Operation of Rolling Mills

Rolls

Rolls are the tools of the rolling trade and the way they are used to execute their duty of deforming steel is in many cases largely determined by the roll pass designer. The accuracy and speed of working and roll life are all related to his design and choice of materials, hence, as is the case with any other designer, he should have a good working knowledge of both the materials used and the loads to which they will be subjected during service. It is indicated in other chapters that any sequence proposed by a designer is subject to the limitations applied by the rolling load, the roll strength and the torque available for rolling. It is also mentioned that in flat rolling the allowance made for roll bending by cambering the rolls necessitates an estimation of roll bending resulting from the rolling load, and it is accordingly advantageous for the designer to be able to estimate the load and torque required for any pass. In addition he must ensure that the physical dimensions and material of the roll are capable of withstanding the heaviest loads arising during the rolling sequence. The rest of this section gives a summary of roll materials and indicates how to estimate the loads which the rolls must withstand. In addition it suggests what mill size is most suitable for given ranges of products so as to ensure reasonable efficiency in working the mill. Perhaps one of the most important single factors where roll life is concerned is the wear properties of the roll material and this is commented on for the various materials available.

Roll Materials

In the working of metals, the material of the tool must be capable of withstanding loads which will plastically deform the stock without itself being plastically deformed. In the rolling of hot steel this is not a difficult problem and iron or steel rolls are suitable if they are operated at a temperature considerably lower than that of the stock. Whether iron or steel rolls are used in any particular case depends on the specific duty they have to perform and whether toughness, resistance to thermal cracking or shock loading or hard wearing properties are most important. Rolls may be classified according to the material and the method of manufacture, the first main subdivision being into iron rolls and steel rolls. This division depends on the carbon content of the material and it is normal to draw the distinction between iron and steel at a carbon content of 1.8%, in the case of rolls the demarcation line is usually taken at about 2.4% C. It is common practice to refer to rolls as being steel base below this figure, and iron base above this figure. There is a marked structural distinction between these two types as there is no free graphitic carbon in steel base rolls.

Steel rolls may be either cast or forged so giving a further subdivision, One other division which cuts across the above classification is that of double poured duplex rolls which may be cast with a hard metal outer surface and a tougher and stronger metal forming the centre of the roll. More details of types of rolls are given below and a table of mill types and the rolls frequently used in them is added.

Iron Rolls

Grain rolls
These are cast in sand or loam and the result is a grey cast iron, *i.e.* it contains flakes of free graphite. The structure of the roll is uniform throughout and is very resistant to fire cracking. It is to some extent self-lubricating due to the free graphite which is an advantage where thrust collars arc used to resist end thrust during rolling. A typical analysis of this material is as follows:

Carbon	Silicon	Manganese	Phosphorus	Sulphur
2.5-3%	0.5-1%	0.4-0.8%	0.5%max.	0.1% max.

The phosphorus is allowed up to 0.5% to increase the fluidity of the metal during pouring but it is advantageous to reduce this if higher casting temperatures are possible as phosphorus is deleterious to the properties of cast iron. Sulphur is kept to a minimum and silicon is chosen to regulate the free graphite content, *i.e.* the presence of silicon promotes graphitisation and with a higher carbon content less silicon is required. Manganese is used to neutralise the sulphur and to deoxidize the metal. Too high a manganese content resists graphitisation.

To improve the quality of the metal various alloying elements may be added to give an alloy grain roll of increased hardness. So-called special grain rolls have only small quantities of nickel, chrome and molybdenum and they give slightly better wear and strength than the straight grey iron. An alloy grain roll with higher quantities of alloy additions is much harder and closer grained and wears better though naturally it is more costly and must yield higher rolled tonnage. The presence of nickel promotes the formation of graphite but as it is in a very finely distributed form it leads to greater toughness and resistance to fire cracking. Chromium increases the tendency to form combined carbon and restricts graphite formation so giving a much harder but more brittle iron. Molybdenum and tungsten promote the formation of combined carbon and in addition they add to high temperature strength. With a chromium alloy iron there is a tendency for collar breakage in section rolls due to the brittleness and in addition a good supply of water is necessary for cooling the rolls to avoid fire cracking. A typical analysis is as follows:

Carbon	Silicon	Nickel	Chromium
3%	1%	1% (or0.5% moly.)	1%

A common brand of alloy grain roll is known as "Adamite" grain.

The hardness of rolls is a measure of the resistance to wear and it is usually expressed in degrees of Shore scleroscope hardness. The relatively soft grey iron rolls have hardness figures of 30-40° Shore, but these can be increased to the range 38-50° in the alloy grain roll. This latter is a grey iron but the graphite is finely divided and the matrix is harder. Softer rolls are favoured for the roughing and intermediate stages of rolling and the harder alloy grain ones for finishing. The table given later gives more details of the uses.

Clear chill or definite chill rolls

A clear chill roll has a surface layer of white iron produced by inducing rapid cooling at the surface (by means of a chill in the mould, shown in figure 14 - 1 and 14 - 2) which restricts the formation of free graphite. The core is of grey iron due to the slower rate of cooling and the intermediate zone is of mottled iron - a mixture of white and grey iron. The necks and wobblers or spade ends must not be chilled and hence retain greater toughness. The chilled layer is hard and wear resistant but it is brittle. It is generally about 1 in. thick on plain rolls but may be increased where shallow grooves are required. The analysis is similar to grey iron grain rolls though the carbon content may be higher. Lower carbon gives a lower hardness but it strengthens the roll and reduces the incidence of surface cracking and spalling hence it is used in cases of high stress such as in plate rolling.

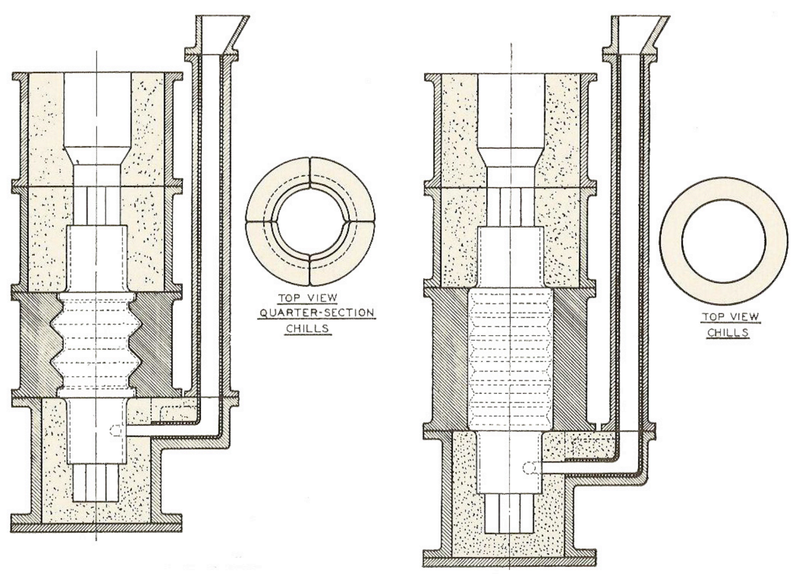

Figure 14 - 1

The surface hardness may be between 55 and 65° Shore but the rolls have good resistance to temperature change and fire cracking. A part chill roll is produced by chilling chosen parts of the barrel *(e.g.* finishing passes) and leaving the rest as grain iron. Alloying elements may be added to chill rolls to give rolls which are harder (65 to 90° Shore) and may contain about 4.5% of nickel with chromium to balance the tendency to form free graphite. The nickel bearing chill rolls are claimed to have a work hardening tendency and are more suitable for cold rolling due to their susceptibility to fire cracking.

Figure 14 - 2

Composite or Duplex roll

A method of combining a very hard surface with a tough core is to cast the roll by double pouring. The first pour gives a shell of highly alloyed white iron which cools rapidly on the surface in a chill mould after which the second pour (often of grey iron) displaces the molten centre of alloy iron and replaces it with a tough core. The shell hardness may be 75 - 95° Shore.

