roll will not create a roll bite. Roll bite is affected with coefficient of friction. Coolant can also reduce the ability of a large roll bite. Some rolls have a rough surface to assure good roll bite. Again, a large reduction is necessary on the very first pass to improve grain structure. If you only make small reductions, you are only reducing the outer surface. The center of the material does not get reduced therefore, the center or core of the material will have a defective grain structure. This is why large diameter roll 2-high mills are sometimes used for reducing thick material with a high percentage of reduction.

The first pass through the mill makes a high reduction, and the second, third, etc. pass make further reductions. Other passes are usually lighter reductions to hold accurate thicknesses or diameters, especially in the case of rod or wire.

Another purpose of reducing is to increase the hardness of the material, which changes the tensile strength and yield strength of the material. In some cases, customers want full hard material because they want the material to be strong with a minimum amount of weight. Such is the case with steel studs where the material is reduced down to .017" thick. Full hard may vary in different alloys. As an example, if you reduce AISI 1008 to full hard, you start with a yield strength of 30,000 PSI and finish at 90,000 PSI. If you full hard some carbon or stainless steels, you may start at 50,000 PSI yield strength and go to 300,000 PSI yield strength. Some spring materials are made without heat treating simply by reducing the alloy steel. Some full hard materials can be such that the yield and tensile become the same and the material will break like glass when bending. So whether you start with a cast ingot, slab, or strip to increase the grain structure, a high reduction on the first pass is required.

Aluminum foil is made consistently with an accuracy of .0002" thick. You cannot have a large variation in thickness in aluminum foil. Aluminum foil is rolled on a rolling mill generally up to 60" wide. The accuracy must not only be held in the center, but at the edges as well, in fact, throughout the entire width of the strip. Aluminum foil is rolled at speeds up to 3,000 FPM. Low carbon steels are generally made from .012" to .250" thick. With high production manufacturing with progressive dies and complicated forming operations, the next operation after rolling has to produce a consistent product. Shim stock as used in the final drive of an automobile to adjust for gear clearance, as an example, requires high precision shims of various thicknesses. There are many uses for shim stock made on a rolling mill. Such accuracy can be ± .0001". There are many uses for stainless steel that are roll formed. The thickness must be held consistent and extremely accurate, and at the same time, have a mirror type finish. Some carbon steels are reduced accurately and are chrome plated as used in household utensils.

**Reducing Coil-to-Coil**

Refer to Drawing #D-6346. Theoretically, if you create enough tension to overcome the yield strength of the material within the uncoiler and recoiler tension reels, you can reduce the thickness without a rolling mill. If you apply a rolling mill with substantial tension input and output and hold the thickness accurately, you can make substantial reductions with a minimum amount of separating force. Using a tandem mill, tension can be created in between many stands by going from the first rolling mill to the second rolling mill. Each rolling mill inline creates tension at the next mill. Tension is not only used to reduce the separating force, but it is also very important in tracking the material through the mill. Without tension, the material with not go through the rolling mill straight and true.

**Combination 4-High Insert/Cluster Mill**

Refer to Drawing #D-3899. Back up rolls can be driven, and a mill can be a combination 4-high insert/cluster mill, which can be used for temper passing using only one mill. Cluster mills can have very small diameter work rolls, say ½" to 8". However, they cannot drive the work rolls because there is not a sufficient amount of torque in such small rolls. The rolls are actually driven by the coefficient of friction between the intermediate roll and the back up roll. The recoiler tension reel helps pull the material through the rolls. Adding tension to the mill is an advantage because it reduces the separating force.

**Lubricants and Coolants**

Reducing can be done with extreme pressure lubricants at speeds over 7,000 FPM. There are many mills that run at very low speeds when reducing expensive alloys such as beryllium, copper, tantalum, and gold and use little or no lubricant or coolant. Many lubricants are good for extreme pressure, but they can also act as a coolant. Water is still considered one of the greatest liquid coolants. An extreme pressure lubricant mixed with water makes a good lubricant. All of the power that goes into reducing goes into heat. The heat goes into the strip and the rolls. Therefore, you need good coolant when reducing at continuous high rates of speed.

**Temper Pass or Skin Pass Rolling**

Refer to Photos #7022 and #7023 and Drawing #D-5190. Material can be reduced accurately while skin passing. Hot rolled steel coming from a steel mill or pickle line may need to be reduced 1% to 2% in thickness. This can be done on a coil-to-coil temper pass mill or in line on a cut-to length line. Many automobile and truck blanks made from hot rolled steel are from laser and plasma burnouts. After the material is temper passed 1% to 2% and leveled on a backed up corrective leveler, the material will lay out flat and hold flat after plasma or laser cutting. It is important to have the skin passed material delivered to the laser or plasma burnout operation because while it is cutting, the material will not bend upward and destroy the plasma torch or laser head during high-speed cutting.

A temper mill is also used to make cold rolled after annealing to assure a consistent quality. After the material is made hot rolled, it needs to be pickled and cold reduced. Cold reducing increases the yield strength and the material can be too hard to be used for any type of deep draw work or accurate bending. Therefore, most cold rolled after reducing must be annealed. The annealed product can be too soft for the next operation. Above all, when uncoiling without tension, very soft material such as AISI 1008 can create coil breaks.

Temper passing or skin passing material will eliminate coil breaks (hairline wrinkles in the surface of the soft metal). Once there are wrinkles in the material, they are difficult to remove. Skin passing eliminates wrinkles or coil breaks. Coil breaks can show up on low carbon, hot rolled, as well as any soft material. When you skin pass, you are only increasing the yield strength of the surface. You have not changed the physical properties inside of the core of the metal. Skin passing can be done on any alloy carbon steel including aluminum. Skin passing and temper passing improves shape as well. Once steel is annealed, distortion can be a problem. Many steel coils are substantially improved by skin passing. Skin passing can also improve surface finish and accuracy. Some materials have very close tolerances of ± .0002". The final pass may be considered a skin pass to hold the tolerance of precision cold rolled material.