Indefinite chill

With this type of roll there is a very thin clearly defined white graphite-free chill (which is turned off by the makers) and no intermediate mottled zone. The surface layers contain very minute particles of graphite and the structure changes smoothly into the grey core. Casting is by normal foundry chill casting methods. The hardness decreases slowly at first from the surface at a rate of about 2° Shore per inch of depth and then more quickly towards the soft centre. Hence there is a good usable depth. The surface is more resistant to fire cracking and spalling than the definite chill roll and the rolls grip the stock better. However, violent fluctuations of temperature should be avoided.

Indefinite chill rolls may be straight carbon or alloyed. In the case of the straight carbon roll the clear chill is limited to 1/2 inch to 1 inch by having a high silicon content and after turning this leaves an indefinite chill roll with surface hardness of 38° to 4.50 Shore. An alloy indefinite chill roll with a surface hardness of 55° to 75° Shore may contain nickel and chromium and molybdenum in the following range of analysis:

Carbon	Silicon	Sulphur	Phosph.	Mang.	Nickel	Chrom.	Mo.
2.5/3 .	*0.75/0.25*	*0.05-0.10*	*0.05-0.10*	*0.*25/.075	0.75/3.0	0.75/1.5	0.25

These rolls may be heat treated to toughen them against shock loadings. An example of this type is the Adamite indefinite chill. High hardnesses of 65 to 85° Shore may be obtained by higher alloy additions particularly nickel and chromium. One type has 5 1/2% nickel, 2% chromium, 1% silicon and 1 1/4% manganese. These rolls may be heat treated and are resistant to spalling and fire cracking.

Spheroidal graphite rolls

Spheroidal graphite (SG) cast iron rolls are finding use in some mills. The advantages of using iron for rolls arc that it is easily and accurately cast, it is readily machinable and takes a good finish, it is rigid, has useful resistance to heat and corrosion and has good wear properties. Unfortunately in a normal grey iron the flake form of the graphite leads to poor mechanical properties as far as strength and toughness are concerned. A malleable cast iron can be produced by casting a white iron and annealing it for several days to cause the graphite to separate out in the form of nodules or spheroids which do not weaken the structure as do flakes. This is not a convenient process (due to the time factor) and an iron has been developed in which the graphite is in the nodular form when cast by the use of a special casting procedure involving the addition of magnesium. The resulting spheroidal graphite cast iron has much greater strength and toughness, the former being about twice that of a high duty flake graphite iron and the latter is increased about twelve times. Most of the rolls so far produced have had a pearlitic structure but the acicular structure is now available giving better wear resistance. A good finish may be obtained on the rolls though care in machining is necessary as noxious fumes are given off.

The wear properties of SG iron rolls it is that they wear evenly and at a similar rate to flake graphite iron. They are suitable for use where a normal iron roll is not strong enough and where steel rolls give poor life due to excessive wear but, as they are more expensive than both iron and steel rolls, care in the choice of application is necessary. Correct application of these rolls can be most rewarding. Hardness can be obtained up to 80° Shore or more.

Steel Rolls

Steel rolls may be cast or forged. They are much stronger and tougher than iron rolls and are used therefore where an iron roll is considered not strong enough. In a particular set of circumstances they would permit heavier draughts to be used especially where deep grooves are required. Breakage due to shock loading are much less likely to occur and the properties can be varied considerably by suitable heat treatment. However, carbon steel rolls wear more quickly than iron rolls due to their low hardness.

Cast steel rolls

These may vary considerably according to analysis. The straight carbon roll has from 0.40% to 0.90% carbon and the hardness is from 28 to 36° Shore. Heavy mills (cogging, slabbing and heavy roughing) use the lower grades (up to 0.60% C) while billet roughing stands use the higher grades. The addition of about 0.5% molybdenum to this type of roll together with small amounts of nickel and chromium (or higher manganese) gives increased strength and reduces the severity of any fire cracks which may occur. The hardness is 30 - 42° Shore. More highly alloyed rolls usually lie within the following ranges of analysis:

Carbon	Manganese	Nickel	Chromium	Molybdenum
0.80/1.0	0.60/0.90	1.0/2.5	0.50/1.10	0.20/0.40

A carbon-chrome roll (1% C, 1.5 to 1.75% Cr) is also made. These rolls are usually heat treated, the hardness range is 35-55° Shore and they are commonly used as back-up rolls in 4-high mills. An alloy steel containing tungsten and with a hardness of 40 - 50° Shore is very resistant to fire cracking and is sometimes used for roughing rolls in wide strip mills. Cast alloy steel base rolls are made also, the range of analysis being:

Carbon	Silicon	Manganese	Nickel	Chromium
0.9/2.5	0.5/1.0	0.4/0.6	0.25/1.0	0.5/1.5

It will be seen that the carbon content is in a higher range than in the cast steel roll. All the carbon is in combined form and not the free graphitic form of the grain iron roll. The hardness range is 30 - 55° Shore, according to carbon content, and the rolls wear well and are strong. The life is in line with the cost - about twice that of a grain roll. Good water cooling is required. An example of this type is the Adamite range of steel base rolls.

Forged steel rolls

Forged steel rolls are forged from a cast steel ingot and the necessary mechanical working results in an improved tougher structure. In the carbon steel form (0.35/0.75% carbon) they are used for cogging, slabbing and heavy roughing mills in the lower end of the carbon range and for smaller intermediate mills. in the higher end of the range. This is somewhat arbitrary and depends on the particular mill conditions. They are normalized before use and the hardness range is 24 - 30° Shore.

In the alloy steel form they may be heat treated to give a wide range of hardness. In the range 50 - 55° they are used for large back-up rolls, around 80° for small back-up rolls in cold rolling, and 90 - 100° (fully hardened) for work rolls in cold rolling. A typical analysis is 1% carbon, 1.5 - 1.75% chromium and 0.5% nickel.

Forged steel rolls in the hot rolling hardness range are highly resistant to shock loading.

Main uses of Various Types of Rolls

The types of rolls and their uses in hot mills are detailed below showing the possible rolls for a given mill type. The selection of any particular roll depends on production demands, initial cost, specific qualities required, etc. and close collaboration with the roll makers is desirable to ensure that these requirements are satisfied as fully as possible.

Type of Mill	Surface Hardness (° Shore)	Types of Roll
Cogging and Slabbing	24 - 30	Forged steel 0.4% C.
	28 - 36	Cast steel 0.4 to 0.9% C ductile.
	30 - 42	Cast alloy steel-0 to 0.5%. Mo+Ni, Cr, Mn - strong, tough, resistant to fire cracking.
	30 - 48	"Adamite" cast steel - high carbon in complete solution +Ni, Cr - good wear but needs copious water cooling to prevent temperature fluctuations.
Billet and bar mills	35	Forged steel 0.75% C - roughing rolls.
	30 - 42	Cast steel - 0 to 0.5% Mo+Ni, Cr, Mn - strong, tough, resistant to fire cracking.
	30 - 38	"Pearlitic" grain rolls - cast iron - strong tough and resistant to fire cracking - strand rolls.
	35 - 40	Special grain rolls - improvement on above.
	30 - 48	"Adamite" cast steel - high carbon in complete solution+Ni and C r- good wear but needs copious water cooling to prevent temperature fluctuations. Roughing rolls.
	35 - 40	Straight carbon indefinite chill rolls - temperature fluctuations must be avoided. Intermediate stand rolls.
	35 - 50	"Adamite" alloy grain rolls - very good hardness penetration, requires temperature control and can be made in a wide range of hardness and strength - strand rolls.
	55 - 65	Straight carbon chill rolls-high resistance to temperature changes, breakage and surface crazing-small section rolls.

Type of Mill	Surface Hardness (° Shore)	Types of Roll
Billet and Bar Mills	55 - 70	"Adamite" alloy indefinite chill rolls-improvement on straight carbon - oval and guide rolls.
	65 - 85	Fully hard alloy indefinite chill rolls - improvement on "Adamite" e.g. "Nironite".
	65 - 90	High alloy cast iron chill rolls with good work hardening-guide mill rolls.
	55	Spheroidal graphite - billet roughing rolls.
	60 - 65	Spheroidal graphite - bar mills - most stands.
Plate Mills	30 - 38	"Pearlitic" grain rolls - cast iron-strong, tough and resistance to fire cracking - roughing rolls.
	30 - 42	Cast iron - 0 to 0.5% Mo+Ni, Cr, Mn - strong, tough and with good fire cracking resistance.
	35 - 40	Special grain rolls-improvement on Pearlitic.
	55 - 65	Straight carbon chill rolls - high resistance to temperature changes, breaking and surface crazing.
	55 - 65	As above but including 0.4 to 1.0% Mo - work rolls - mill conditions must be stable.
	65 - 85	Alloy indefinite chill rolls - temperature fluctuations must be avoided by cooling - work and finishing rolls.
	65 - 90	Alloy chill rolls-cast nickel alloy iron-good work hardening - finishing rolls.
	75 - 95	Compound alloy chill rolls - outer shell of alloy white iron forming working surface and remainder of a tough grey iron-good for superfine finishes-advantage of shell being self-hardening - work rolls.

Type of Mill	Surface Hardness (° Shore)	Types of Roll
Section Mills	24 - 30	Forged steel rolls - roughing, intermediate and finishing.
	28 - 36	Cast steel - 0.4 to 0.9% carbon-roughing rolls.
	30 - 38	Pearlitic grain rolls - strong, tough and resistant to fire cracking - roughing, intermediate and finishing rolls.
	30 - 42	Cast steel-0 to 0.5% Mo+Ni, Cr, Mn, strong, tough and with good fire cracking resistance. Roughing rolls.
	30 - 48	"Adamite" cast steel-high carbon in complete solution+Ni, Cr, good wear but needs copious cooling to avoid temperature fluctuations. Roughing rolls.
	35 - 40	Special grain rolls-improvement on above.
	35 - 45	Hyper Eutectoid steel with Ni, Cr, and Mo. Wear resistance and strength in about equal proportions - roughing and semi-finishing rolls.
	38 - 40	Straight carbon indefinite chill rolls - temperature fluctuations must be avoided-intermediate stand rolls.
	38 - 50	"Adamite" alloy grain rolls-very good hardness penetration-require temperature control - made in wide range of hardness and strength, intermediate and finishing rolls.
	40 - 50	Cast steel with Cr and Tungsten-high resistance to crazing and fire cracking - semi-finishing rolls.
	55 - 70	"Adamite" alloy indefinite chill rolls-improvement on above-intermediate and finishing rolls.
	45	Spheroidal graphite for reversing roughing rolls.
	60 - 65	Spheroidal graphite for small section mills.

Type of Mill	Surface Hardness (° Shore)	Types of Roll
Hot strip mills	24 - 30	Forged steel rolls-work rolls
	30 - 38	"Adamite" cast steel-high carbon in complete solution with Ni and Cr-Good wear but needs temperature control by cooling-work rolls.

Type of Mill	Surface Hardness (° Shore)	Types of Roll
Hot strip mills	35 - 45	Hyper Eutectoid steel with Ni, Cr and Mo wear resistance and strength in equal proportions: roughing rolls.
	38 - 40	Straight carbon indefinite chill rolls-temperature fluctuations must be avoided. Intermediate stand rolls.
	35 - 50	Adamite alloy grain rolls-very good hardness penetration but require temperature control. Made in wide range of hardness and strength. Intermediate and finishing rolls.
	40 - 50	Cast steel with Cr and W. High resistance to crazing and fire cracking - roughing rolls.
	55 - 65	Straight carbon chill rolls. High resistance to temperature changes, breakage and surface crazing.
	55 - 65	As above but including 0.4 - 1.0% Mo - mill conditions must be more stable and controlled more closely - work rolls.
	55 - 70	"Adamite" alloy indefinite chill rolls - improvement on above-hot finishing and planishing rolls.
	65 - 85	Alloy indefinite chill rolls-improvement on Adamite - work rolls.
	65 - 90	Alloy chill rolls cast iron roll similar but improved qualities to alloy indefinite chill rolls.
	75 - 85	Manganite alloy indefinite chill rolls - very resistant to fire crazing, tail marking bruising and spalling - train work rolls.
	60 - 65	Spheroidal graphite - roughing rolls
	65 - 70	Spheroidal graphite - finishing rolls
	50 - 55	Spheroidal graphite - backup rolls

As shown in the above table, the most common method of testing roll for quality and predicted wear properties is hardness. The most commonly used roll testing method is the Shore C scleroscope test. This method uses an instrument to measure the rebound height of a diamond-tipped indenter which is dropped onto the roll surface under standardized conditions. The kinetic energy of the indenter is dissipated in three ways: in the elastic deformation of the roll surface, in the plastic deformation of the roll surface and in the rebound of the indenter from the roll surface, The rebound height is a measure of the last component of the kinetic energy and varies according to the energy spent on deformation of the roll surface. This deformation will be larger in a softer roll than in a harder one With the Shore C scleroscope, the rebound height is observed visually. The Shore C scale is defined by a standard roll, hardened in a predefined manner, which exhibits the hardness 100 Shore C.

There is a standard recommendation for scleroscope hardness testing in the U.S. (ASTM A448-72). Among the questions raised in this recommendation are the requirements on the surface finish (the harder the roll, the better the required surface finish-for a hardened steel roll a fine-ground surface is needed); the requirement of a minimum distance between the indentations (0,5 mm, 002 in.), the requirement of a minimum number of measurements (5); the requirement of frequent calibration (20 measurements on a calibration block; 90% of the values must be within :t3 units from the nominal hardness of the calibration block); the requirement of daily control (at least 5 measurements on a test block at [east once a day).

More modern hardness testers are even more portable than the Shore C hardness testers. Most read on the HL, HRC, HRB, HB, HV, and HSD scales.

Effect of elements in Iron and Steel Rolls

The effects of some of the alloying elements on the properties of iron and steel roll metals are summarized in Table 14 - 1.

Alloy Iron	Element	Alloy Steel
Increases hardness, brittleness and wear resistance. Decreases ductility, depth of chill.	Carbon	Increases hardness, brittleness and wear resistance. Decreases resistance to shock.
Increases graphite, adds to cleanliness. Decreases depth of chill.	Silicon	Cleanses steel in proportion of 0.20 - 0.35%. Adds to hardness. Deoxidizer, promotes sound casting.
Increases hardness and brittleness.	Phosphorus	Increases hardness and brittleness. Decreases ductility. Has tendency to segregate.
Increases hardness, brittleness, and depth of chill.	Sulphur	Increases hardness and brittleness. Decreases ductility. Must be used with discretion.
Reduces chill in lower ranges, increases chill in higher ranges, increases hardness in combination with nickel and chromium, increases brittleness.	Manganese	Increases hardness and brittleness. Cleanser for oxides and sulphur. Increases tensile strength and wear resistance.
Increases strength, hardness and wear resistance. Decreases depth of chill.	Nickel	Increases strength, hardness and resistance to fire-cracking in combination with chromium and others
Increases strength, hardness, and resistance to fire-cracking, makes fine grain.	Molybdenum	Increases strength and hardness
Increases chill depth, strength, and resistance to fire-cracking. Lowers ductility.	Vanadium	Increases toughness, hardness and susceptibility to heat treatment
Hardener at all times; used in combination with nickel or molybdenum or both, increases depth of chill.	Chromium	Hardener - works best in combination with nickel or molybdenum or both
In small amounts similar to nickel	Copper	Similar to nickel
Hardener, used with discretion	Boron	Increases hardness

Table 14 - 1

Carbide Rolls

Tungsten carbide, WC or W2C, is a chemical compound containing tungsten and carbon. Its extreme hardness makes it useful in the manufacture of mill rolls for extended life in applications where long rolling campaigns are required. WC in combination with the binder materials in powder form are mixed, milled, granulated, and compacted to near net shape blanks which are finally sintered in a vacuum furnace. Some rolls are then hot isostatically pressed (HIP). The rolls are then ground using diamond grinding wheels or lathe turned using very hard turning tools to the required dimensions.

In general use in wire rod finishing blocks and in some shape rolling applications, carbide rolls require high quality cooling water in a narrow pH range and limited hardness. Using roll cooling water outside the recommended pH range leeches the binder from the roll causing premature roll surface failure. Various grades of carbide rolls area available based on grain size and binder content and binder composition.