**Stand-Alone Rolling Mills**

Refer to Photos #742 and Drawing #D-6123. There are many different sizes and types of stand-alone rolling mills. They can be 2-high or 4-high. They can be used for large reductions or skin passing a single piece, strip, or plate. Stand-alone rolling mills can reduce expensive exotic alloys that cost more than the price of gold. These are used in the electronics industry for making what is called targets. Targets go into a sputtering machine for applying metal onto a surface with extreme accuracy. In fact, many targets are used to apply metal onto plastics such as the silver lining in potato chip bags to keep the potato chips fresh. Many unusual shapes can be made with a stand-alone rolling mill. In fact, in developing countries, many aluminum slabs are cast, and the material is reduced in a stand-alone rolling mill to produce aluminum sheet for cooking utensils. This process takes a substantial amount of labor. Many plate mills are stand-alone. Hot steel can be in slab form and reduced to plate. This is sometimes done on a revering basis with passes going back and forth with roller tables to allow for substantial reductions.

Rubber and certain plastics are made on a stand-alone rolling mill. Sometimes these are referred to as calendar mills. Many unusual plastics, such as brake linings, are made on stand-alone rolling mills. Expensive alloys, such as gold, silver, tantalum, and niobium, are made on stand-alone rolling mills.

**Cladding**

Refer to Photo #760 and Drawing #D-3941. Cladding is a method of fusing different metals into a strip. Thermostats are made with a cladded material of different coefficient of expansion. By cladding copper and steel together, the changing temperature makes the product bend to operate electrical contacts. The temperature range can be adjusted such as a thermostat.

Certain vessels require food to all be within stainless steel. When cooking in large high pressure vessels, it is necessary to have a high pressure, safe vessel to withstand substantial pressure with large safety factors therefore, the inside walls are made of stainless. The outer walls of a vessel are made of heavy carbon steel. Carbon steel can be heavy in thickness because it is easy to weld and assures a good bond for possible high pressures. The vessel is made from cladded plate,

Cladding can be copper to plastic, such as used in printed circuits. One purpose for cladded material is main bearings and connecting rod bearings for gasoline and diesel engines. Bearing material used to be Babbitt, which is a lead alloy. Babbitt was fused to the steel as an insert. Babbitt, being soft and with proper lubrication, made a good bearing however, lead is not good for the environment and better material is now used, including aluminum tin copper alloys. This soft alloy needs to be cladded to the steel. To fuse this material to steel, you need a cladding process developed by Cauffiel Corporation, Toledo, Ohio. Many types of bearings have been developed using rolling mills.

**Embossing**

Many architectural materials are embossed for beauty and appearance. Metals can be embossed and painted to look like wood. The inside of an elevator has embossed material. Some cold rolled is rolled with a satin finish so that it has more area to fuse to the paint or galvanized surface. Spiral grooves are embossed on the inside of copper tubes as used in air conditioning and refrigeration. There are spiral grooves on the inside of some boilers and heat exchangers. This allows the area within the tube to be substantially increased in area, and at the same time, creates turbulence to improve the boiler or heat exchanger without increasing the cost of the metal. It also reduces the cost and size of the boilers or heat exchangers.

Any unusual embossed design can be performed on a rolling mill with enough separating force to create the embossed area. In fact, there are hand crank machines that take a penny and emboss a message on it. Embossing can produce a surface that will not stain and is easy to clean. Embossing improves the appearance of the material in some instances. Again, embossing improves the surface area of the material, which can allow for more transfer of heat per square area.

### Modifying the Surface of Any Metal

Some aluminum or stainless products, such as concentrated solar collectors, require a mirror finish, reflective surface. If the rolling mill roll is polished, high chrome surface, the roll will develop the same polished surface. The rolls need to be kept absolutely clean, and as with many rolling mills, the rolls are constantly cleaned while they are rotating. Cleaning rolls is sometimes done with a 3M Scotch-Brite™ abrasive product. Many of these brushes are mounted in a rotating type shaft covering the full width of the work roll and the back up roll.

### Concrete Rebar and Embossed and Slit Flat Bar

Rod and wire require an unusual surface so concrete fuses well to it. This increases the tensile strength of the concrete to prevent cracks. Special embossed rod and wire, including stainless and carbon steel can be used for concrete. Any embossed flat bar or slit wire can be used instead of rebar. Much wire and rebar is held in tension while the concrete sets. This is known as precast concrete. Slit flat bar is embossed cold and used in concrete in developing countries.

### Expanded Metals

Expanded metal is used primarily for grating, filtration media, and fencing. Carbon and stainless steels can be perforated with holes or expanded to a diamond shaped pattern, which reduces the surface area. When an expanded metal is made, it is sometimes skin passed, which removes any burrs from elongation process. It also improves the expanded metal characteristics because with a slight reduction in the thickness of the metal, you increase the yield strength and make the material stronger.

### Tapered Rolling

Another purpose of reducing is to make tapered material. As an example, knives are made from high carbon steel that is heated up red hot and reduced from a thickness of approximately 3/16” to 1/16” by 10” to 48” long.

Why is your golf club shaft tapered? Why is a knife thick at the handle and thin at the end? Why are aircraft parts made with one side thicker than the other? Such tapered rolling is becoming more common. Shapes need to be high strength and flexible to keep the overall weight to a minimum. Tapered rolling is done with mechanical or hydraulic screwdowns. The work rolls are adjusted automatically with an encoder from the rotation of the work rolls. Almost any taper, form, or irregular shape can be rolled on this type of special rolling mill. Tapered rolling mills can be a 2-high or 4-high configuration, depending upon the separating force and other factors to determine the best possible design.

## III. CONFIGURATIONS AND TYPES OF ROLLING MILLS

### 2-High Rolling Mills

Refer to Drawings #D-5757 and #D-5881. Two-high rolling mills have a unique advantage in cost savings because a 2-high configuration is less expensive to manufacture. A 2-high mill can be any size. Large rolling mills, similar to photo left, are used for skin passing with small reductions of 1% to 2%. Since the material is not always uniform across the width, a 2-high rolling mill can be equipped with roll bend. Roll bend uses bearings located outside of the main bearings that actually bend the rolls to compensate for the various thicknesses across the width of the material. Two-high mills can be equipped with automatic gauge control or automatic shape control using heat or coolant for thermal expansion to assure a uniform rolled shape on a continuous basis, generally with cold rolling. With hot rolling, 2-high rolling mills have an advantage over 4-high rolling mills because the rolls are self-cleaning, and the work rolls do not need to be replaced as often as they do in a 4-high mill. In any event, the rolls can be pushed out from the side of the mill and quickly changed with new rolls.

Two-high mills are used in pickle lines, galvanizing lines, and skin pass mills. The large diameter rolls allow for a large roll bite. This means the material can be soft, such as hot steel that can be reduced from slab to plate in a single pass with large reductions. This cannot be done with small diameter rolls. This is why 2-high mills are used in the rubber and plastic industries. They are also used to improve the shape of expanded metal or perforated metal. A 2-high mill can make a slight reduction and lay the material out flat and uniform. The photo right shows a 2-high rolling mill used for skin passing and reducing soft materials such as lead and copper. A disadvantage of 2-high rolling mills is the fact that the rolls are large in diameter giving you limited reduction. This is because of the roll flattening affect. This is when the actual diameter of the roll changes its shape under separating pressure, and the area being reduced under the roll becomes quite large.

### 4-High Rolling Mills

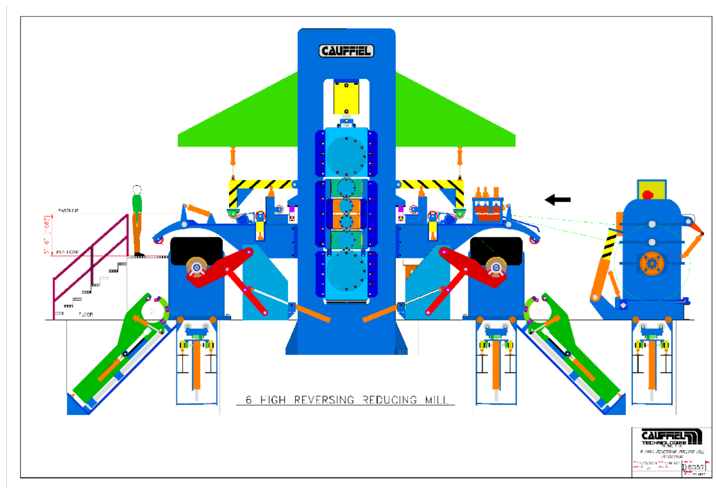
Refer to Drawing #D-6346. A 4-high rolling mill can be a small mill similar to Photo #731 or a stand-alone, high torque, high reduction mill similar to Photo #742. A typical reversing mill is similar to Photo #7021, which has a quick change roll system. Four-high mills can be equipped with roll bend and shape control, similar to Photo #788 for rolling a precision consistent product. Old 4-high cold rolling mills can be upgraded similar to Photo #789. Four-high rolling mills can be put in tandem, two to seven stands, instead of a reversing mill. They can be equipped with load cells to tell the separating force and hydraulic or mechanical screwdowns, depending if it is hot or cold rolling. Sometimes mechanical screwdowns are preferred when there is a risk of fire. Most rolling mills today are equipped with hydraulic screwdowns with automatic thickness or gauge control. They can be equipped with positive and negative roll bend and used to make a very precision rolled product, especially across the width to eliminate center buckle or stretched edges. They can also be equipped with exit passline rolls with load cells to control tension so that the coil is made with uniform tension throughout. The biggest advantage of a 4-high mill is that the work roll can be large or small in diameter and allow for substantial reduction because the area under the roll is substantially reduced.

The work rolls can be large in diameter which allows large spindles and universals or flex couplings to transfer substantial torque into the work roll. They can also be equipped with dual motor drives so that one work roll can be ground a little different in diameter than the opposing work roll. This is becoming common whether a 2-high, 4-high, 6-high, or cluster mill. Before dual motor drives, rolls had to be ground the same diameter. If one roll needs to be ground, the opposing roll must be ground at the same diameter. Four-high mills are very common for steel, aluminum, copper, and any high production metal rolling.

One disadvantage of a 4-high mill is that the edges of the material tend to elongate. There is no supporting surface at the edges. Even though the roll is equipped with roll bend, a complicated roll shape may be necessary to eliminate elongation of rolling the edges to make a uniform thickness across the width of the strip.