The range of application in recent years has extended the use of carbide rolls back into the intermediate mills by using a carbide sleeve mounted on a steel shaft, as shown in figure 14 - 3 and 14 - 4. The mounting can be accomplished using a mechanical method or by creating a composite roll by pressing and sintering a carbide ring on the shaft. Minimum rolling speeds for carbide working surfaces have now been reduced to about 2m/s (400 ft/min).

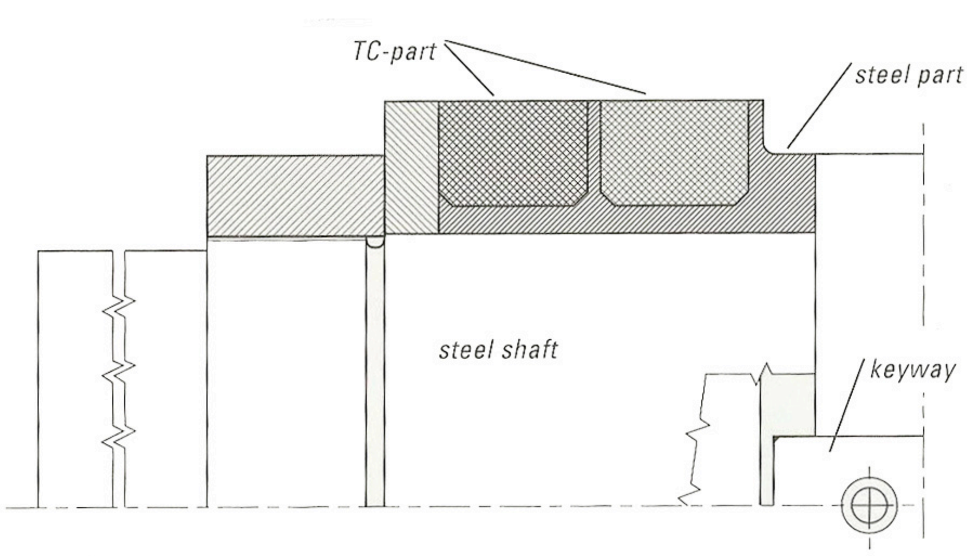

Figure 14 - 3

Figure 14 - 4

Figure 14 - 5 shows the basic parts of a modern roll. The body is the part that is used for the deformation of the rolled product. The spade drive end is driven through a coupling that attaches to a spindle that connects to the drive system. The roll necks are the mounting surface for the main bearings. The compound radius blends the transition from the roll necks to the roll body. This large radius minimizes the stress concentration that occurs at any transition radius. The larger these radii, the stronger the roll neck. Typical failure points on a roll are the necks from overloading by separating force, the roll body from cyclical heat damage - fire cracks that grow and connect together to gradually weaken the body, and the spade end from torque overload.

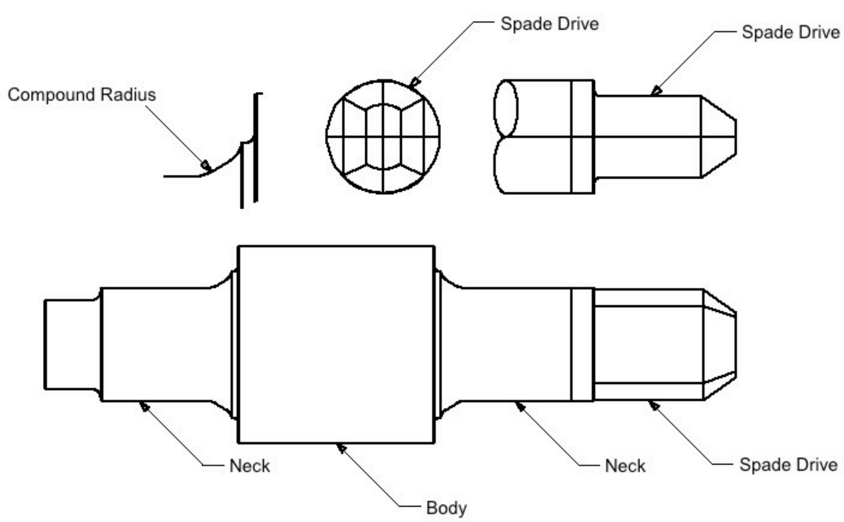

Figure 14 - 5

Roll Cooling

In the working of of hot steel, heat is transferred to the rolls. If not cooled, the heat buildup will heat the roll to a temperature equal to that of the rolled bar where the roll will also undergo plastic deformation. To remove the heat from the roll, cooling water is applied. The difficulty in remove the heat from the roll is the result of two factors. The first is called the coefficient of thermal conductivity, the second is the interface between the roll and the bar compared to that of the cooling water and the roll. Heat is transfered by conduction, convection, and radiation.

Coefficient of Thermal Conductivity
Definition: The rate at which heat is transferred by conduction through a unit cross-sectional area of material when a temperature gradient exists perpendicular to the area. The coefficient of thermal conductivity, sometimes called the K-factor, is expressed as the quantity of heat that passes through a unit cube of the substance in a given unit of time when the difference in temperature of the two faces is 1°. The coefficient of thermal conductivity for 1020 steel is 46.73 watts per meter °C (W/m°C), for water 0.6030 W/m°C. Water is 78 times less effective than steel at transferring heat, given the same conditions.

Thermal Conductivity
Definition: The measure of the ability of a material to conduct heat. For a homogeneous material it is the item rate of heat flow, under steady conditions, through unit area, per unit temperature gradient in the direction perpendicular to the area.

Convection is the transfer of heat by currents within a fluid. It may arise from temperature differences either within the fluid or between the fluid and its boundary, which would affect density.

Heat conduction is the transmission of heat across matter. Heat transfer is always directed from a higher to a lower temperature. Denser substances are usually better conductors; metals are excellent conductors.
The law of heat conduction states that the time rate of heat flow *Q* through a slab is proportional to the gradient of temperature difference:

$$\frac{\Delta Q}{\Delta t} \sim kA\frac{\Delta T}{\Delta x}$$

In other words, the greater the temperature difference, the greater the heat flow. *A* is the transversal surface area, Δx is the thickness of the body of matter through which the heat is passing, *k* is a conductivity constant dependent on the nature of the material and its temperature, and ΔT is the temperature difference through which the heat is being transferred. This law forms the basis for the derivation of the heat equation. R-value is the unit for heat resistance, the reciprocal of the conductance.

Thermal radiation is electromagnetic radiation from the surface of an object which is due to the object's temperature. Heat from a common household radiator is an example of thermal radiation, as is the light emitted by a glowing incandescent bulb. The thermal radiation is generated when heat from the movement of charged particles within atoms is converted to electromagnetic radiation. Hot steel loses most of its heat by radiation during rolling.