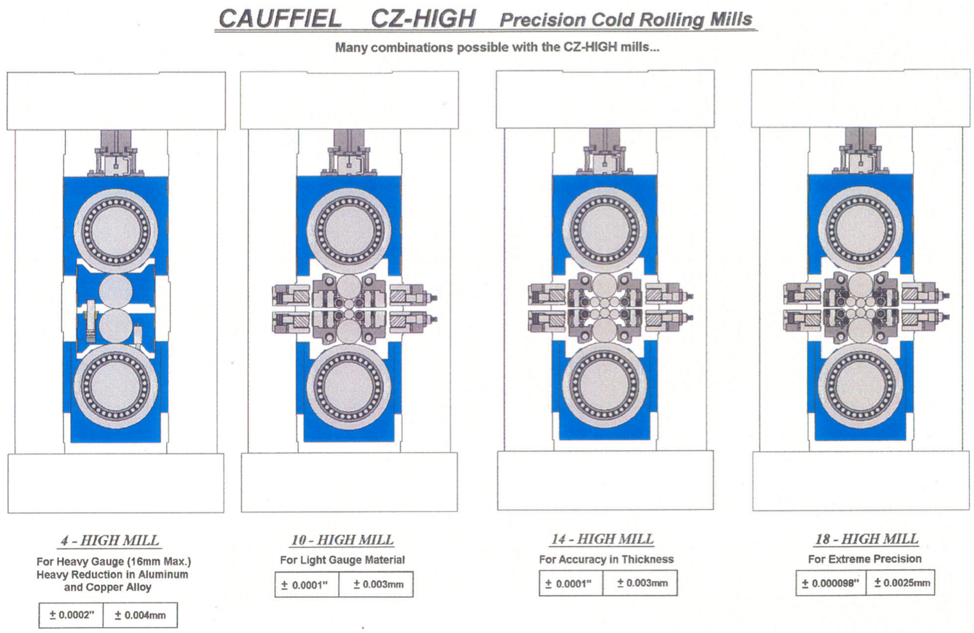
**6-High Rolling Mills**

Six-high rolling mills are the similar to 4-high rolling mills however, they have work rolls, intermediate rolls, and back up rolls. Refer to Drawings #D-6348 and #D-6357 (below), which shows a 6-high reversing mill for rolling light gauge steel. The intermediate rolls can be adjusted horizontally to prevent edge drop, which means the edge become lighter in thickness because there is no support at the edge. The rolls can be ground to an hourglass shape. A 6-high mill also allows for substantial roll shape, depending upon the horizontal movement of the rolls. Another advantage of a 6-high mill is a larger work roll which can transmit considerable torque and allow for high speeds up to 7,000 FPM. Large diameter, light gauge coils can have thousands of lineal feet, and unless the speeds are substantial, (4,000 to 7,000 FPM), the cost of making the material is substantial. Also, the larger rolls allow for heat transfer so the temperature is held with or without thermal change at these high speeds. Roll bend can also be provided in a 6-high mill. These mills can be pinion stand or dual motor driven. Six-high rolling mills are equipped with hydraulic screwdowns, automatic shape control, and automatic gauge control.




**Cluster Mills**

Refer to Photo #715 below. Cluster mills can be 10-high, 14-high, or 18-high. In all cases, cluster mills are designed to reduce stainless or high carbon, high strength alloy steels, or any material when reducing increases the yield strength. Cluster mills have the advantage of running very light gauges under precision tolerances. As an example, a Cauffiel 18-high rolling mill is used for running high carbon alloys at an accuracy of ± .00098” ( ± 0.00025mm) at speeds up to 1,000 FPM. A 10-high mill can have a much larger work roll, as it has the advantage of a cooling affect, which means you can run at speeds up to 2,500 FPM with reductions of 50% per pass on low carbon steels. Cluster mills are also less expensive than 18-high and 14-high mills. See illustration below showing typical cluster mills.




In all cases, one of the main advantages of a cluster mill is the large back up rolls. The back up rolls act as a heat sink because there is a considerable amount of heat energy going into the strip and the work roll. Much of the heat in the work roll is transferred to the back up roll. Having a large diameter back up roll allows the mill to run at high rates of speed compared to an old 20-high mill. To do high reductions on high carbon or stainless steel alloys up to 50% in a single pass, considerable tension can be required. This also reduces the amount of energy that the rolling mill itself has to perform. To wind such high tensions, the tension reel sometimes has a solid alloy drum with only a gripper slot. When winding under high tension, the endward radial forces on the drum are extremely high with each wrap and any type of mechanical wedge system becomes complicated and expensive. Many warp radial forces add up so large that the coil can buckle on the inner wrap after removal. This is referred to as a "mouse affect". When this happens, it is very difficult to position the coil onto the next operation such as the uncoiler. Normally, when this happens, the coil is left on the solid drum and transferred to the next operation where it is uncoiled and put through a tension stand and recoiled under a lighter tension for slitting or annealing. Also, when you anneal a coil that is wound under considerable tension, you get all types of distortion, such as stretched edges, center buckle, etc. It is best to recoil under light tension before annealing.

The same is true at the uncoiler section to assure consistent tension. Sometimes you need to uncoil a coil onto a drum which can be transferred to the uncoiler tension reel area. Uncoiling going into the rolling mill is wound with tension so that the coil will not slip on itself which causes scratching. Scratch marks may not come out during reducing. Therefore, the coil must be made under tension before uncoiling for high reduction rolling.

Another method for reducing tension at the recoiler is to put in a tension level line. On narrow mills running high quality, high strength, high carbon and stainless alloys, you may need to make a high reduction in a single pass with low tension to the final recoiler tension reel. If this is the case, you may want to consider putting in a tension level system. This assures substantial tension from the rolling mill and delivers light tension to the recoiler tension reel to prepare the coil for the next operation. This also removes stretched edges and center buckle to assure a high quality, consistent product. A tension level system normally has two entrance rolls and two exit rolls with staggered rolls to elongate the strip. The exit rolls must run to accommodate the percentage of elongation. In other words, if the elongation is 2%, the exit roll must run at least 2% higher peripheral speed than the entrance rolls.

To reduce high carbon and stainless steels, annealing is required because the material can start at 50,000 PSI and go to 300,000 PSI. Once the material reaches 300,000 PSI yield strength, additional reducing becomes very difficult. Therefore, it is best to anneal and reduce again. Annealing is also a way to satisfy the customer's requirements as sometimes they require, as an example, a consistent 50,000 or 80,000 PSI yield strength and annealing must be carefully controlled in an atmospheric furnace.

Sometimes extortion exists after a coil is annealed when the surface of the steel is soft. With low carbon steels, if the material is extremely soft when uncoiling with little tension, cross breaks occur (wrinkles). Cross breaks are very common on low carbon steels, but can occur with any metal. This can be a rejection by the customer because the cross breaks come through a painted surface. On both sides of the rolling mill are polyurethane bridle rolls. This allows substantial tension at the rolling mill and yet delivers low tension to the recoiler. This means the coil will be wound under the exact required low tension. Bridle rolls in a rolling mill are becoming more common to control tension at the final tension reel or recoiler.

**3-High Rolling Mill**

Refer to Photos #7009 and #7010. Three-high rolling mills consist of a large back up roll, small work roll, and another large back up roll. The purpose is to have a very minimum amount of reduction. Three-high mills are commonly used for making bearing material for gasoline and diesel engines (see cladding).

Three-high rolling mills are also used to reduce costs for high reductions for expanded metals because large roll bend is possible with one of the work rolls. Three-high mills can also be used as a low cost skin pass mill and put into a cut-to-length or slitting line.

# IV. ADVANCED ROLLING MILL TECHNOLOGY

### AC Variable Frequency Drives

The latest technology in electrical is AC variable frequency drives. AC variable frequency drives vary in horsepower from 1 to 10,000. AC variable frequency drives are energy efficient. They only use the amount of electrical energy required for the job. In rolling mills, it is very common to use a fraction of the horsepower that is available. By having an energy efficient AC variable frequency drive, you only use the energy that is needed at the time. Of course, you can vary the torque on the drive at the control console or main control cubical. Sometimes very little torque is required for a large drive during feed up or light reduction. The main advantage of an AC variable frequency drive is that the motors are enclosed. Large motors can be water cooled. Another advantage is that you can vary the speed. The speed and torque can be automatically controlled. AC variable frequency drives can have a substantial amount of safety features and many drives can withstand overloads up to 100% for a period of time. While the motors are inexpensive, compared to old DC motors, the drive itself is more expensive, but of course, this technology is improving with cost and quality every day. One of the costs overlooked in AC variable frequency drives is regeneration. For a rolling mill to be efficient, the uncoiler tension reel's large motors may act as a brake, and the recoiler tension reel is under substantial tension. Therefore, it is best to take the energy generated from the uncoiler to the recoiler. This saves a substantial amount of electrical energy. However, this becomes more complicated than an AC to DC drive. Another disadvantage of an AC variable frequency drive is it does not have the ability to stop quickly. Rolling mills have a tremendous amount of kinetic energy, and to stop the mill quickly, in the event of an accident or strip breakage, it is best to have a regenerative system to bring the equipment to a stop quickly. This means you must have substantial expensive resistors and electronics in the drive system.

### DC Motors and AC to DC Drives

DC motors can do everything AC drives can do, however, the disadvantage of a DC motor is that it requires brushes and these types of motors are open and require some maintenance. Rolling mills usually run around the clock, and DC motors may cause downtime and are expensive to maintain such as the continuous need to be machined, and of course, the brushes wear. However, the amount of maintenance on a DC motor, if maintained properly, can be infinitesimal.

An advantage of an AC to DC drive or rectifier is the cost. Drives can be upgraded utilizing older DC motors. The rectifier system from AC to DC has substantially reduced in cost, and the drive itself is usually less expensive than an AC variable frequency drive. Another advantage of a DC drive is that it can be regeneration. The uncoiler or tension reel can generate a substantial amount of electrical power that can be put back into the machinery so the electrical power generated by the uncoiler tension reel can be utilized at the recoiler tension reel. Another advantage is that DC drives do not require large resistors or sometimes no resistors depending upon the electrical utility. This is because the breaking system on a DC drive can go into the electrical utility for regeneration quickly and bring the drive down to stop quickly without resistors.

Many mills and components still prefer DC variable speed, variable torque drives. These are energy efficient as they only require the amount of energy required to do the work. If a motor has 5,000 HP and only 1,000 HP is needed to do the final pass, it will only use 1,000 HP.

Another benefit of modern electronic DC technology is the fact that you eliminate many relays and expensive conduit and wiring, as controls can be sent from the control console to the motor through small cables instead of a hundreds of wires.

All new variable speed drives can be controlled through Human Machine Interface (HMI) touchscreen controls. Electrical controls and circuits to a rolling mill require experienced rolling mill electrical engineers to design a system based on information obtained from an experienced rolling mill engineer. Of course, speed, tension, thickness, lineal feet, part number, run time, roll replacement/change and any variable involved can be put into a modern HMI touchscreen.

**Mechanical Screwdowns**

Mechanical screwdowns are still used for small mill reducing and large mills for cogging and hot plate reducing where accuracy is not a precision factor, and where fire may be a concern. However, hydraulics can now be water hydraulics. By adding chemicals in the water, you have a hydraulic system that will not catch fire. However, water hydraulics require limited low pressure, and they are high in maintenance and many customers still prefer mechanical screwdowns. Mechanical screwdowns consist of a gear reducer and screw to control the roll gap and withstand the separating forces required in a rolling mill.

**Hydraulic Screwdowns**

Practically all new rolling mills today are equipped with hydraulic screwdowns for hot or cold rolling. A disadvantage of mechanical screwdowns is the fact that you cannot adjust accurately while the screwdowns are under pressure. When you want to move upward with a roll gap, you always have some mechanical backlash. Even though you can measure the roll gap, the backlash is still there and the roll gap can drift. To accomplish this, the operators or machine normally make some adjustment and then come back down again with mechanical screwdowns. Hydraulic screwdowns eliminate this. There is no backlash with hydraulic screwdowns. Cylinders can be almost any size necessary to create separating forces for the rolling mill. At the hydraulic cylinder are servo valves. The invention of a servo valve was to quickly operate a torpedo toward the direction of the ship. Hydraulic servo valves can allow a drop of oil to move the screwdowns, or if necessary, put in large quantities of oil to position the screwdowns quickly. The screwdowns can be operated with the automatic gauge control system. Hydraulic screwdowns are powered with a hydraulic pump and tank unit. The pump is usually a pressure compensated pump. The pressure is held at all times into an accumulator so that the hydraulic pressure is ready to go to put one drop or a large quantity of oil into the hydraulic cylinders. The hydraulic cylinders have an encoder to measure with each movement of the hydraulic cylinder, usually .0001”. Some encoders are inside the hydraulic cylinder and some are located outside of the hydraulic cylinder. The encoder tells the position of the cylinder or the roll gap. The usual pressure is a maximum 4,500 PSI. Usually precision screwdowns work best at higher pressures between 3,000 and 5,000 PSI. New servo valve technology is being developed to operate at up to 10,000 PSI. Movement in the cylinder is done within milliseconds so that the strip coming out of the rolling mill has uniform thickness with closed loop electronics.