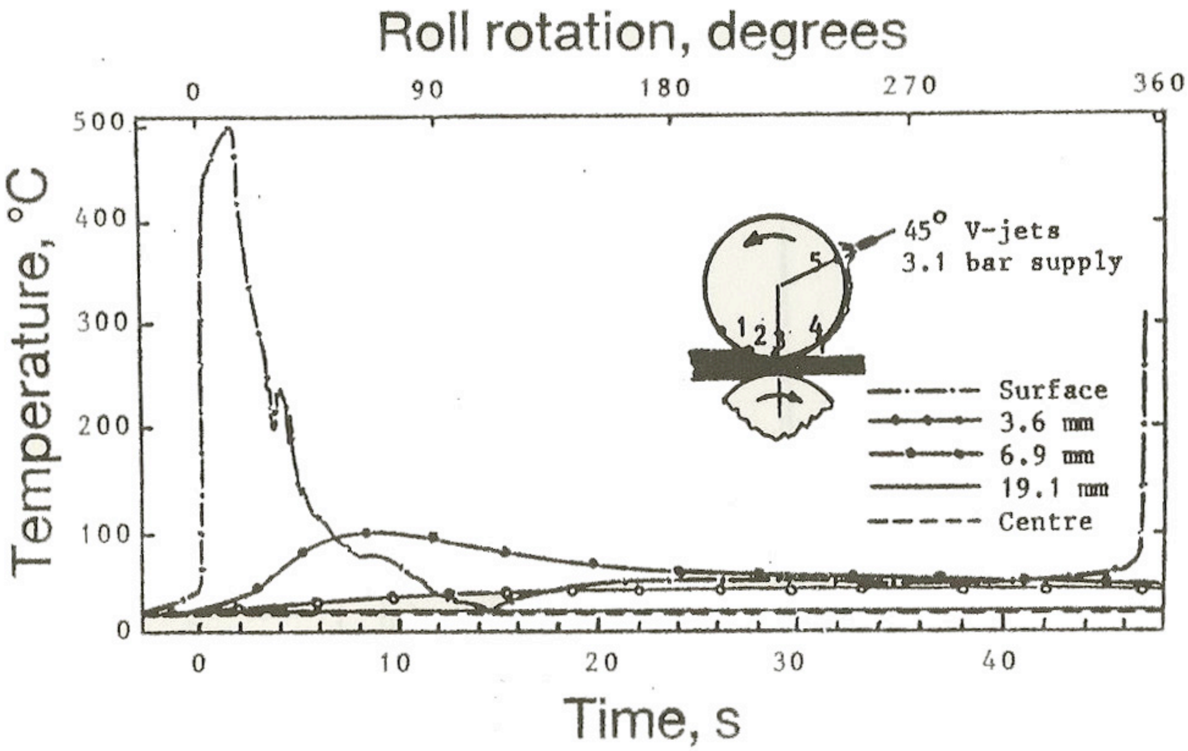

Figure 14 - 6

During the contact time of the bar in the pass, the hot bar heats the roll due to conduction during the contact time with the roll. As shown in figure 14 - 6, the temperature profile on the surface of the roll increases when in contact with the roll and then drops as the heat is absorbed by the roll body. This also means that the best place to remove the heat from the roll is immediately after the bar leaves contact with the roll. From above, the best rate of heat removal occurs when the difference in temperature (ΔT) is the greatest. As shown in figure 14 - 7, a typical roll cooling water delivery system consists of holes in the delivery guide for the application of water as close to the point where the ht bar leaves contact with the roll as possible. Two half circle water pipes for each roll also deliver secondary cooling water to assure the heat of rolling does not penetrate the roll body. The application of cooling water must be controlled so that the water does not fall on the bar at the entry point to the rolls. This will only cool the bar, create steam pockets between the roll and the bar, and waste water that could be better used on the other side of the roll. To minimize roll wear, roll cooling water must be applied as close to the point where the bar leaves the roll. Typical pressures are 2 to 5 bar (30 to 75 psi) at a flow rate of approximately 1.5 l / mm per minute (10 gal / in per minute). The best delivery systems use tube, nozzle and spray headers to get "soft cooling" at low pressure and high flow, not a hard jet that "bounces" the water off of the roll.

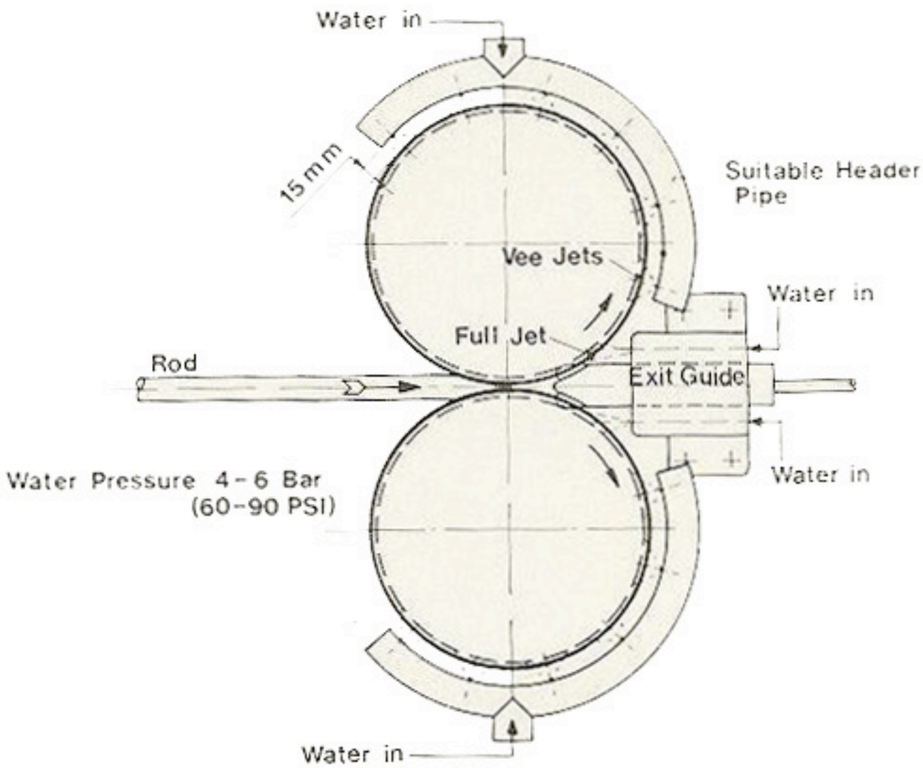

Figure 14 - 7

Figure 14 - 8 shows a water header in place in a set of angle rolls.

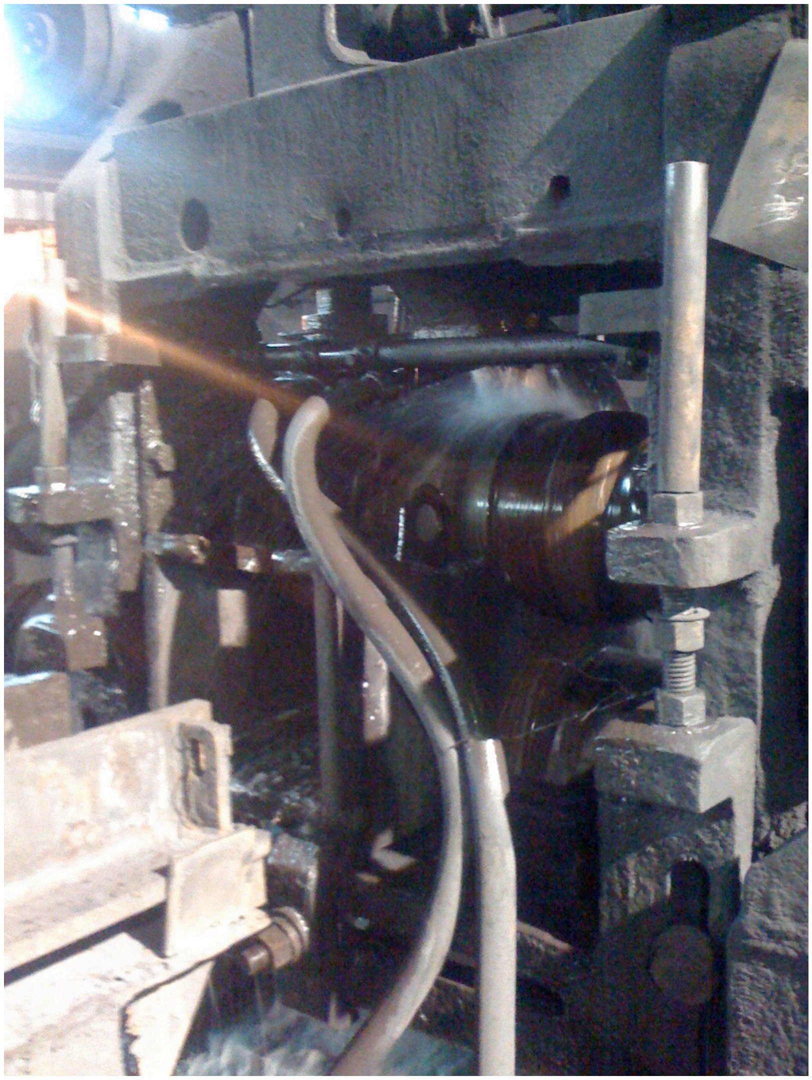

Figure 14 - 8

Roll surface degradation occurs primarily due to the thermal cycling of the heating and cooling of the surface versus the relatively steady state of the subsurface and adjacent material. This creates local tension and compression as the roll moves through 360° of rotation. The objective of roll cooling is to minimize this cycle. The objective of roll material selection is to use materials that can tolerate this cycle without fire-cracking, crazing, or wearing prematurely.