**Automatic Gauge Control (AGC) and Direct Gap Control (DGC)**

In older rolling mills, a flying micrometer was used for gauge control. A flying micrometer is rollers in a C-frame. The rollers operate an encoder, which tells the position of the gap between two rollers. The micrometer is held perpendicular to the surface of the moving strip. This is called a mechanical gauge. Advancements have been made in this gauge. Instead of using rollers with bearings, it can be a diamond assembly with very little air pressure to measure the thickness. The diamond assemblies are equipped with encoders and located on both sides of the strip so that if you have strip vibration, you are still measuring the thickness of the strip. These mechanical gauges are always on a C-frame and can be removed on a slide during threading. The strip can be inserted into the rolling mill and positioned. The diamond does not require considerable maintenance as it is under very little pressure. Mechanical gauges are not good for polished material because they can leave a slight line on the surface. An advantage of a mechanical C-frame gauge is the fact that you don’t need to make any adjustments if you are running brass, copper, stainless steel, or steel. If you use a radiation gauge or an x-ray gauge, they may need to be recalibrated for each type of material. In fact, radiation gauge measurement can change from one carbon steel to another. Mechanical measuring of a moving strip has many advantages. It also eliminates the fear of the operator of being around x-ray gauges.

Direct gap control actually measures the distance between the roll gap. Even though the rolls are perfectly concentric, the large back up bearings can be slightly eccentric, and the roll can runout over .001”. With every revolution, there can be a change in thickness of .001” therefore, direct gap control is necessary. If the bearing or roll is not concentric, say .001”, the automatic screwdowns with direct gap control can make this correction. Eccentricity may not be from roll grind, but from the bearings themselves. Direct gap control can hold tolerances to ± .0005” with a very simple gauge system.

Mechanical or non-contact radiation gauges, such as gamma or x-ray gauges, are usually located on the entrance and exit sides of the rolling mill. When the strip needs a change in input thickness, it automatically, in microseconds, depending on line speed, adjusts the rolling mill so that a uniform thickness is on the output side. The output side sometimes checks with the direct gap control gauge to assure thickness. At all times, the non-contact gauges are perpendicular to the strip.

To start measuring before rolling is referred to as anticipatory automatic gauge control. When speeds are moving at over 1,000 FPM, adjustments are made in microseconds. In all cases, all of these gauges can be used to operate the hydraulic screwdowns. Again, the benefit of hydraulic screwdowns is that the cylinder can move upward or downward in microseconds.

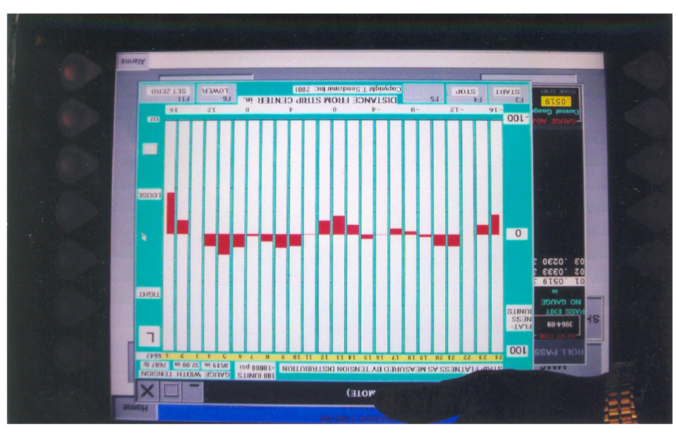
The latest non-contact gauges have been developed by Cauffiel using laser technology. They can measure moving aluminum or steel strip at any speed without contact. This new proprietary development is in used today.

**Roll Bend**

As you look at Photo #7022, you will see a method of bending the rolls from the outside of the rolling mill. This is a separate bearing block with hydraulics located between the bearing blocks to actually bend large diameter rolls. This is very common on 2-high and 4-high mills. Depending upon the amount of reduction, rolls are already crowned to take care of some deflection of the roll. Roll bend is used to adjust the roll shape and can be positive concave or negative convex to remove center buckle or stretched edges. Sometimes, roll bend is accomplished with hydraulic cylinders that are offset with the main centerline bearings, which allows the roll to bend one way or the other, usually with hydraulic cylinders located within the bearing blocks or chocks. Small hydraulic cylinders can operate at pressures up to 10,000 PSI to bend the rolls.

**Shape Control**

Looking at the screen right, you can see there is a shape coming out of the exit side of the mill Shape may include stretched edges or center buckle. The operator can see this when operating the mill. Many shape controls are adjusted by the operator at speeds up to 7,000 FPM. Instead of having gauges across the width of the strip, say every 2”, to measure the difference in thickness, you really want to measure the tension across the width of the strip. If you have an elongated edge, you will see a wave. If you see an elongated center, you will see center buckle. The operator needs to make adjustments accordingly. He first may adjust for roll bend. When you run very light gauges, roll bend is not satisfactory because you need to get a finer measurement than roll bend. Instead, the shape is controlled with coolant.



Coolant nozzles with valves are placed approximately every 2” across the width of the work roll or back up roll or both. If there is a wavy center, it means that the center is expanding and more coolant is applied in the center. This allows the roll to change its shape by thermal expansion. The roll can actually change its shape anywhere along the surface of the roll with coolant. Instead of observation of the outgoing shape by the operator, it can be done with a shape roll. Shape rolls are usually a series of rollers that measure the deflection across the width of the strip. These rollers are air actuated and each shape roll can be every 2”. If the shape roll detects center buckle or stretched edges, it deflects the strip under tension and is measured accordingly. This gives a reading on the screen as shown above. Some shape rolls use a common shaft with rolls every 2” using air bearings. As the roll is under pressure, air is measured under each air bearing and gives a reading every 2” across the width of the strip. All shape rolling can be done by observation or automatically. An automatic shape roll system is very expensive because it needs to operate the nozzles to change the shape of the rolls at any speed. The air for the air bearings must be highly filtered for this purpose.

**Automation for Reverse Mill Rolling**

Refer to Drawing #D-6357. A pit type coil car receives coils from the rack over a pit. The coil car places the coil onto the single-end hydraulic expanding mandrel uncoiler. The uncoiler is equipped with an electric motor regenerative brake or a water cooled brake system. The uncoiler has a hold down roll and peeler blade that is adjustable up/down and in/out to thread the coil to the flattener pinch rolls.

The flattener with pinch rolls flattens the material. Only the top rolls in the flattener are driven, and the lower rolls spin freely. The material is fed through the pinch rolls of the flattener, across the breaker roll, across the shape roll, through the crop shear, and across an apron through the work rolls. As soon as the material is through the work rolls, the work rolls can come down to take a small reduction.

The material passes through the rolling mill, across an exit apron, through the exit crop shear, shape roll, breaker roll, and is positioned downward onto the drum.

A belt wrapper is used to quickly thread the material around the drum of the recoiler. Once it is threaded on recoiler drum, the outboard hydraulic support can be positioned to assure that the recoiler tension reel does not deflect regardless of tension or coil weight. After a few wraps around the drum, the belt wrapper backs away from the recoiler tension reel, and the mill is now ready to uncoil the coil through the rolling mill onto the other recoiler tension reel at the first pass. Once the tail of the coil is almost through the end of the rolling mill, the material can be put in reverse to the other recoiler tension reel with outboard support. A deep reduction can now be made, one tension reel acting as an uncoiler and one acting as a recoiler. The material goes back and forth two to five times depending upon the amount of reduction with each pass. The coil can be removed from either tension reel by way of the pit type coil car.

As you can see, an operator needs to be equipped with considerable high technology electronics and data recorder for each coil number, each pass, including time for threading, separating force, reduction of each pass, line speed, incoming and outgoing strip tension, and any comments. Also, maintenance schedule and unusual problems with material such as surface finish, coil removal, and reason for downtime should be included.

Modern rolling mills have many hydraulic cylinders, small AC gear motors, modern solenoid valves, flow control valves, heavy pipe, compressed fittings to prevent hydraulic oil from mixing with coolant, and many hydraulic pump and tank units with heat exchangers to assure consistent temperature to assure a minimum of thermal expansion which can cause leaks. All functions can be observed at the control console.

### Coolants

There are many types of coolants. Water is a good coolant, but is a poor lubricant. By adding extreme pressure soluble oil to water, you can have a very good coolant. However, this type of coolant can leave stains on the strip, which is not acceptable for many products. It is best to use a coolant that will not burn. It is very common to use an extreme pressure oil like gear lube on low speed mills. Kerosene mixtures are very common for aluminum because they make a beautiful product without stains. However, a water based lubricant is still used for aluminum rolling. The problem with kerosene lubricants is the possibility of a fire. Aluminum rolling mills are equipped with many $CO_2$ automatic valves. With rolling mills that run aluminum at high speeds, a bearing or friction could cause a spark and start a fire. When you use a kerosene based lubricant, it is very common to use a good $CO_2$ system. There are many different types of coolants with product mix. A good coolant lubrication system uses a good filter system and heat exchangers to keep the coolant temperature constant. Certain products that are cladded, require little or no coolant, especially with stand alone, high reduction rolling mills or rolling mills that are in a continuous casting line.

### Coolant Fume Control

Refer to photo right. With a special type hood, the coolant fumes are used to produce a high velocity of fume input to withdraw all of the fumes into the hood. The material is sent from the hood through a large fan that extracts the fumes. The fumes go through a scrubber system so the oil vapor or fumes do not go into the environment. You will notice these mills are totally enclosed to prevent fumes from going into the factory. All good fume systems require a large vacuum fan and scrubber system.

### Dual Motor Drives

The main advantage of a dual motor drive is that each work roll is individually driven. If one roll gets damaged and needs to be ground down, the other roll does not have to be ground down to the same diameter. This allows each motor drive to compensate for the different diameters. If they are geared together in a pinion stand with one motor, and one roll is damaged, both rolls must be ground down to the same diameter; otherwise, one roll will rotate faster than the other. This is a big advantage because rolls that have to be ground in pairs increase the maintenance cost. Also, with a pinion stand, if the roll sets get mixed up in inventory, you will have a different peripheral speed and this creates a tremendous load on the universals or spindles and gears.

### Housings

Housings can be made from forged steel and 100% welded. Housings can be made quickly without waiting for patterns and castings. Many old cast iron housings were extremely heavy, as they were not forged, and due to inherent imperfections during the casting process, had to be twice as large as a superior forged housing. The housings had to be made very heavy because of the possibility of cracking. This is very common with large cast housing. In my 60 years of building rolling mills, I have never heard of a cast housing breaking. The stresses the housings are under are extremely low, especially on older rolling mills. Also, old mills did not have automatic gauge control. They tried to make the housings extremely stiff to prevent elongation to get a uniform thickness coming out of the rolling mill. Older rolling mills have mechanical screwdowns where today we use hydraulic screwdowns. Customers don't insist on heavy housings, but Cauffiel makes the housing extremely heavy to impress the customer because steel is not a large cost in a rolling mill.

## Roll Removal

Refer to Photo #7021. All modern rolling mills have to be able to remove the rolls quickly, especially the work rolls. The work rolls wear and get damaged from time to time.

A shuttle table is used to remove the rolls. One set of rolls can be positioned on a shuttle table while another set is being removed. Once the rolls are removed from the mill and put onto the shuttle table, the shuttle table moves over and new rolls can be inserted into the rolling mill. This is accomplished with hydraulic cylinders and spindle clamps located on the rear of the rolling mill.

Before removing the rolls, spindle clamps located on the rear of the mill are used to clamp the universals or spindles accurately so when new rolls are put back in they line up perfectly with the spindles. Spindles can be spherical gear type enclosed in grease or they can be large, forged "U" type universals. Many older rolling mills have a four-leaf design, which make noise when the rolling mill is running, especially at low speeds. Refer to Photo #3004.

## Load Cells

Load cells are positioned between the hydraulic cylinder top chocks. Load cells not only tell the operator what the separating force is at each pass, but they can be automatically applied to control the hydraulic pressure accurately for skin pass rolling.

Above all, load cells allow for quick set up. Without strip going through the rolling mill, the rolls can be brought together and by simply pushing a button, the rolling mill is zeroed in. Load cells are also used to accurately control tension at any speed. Load cells are placed in passline roll housings. This system is more consistent than using torque at the tension reels.