Examples of firecracking of rolls are shown in figures 14 - 9, 10, and 11. These cracks require the removal of considerable material by turning down the roll diameter and reduce roll life and increasing roll cost per ton.

Figure 14 - 9

Figure 14 - 10

Figure 14 - 11

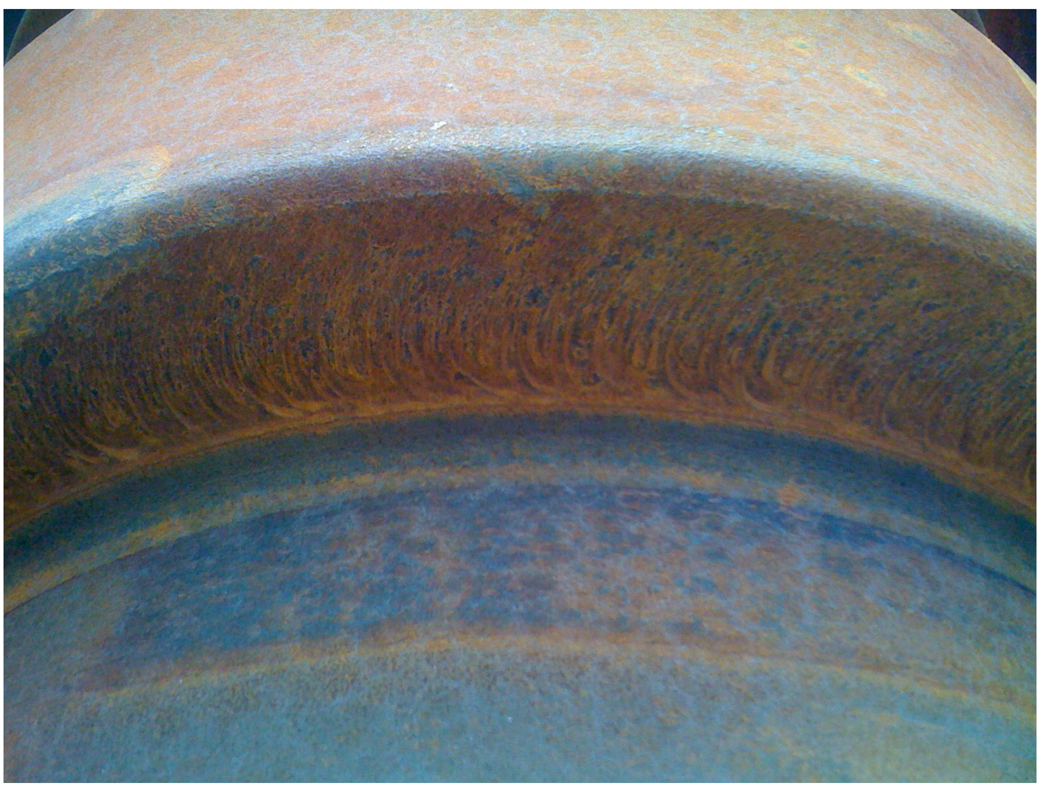

Figure 14 - 12

The pass shown in figure 14 - 12, is a box pass with relatively steep sides. The friction effects of the speed difference between the bar and the roll is evident by the curved marking on the sides of the groove. Due to the steep angle of the sides of the pass, to clean up this pass will require the removal of a considerable amount material by turning down the roll diameter also reducing roll life and increasing roll cost per ton.

It is a fact that all mill rolls eventually deteriorate and passes need to be changed to achieve size control and finished product surface quality. Table 14 - 2 shows typical average values for roll and pass life, accumulated from several different mills and sources.

	Stand No.	Roll Dia. Max. (in)	Roll Material	Roll Hardness	Tons per Groove	No. Dressings	No. Grooves	Tons per roll	Cost per Roll	$/ton	# of rolls
Roughing Mill	1H	29.528	S.G.	48/53 deg Shore C	15,000	3	2	90000	$ 9,337.81	$ 0.10	8
	2V	29.528	S.G.	48/53 deg Shore C	15,000	3	2	90000	$ 9,337.81	$ 0.10	8
	3H	29.528	S.G.	48/53 deg Shore C	15,000	3	2	90000	$ 9,337.81	$ 0.10	8
	4V	24.606	S.G.	48/53 deg Shore C	8,000	7	2	112000	$ 7,398.60	$ 0.07	7
	5H	24.606	S.G.	48/53 deg Shore C	7,000	7	3	147000	$ 7,398.60	$ 0.05	5
	6V	20.276	S.G.	48/53 deg Shore C	5,000	9	4	180000	$ 3,834.29	$ 0.02	4
Intermediate Mill	7H	20.276	S.G.	48/53 deg Shore C	3,000	9	4	108000	$ 3,834.29	$ 0.04	7
	8V	20.276	S.G.	48/53 deg Shore C	3,000	9	5	135000	$ 3,834.29	$ 0.03	6
	9H	20.276	S.G.	48/53 deg Shore C	1,500	11	5	82500	$ 3,834.29	$ 0.05	9
	10V	20.276	S.G.	48/53 deg Shore C	1,500	11	7	115500	$ 3,834.29	$ 0.03	6
	11H	14.764	S.G.	48/53 deg Shore C	1,000	6	4	24000	$ 1,705.57	$ 0.07	31
	12V	14.764	S.G.	48/53 deg Shore C	1,000	6	6	36000	$ 1,705.57	$ 0.05	21
Finishing Mill	13H	14.764	A.I.C.	53/58 deg Shore C	800	11	7	61600	$ 1,705.57	$ 0.03	12
	14V	14.764	A.I.C.	53/58 deg Shore C	800	11	9	79200	$ 1,705.57	$ 0.02	9
	15H	14.764	A.I.C.	53/58 deg Shore C	600	11	9	59400	$ 1,705.57	$ 0.03	13
	16V	14.764	A.I.C.	53/58 deg Shore C	600	11	11	72600	$ 1,705.57	$ 0.02	10
	17V	15.197	WC		1,000	9	2	18000	$ 2,055.59	$ 0.11	42
	18H	15.197	WC		1,000	9	2	18000	$ 2,055.59	$ 0.11	42
	19V	13.504	WC		500	8	2	8000	$ 1,519.98	$ 0.19	94
	20H	13.504	WC		500	8	2	8000	$ 1,519.98	$ 0.19	94

Table 14 - 2

Table 14 - 2 summarizes roll consumption for bar and rod mill. The S.G. roll material is Spheroidal Graphite, A.I.C. roll material is Alloy Indefinite Chilled Iron, and WC is tungsten carbide. Based on the above information, a mill rolling 750,000 tons per year would spend $1,057,750 on rolls, $1.41 per ton. As can be seen from these values, roll performance is an important part of the financial performance of the mill.

Stand and Guide Set-up

The goal of mill building and setup is to get the first bar rolled when changing product, on the cooling bed in tolerance and sellable. The data required to perform this function is usually provided in two forms. On is used by the mill builders and provides information about rolls, guide parts, and other equipment that needs to be changed from the previous setup. It will also include gap settings, guide adjustments, and any special instructions.

Mill floor and pulpit setup sheets also contain loop height settings, motor RPM, run-out speed, production rate, R-Factors, shear setup information and other pertinent information. To enable the fastest startup possible, the retained information should reflect the conditions at startup. That is, if the rolls are always dressed at change over, the R-Factors should be what they were the last successful rolling on new rolls. Data collected at the end of a rolling with used rolls will not be accurate when rolling on new rolls.

Some example setup sheets are shown in tables 14 - 3, 14 - 4 and 14 - 5. Table 14 - 3 represents a sheet used by a mill building crew to accurately assemble stands with guides and rolls. Table 14 - 4 show what a pass designer would provide for the creation of the other two sheets. Table 14 - 5 is an example of a mill floor setup and rolling sheet.

2 x 1/8" Angles														
Stand Data					Entry Guides					Delivery Guides				
Stand	Pass ID	Collar Gap	Bar Height	Bar Width	Box	Rollers	Inserts / Nose	Guide Setting	Guide Life	Box	Rollers	Inserts / Nose	Guide Setting	Guide Life
1H	1-1	0.800	3.356	5.710	TE - ST1		22253	5.750				27701 A & B	4.056	
2V	2-1	0.613	2.873	4.450	FRE-TA-12	11857	11855	3.436				27723 & 27721	3.573	
3H	3-1R	0.500	3.264	3.264	FRE-TA-12	11857	11856	2.953				27719 A & B	3.964	
4H	4-1O	0.484	1.850	3.950	TE - ST4		10063	3.500		DS/3		4 - 41		
5V	5-2R	0.330	2.330	2.280	SR7	452916	452917	1.870		DS/2V		3-1/2" Pipe		
6H	6-5D	0.102	1.030	2.980	TE - ST8		25010	2.560		AD-1		703P0324		
7V	Dummy													
8H	8-5U	0.110	0.710	3.140	RE-45FRS	6009-9/11	4432-2	3.240		PS125SC	I-0358-1	Top: I-0691-1 Bot.: I-0691-2		
9V	Dummy													
10H	10-3D	0.119	0.460	3.250	RE-45FRS	6009-9/11	3032P32	3.280		PS125SC	I-0358-1	Top: I-0692-1 Bot.: I-0692-2		
11V	Dummy													
12H	12-21U	0.143	0.340	3.235	RE-45FRS	6009-9/11	3032-12-h	3.320		PS125SC	I-0209-1	Top: I-0693-1 Bot.: I-0693-2		
13H	13-37D	0.122	0.265	3.235	RE-45FRS	6009-9/11	6601-13/1	3.275		PS125SC	" "	Top: I-0694-1 Bot.: I-0694-2		
14H	14-11U	0.130	0.200	3.135	RE-45FRS	6009-9/11	6601-14/2	3.275		PS125SC	" "	Top: I-0695-1 Bot.: I-0695-2		
15H	15-Nov	0.127	0.152	1.985	REA-1	21383Sh1-01/02	6601-15/2	0.205	3,000	PS125SC	I-0209-1	Top: I-0696-1 Bot.: I-0696-2		

Table 14 - 3

							4" x 1" Flat											
				Production	144.4	T/hr			Billet Size	5 1/8 x 5 1/8								
				Finish Size	4" x 1" Flat				Billet Area	26.7	Inch²							
				Finish Speed	358	ft/min			Material	1080								
															Roll	Roll	Motor	Motor
Stand	Groove	Pass Area	Reduction	Ave. Roll	Groove Factor	Parting	Work Dia.	Power	Eq. Power	Torque	RPM Ave.	Sep. Force	Speed	Discard	New	Discard	New
	Name	Inch²	%	inch	inch	in	inch	HP	HP	lb-ft		lb-force	ft/min	RPM	RPM	RPM	RPM
Billet		26.738															
1H	B1-2	19.530	27.0%	20.276	2.232	1.161	18.044	336	363	121011	16.0	409692	75.0	17.4	14.6	1269.8	1066.0
2V	B2-2	14.731	24.6%	20.276	2.488	1.134	17.787	300	300	80233	21.5	255424	99.5	23.4	19.6	1429.0	1196.6
3H	OP3-2	12.571	14.7%	20.276	0.873	1.787	19.402	171	171	42386	23.1	136447	116.6	25.0	21.2	1448.1	1230.6
4V	R4-2	9.320	25.9%	19.390	2.095	0.610	17.294	335	335	52749	34.8	211130	157.2	36.2	33.4	1735.3	1602.3
5H	Flat	8.734	6.3%	19.783	0.000	2.209	19.917	76	76	13651	32.5	50083	167.7	35.9	29.1	1614.9	1311.2
6V	EG6-1	7.711	11.7%	18.996	1.641	0.254	17.069	149	157	21501	43.7	111642	190.0	51.0	36.4	1531.3	1092.5
7H	Flat	6.786	12.0%	17.520	0.000	1.738	17.553	159	159	18759	47.1	109023	215.9	49.8	44.5	387.6	346.5
8H	Flat	5.537	18.4%	17.520	0.000	1.374	17.533	267	404	25720	57.8	187775	264.6	61.1	54.6	222.3	198.6
9H	Edger	5.450	1.6%	14.016	1.625	0.738	13.387	22	30	1643	77.7	28655	268.8	86.3	69.0	267.6	213.8
10H	Flat	4.693	13.9%	14.016	0.000	1.154	14.016	211	289	14390	86.0	142165	312.2	95.2	76.8	270.4	218.3
11H	Flat	4.340	7.5%	14.016	0.000	1.052	14.016	115	168	7287	93.0	109009	337.6	103.0	83.1	255.4	206.1
12H	Edger	4.252	2.0%	14.016	0.283	0.774	13.733	31	107	1878	97.0	27880	344.6	107.5	86.4	107.5	86.4
13H	Flat	4.097	3.6%	14.016	0.000	1.012	14.015	56	192	3367	98.6	69729	357.6	109.1	88.0	109.1	88.0

Table 14 - 4

4 X 3/8 FLAT
RUNOUT SPEED@1416FPM 5/9/06
KICKOFF TIME@3.16(SEC)
Billet: 5 1/8 (Area = 17250 mm2)
Finishing Speed of 755 fpm

Std#	End Collar Roll Size (mm)	Stock Dimension H	W	Groove	Roll Parting	Motor RPM	ENTRY GUIDES	EXIT GUIDES	
1	475	93.1	140.7	B1-1	93.1	950	STATIC	STATIC	
2	553	104.3	98.2	B2-1	98.2	889	RE-150 93	STATIC	
3	485	77.4	109	OP3-1	77.4	1163	RE-150 98.7	STATIC	
4	555	88	88	R4-2	88	1111	RE-150 77.7	STATIC	
5	485	56.2	106.3	Flat	56.2	1253	RE-115 89	STATIC	
6	536	59	87	EG6-1	87	872	RE-115 56.2	STATIC	
7	464	33	106.8	Flat	33	328	STATIC	HANGING GUIDES	
8	479	23	109.4	Flat	23	206	FL-85 108	MORGAN 15D - 28.7	NEW PROFILE 18D-27.6
9	389	107.7	24.5	Edge	107.7	299	EDG STATICS	MORGAN 71D - 34	NEW PROFILE 72D-26.0
10	384	17.9	109.3	Flat	17.9	269	FL-85 108.7	HANGING GUIDES	
11	384	10.9	111.6	Flat	10.9	364	FL-85 110.3	RTO-3 31D - 43.1	NEW PROFILE 20D-26.4
12	373	100.5	12.3	Edge	100.5	196	EDG STATICS	MORGAN 69D - 25.9	NEW PROFILE 62D-22.9
13	391	9.5		Flat	9.5	187	FL-85 101.4	HANGING GUIDES	

CHANGE PASS ON STD 12.
CHANGE STATIC INSERTS ON ENTRY OF 12.

Table 14 - 5

Tension Control

In a continuous mill speed matching the stand to achieve a constant mass flow through the mill assures a low cobble rate and less defects. High tension can stretch reduce the cross section of the bar making shape control very difficult. At the extreme, tension can pull the bar apart, creating a cobble. Compression of the bar between stands can create flutter creating defects, or at the extreme will cause loop growth leading to a cobble.