## Special Mills and Features

Refer to Photo #7010. Expanded metal is a common product throughout the world and much expanded metal goes through a rolling mill. These are normally very large 2-high or 4-high rolling mills that are very expensive. The top two rolls is where the reduction is taking place. This mill has only 16" diameter rolls. The lower roll has a sizeable crown with hydraulic cylinders that allows the center rolls to bend substantially when under load. The top and bottom rolls are bending, but the material is a chrome moly alloy steel. The rolls bend safety at no more than 15,000 PSI. The expanded metal goes through the rolling mill flat and level with a slight crown of 1/16" across the width.

Two-high rolling mills with water hydraulic screwdowns are used in aluminum continuous casting lines. The mill can be placed at an angle, which allows the liquid aluminum to be placed in front of the rolling mill. The rolls are generally large in diameter and water cooled to cool the aluminum as it is made into a thick strip. A cast aluminum coil is then placed onto a separate reducing mill to make the light gauges. Aluminum continuous casting lines can be made any width and any thickness. The material is blanked into small diameters and used to make small aluminum cups and containers. Aluminum beer bottles are extruded from cast and reduced in line on an aluminum continuous casting line.

## Rolling Mill Rolls

The work rolls in a rolling mill are essential to high quality, consistent rolling. These rolls are engineered by Cauffiel and always made by America's leading roll manufacturer. The alloy forgings and heat treating of the roll is extremely important. As an example, the work rolls can be very hard, up to 65 RC or less, and the back up rolls are always softer say 55 RC to flex under pressure without breakout. All rolls purchased by Cauffiel are made from alloy forged steel. They are high carbon, high chrome with other elements.

Another factor that affects the cold rolling is the steels involved in the rolls themselves. Steel is considered one of the finest grades of tool steel for all around hardness, wear and shock resistant characteristics. Cauffiel's rolls can be better than tool steel rolls, which out last most, rolls and allows for a longer period of time between grinding.

Many rolls today are made from powdered metal and forged. To reduce high yield material, carbide is used because they do not wear or break down. The journal on high torque work rolls are heat treated tough and do not break under high torque or possible shock.

**Rolling Mill Aprons**

Refer to Drawing #D-6123. All rolling mills should be equipped with an apron to feed and receive the part or strip. Photo #740 shows a stand-alone 4-high rolling mill feeding material. The material can be niobium, tantalum, titanium, or aluminum. These rolling mills require very large separating forces and an apron to feed and receive the small pieces at the passline of the rolls. These high strength aprons are equipped with heavy duty rolls to withstand substantial downward forces in the event the small pieces come through slightly bent. Even with coil-to-coil rolling mill lines, aprons are necessary to assure hands off threading. The important aspect of an apron is that it needs to be quickly removed to eject the rolls from the rolling mill.

**High Torque Spindles**

Refer to Photo #742. This is a typical lubricated gear type universals or spindles. The spindles must be able to withstand large torque to drive the work roll for heavy reductions. Spindles can be made to handle large torque at any speed. Some spindles use large forged "U" joints similar to small truck universals

**Slab to Recoiling (Steckel Mills)**

Refer to Photo #799, which shows a 4-high rolling mill with tables and recoiler. This rolling mill is used to make products for the computer industry. Thick slabs can be rolled back and forth on the table with the rolling mill. The material can then be rolled on a coil-to-coil rolling mill. This can be done with large mills, hot or cold, called Steckel mills. Sometimes hot rolling requires the recoiler to be placed in a furnace. This can be doing for high temperature stainless or carbon steel when hot rolling is necessary.

**Tension Reel Drums**

Refer to Drawing #C-2727. This shows a narrow mill running high strength stainless steel that must be wound under considerable tension at the rolling mill. Solid drums are used in this instance. The coil is removed from the solid drum and to the recoiler so that controlled tension can be made at the finished coil ready for the customer or for annealing. The front side of the mill shows a typical cluster mill with very small work rolls with adjustable intermediate rolls.

**Edging Lines**

Rolling mills can be used for reducing edged material. Such a round edge is used to make lawnmower blades and many other products that require a burr free flat bar. Coil-to-coil edging can be done in many rolling mills.

## Anticipatory Automatic Gauge Control

Refer to Photo #711. This shows a very accurate output thickness (red) even though the input thickness (blue) varies substantially. Precision measuring normally requires an entrance gauge, which records the thickness of the material going into the rolling mill. This is referred to as anticipatory automatic gauge control. The entrance thickness gauge adjusts the rolls in microseconds if there are any changes in thickness. The exit gauge records the thickness, and the rolls adjust based on the thickness of the material going through the mill. Adjustments are made in microseconds to hold the final gauge. There are many types of automatic gauge controls, and because of the latest technology in automatic gauge control and shape control, it is now possible to roll material with extreme accuracy at speeds up to 7,000 FPM. Also see Automatic Gauge Control (AGC) and Direct Gap Control (DGC).

## Tension Level Systems

Refer to Photo #583. It is possible to put a tension level system into a rolling mill. This is an open side tension level line for ease of threading. It shows a high quality product with no center buckle or stretched edges. It can also be used to give substantial tension to the rolling mill, as well as deliver a minimum amount of tension to the recoiler for annealing or shipping off to the customer. Any size, width, or speed tension level system can be made to order to assure a high quality, consistent product.

## Electrical Systems

Refer to Photos #784 and #3013. A modern electrical system uses computer controls enclosed in a control cubicals. This is a long subject that will not be discussed in this book.

## Service Engineers

There have been many innovations developed by Cauffiel over the last 60 years. Cauffiel hears from customers from time to time who need help on spare parts, electrical or hydraulics. Cauffiel can send a service engineer to train operators on any rolling mill built by any manufacturer in the world.

Many service engineers are available on our staff. We also use independent service engineers. The letter attached shows an independent service engineer looking for work to start up a rolling mill. This engineer can train operators on how to run the rolling mill and the maintenance personnel on how to maintain the rolling mill.

## Final Approval

Final approval letters are normally required from the customer to collect the last payment under a bank letter of credit. The attached examples (#729 & #730) show that the rolling mills performed per the contract. Most rolling mills built are put under power on Cauffiel's large overhead assembly and testing floor before shipment. Training is sometimes required before shipment to assure the operators and maintenance personnel are well trained for the success of the rolling mill.

# V. BRIEF CALCULATIONS