Shown graphically in figure 14 - 13, the formula for constant mass flow is:

$$V_0 \times A_0 = V_1 \times A_1$$

If tension exists:

$$V_0 \times A_0 < V_1 \times A_1$$

If compression exists:

$$V_0 \times A_0 > V_1 \times A_1$$

Solving for speed (S) and area (A):

$$V_0 / V_1 = A_1 / A_0$$

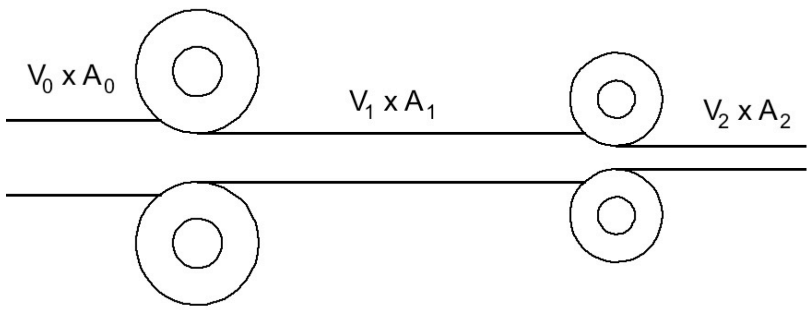

Figure 14 - 13

Using the working diameter of the rolls, we can match the roll RPM to the bar speed through the mill. As the rolls wear and the spread of the bar in the pass changes, the RPM of the stands will need to be adjusted as the bar area changes. Most modern control systems will modify the R-Factor as this occurs.

Mill Speed Setup Example

Input values for setting mill motor speeds are production rate, roll collar diameters, roll gaps, bar areas and widths, and gear ratios. Motor speed ratings will be checked against calculated speeds.

Bar Speed

Using the production tonnage rate for the product a mill constant will be used to find the bar speed at each stand.

We will calculate the setup data for the 1 9/16” round passes design we developed in chapter 6. The pass design data is shown below in table 14 - 5 and the stand information from table 14 - 7.

Stand	Shape	Area	Reduc-tion	Round Dia.	Draft	Spread Factor	Width	Thick-ness
6H	Square	6.401					2.530	2.530
7H	Oval	4.914	23.2%		0.666		3.356	1.864
8V	Round	4.072	17.1%	2.250”	1.079	0.40	2.277	2.277
9H	Oval	3.326	18.3%		0.724		2.718	1.553
10V	Round	2.829	14.9%	1.875”	0.82	0.42	1.898	1.898
11H	Oval	2.254	20.3%		0.603		2.217	1.295
12V	Round	1.963	12.9%	1.5625”	0.636	0.45	1.581	1.581
13H								
14V								
15H								
16V								
17H								
18V								

Table 14 - 5

Given a tonnage rate of 100 tons/hour and a finished area of 1.963 in^2 we have a finishing bar speed of:

(100 tons/hour x 1 hour/60 minutes) x 2000 lbs/ton =

1.6667 tons/min x 2000 = 3333 lbs/min

3333 lb/min ÷ (1.963 in^2 x 12in x 0.283 lb/in^3) =

3333 lb/min ÷ (6.667 lb/ft) = 500 ft/min

Mill Constant

Using the delivery speed out of stand 12V and the bar area we construct a mill constant to find the bar speed at each stand.

Mill Constant = Bar Area x Speed at 12V:

$$1.963\ in^2 \times 500\ ft/min = 981.5\ (\ in^2 - ft/min)$$

Then to find the bar speed at each stand we divide the Mill Constant by the bar area:

$$\text{Bar Speed} = \text{Mill Constant} \div \text{Bar Area}$$

At stand 11H:

$$981.5\ (\ in^2 - ft/min) \div 2.254\ in^2 = 435.4\ ft/min$$

Repeating at each stand resolves the bar speed at each stand.

Groove Factor

Using the bar area width and roll gap, we can develop a Groove Factor that we will use to find the Working Diameter given the roll end collar diameter.

$$\text{Groove Factor} = (\ \text{Bar Area} \div \text{Bar Width}\ ) - \text{Roll Gap}$$

At stand 12V:

$$(\ 1.963\ in^2 \div 1.581''\ ) - 0.125'' = 1.117''$$

This value is then subtracted from the roll end collar diameter to find the Effective Working Diameter.

Effective Working Diameter

Using groove factor and the roll diameter provided we calculate the Working Diameter by subtracting the Groove Factor from the end collar diameter. For this example we will assume all new roll diameters (maximum) from table 14 - 7.

At stand 12 that is:

$$16.700'' - 1.117'' = 15.583''$$

Roll RPM

Calculating the roll circumference at the Working Diameter (WD) and dividing that into the bar speed gives us the roll RPM:

$$(\ WD / 12\ ) \times \pi = \text{Circumference (feet)}$$

$$\text{Bar Speed (ft/min)} \div \text{Circumference (ft)} = \text{Roll RPM (/min)}$$

At stand 12 that is:

$$(\ 15.583'' / 12\ ) \times \pi = 4.080'$$

$$500\ ft/min \div 4.080' = 122.6\ /\ min\ (RPM)$$

Motor RPM

The Motor RPM is the Roll RPM multiplied by the drive ratio.

At stand 12 this is:

122.6 Roll RPM x 9.5 = 1164 Motor RPM

Carrying these calculations back to stand 6, using the Mill constant gives Roll and Motor RPM settings for zero tension rolling.

Table 14 - 6 shows the results of our calculations.

Stand	Area in^2	Width in	Gap in	Groove Factor in	Roll Dia. in	Work Dia. in	Mill Con-stant	Bar Speed ft/min	Roll RPM	Drive Ratio	Motor RPM
6H	6.401	2.530	0.500	2.030	24.000	21.970	981.5	153.3	26.66	38.0	1013
7H	4.914	3.356	0.250	1.214	19.700	18.486	981.5	199.7	41.27	25.0	1032
8V	4.072	2.277	0.250	1.538	19.700	18.162	981.5	241.0	50.69	25.0	1267
9H	3.326	2.718	0.250	0.974	19.700	18.726	981.5	295.1	60.19	15.0	902.9
10V	2.829	1.898	0.250	1.241	19.700	18.459	981.5	346.9	71.79	15.0	1077
11H	2.254	2.217	0.250	0.767	16.700	15.933	981.5	435.4	104.4	11.0	1148
12V	1.963	1.581	0.125	1.117	16.700	15.583	981.5	500.0	122.6	9.5	1164

Table 14 - 6

Motor Curves

The motor operating points can be graphically checked against rated capacity by plotting a motor power curve and motor torque curve. The motor power curve shown in figure 14 - 14 shows the motor operating range. The RPM across the X-axis and the power along the Y-axis. Minimum operating speed is taken as 30% of base speed, maximum speed limited to 95% of top speed to allow the motor some additional speed to adjust during operation for tension free rolling. Mill duty motor are typically rated with a 15% continuous operating overload capacity. This is shown as the upper curve. The graph shown is for stand 12 with the operating points shown as calculated above, with the power found from the power curve shown in chapter 2.

The torque curve shown in figure 14 - 15, shows the torque capacity of the motor at stand 12 and the operating points for the example above. All torque data on the curve is torque at the motor.

Speed Cone

A speed cone is used to plot bar speed against the speed capacity of the stands. For this mill arrangement a speed cone is shown in figure 14 - 16. The linear speed is plotted against the Y-

Stand	New Roll Dia	Discard Roll Dia	Motor Base RPM	Motor Max. RPM	Drive Ratio	Motor Power
1	28.000	24.080	900	1800	75	350
2	28.000	24.080	900	1800	58	350
3	28.000	24.080	900	1800	48	350
4	24.000	20.640	900	1800	48	450
5	24.000	20.640	900	1800	38	450
6	24.000	20.640	900	1800	38	450
7	19.700	16.900	900	1800	25	550
8	19.700	16.900	900	1800	25	550
9	19.700	16.900	900	1800	15	550
10	19.700	16.900	900	1800	15	650
11	16.700	14.400	900	1800	11	650
12	16.700	14.400	900	1800	9.5	650
13	16.700	14.400	900	1800	7	650
14	16.700	14.400	900	1800	7	650
15	16.700	14.400	900	1800	3.5	650
16	12.800	11.000	900	1800	2.8	650
17	12.800	11.000	900	1800	1.5	650
18	12.800	11.000	900	1800	1.5	650

Table 14 - 7

axis and the stand number across the X-axis. The top curve is the motors operating at 95% of rated speed with the rolls at discard diameter. The middle motor curve is the motor operating at base speed and the rolls at average diameter. The bottom curve is the motor operating at 30% of base speed with the rolls at new diameter. Linear speed of the bar is plotted to assure that it falls within the speed available at each stand.

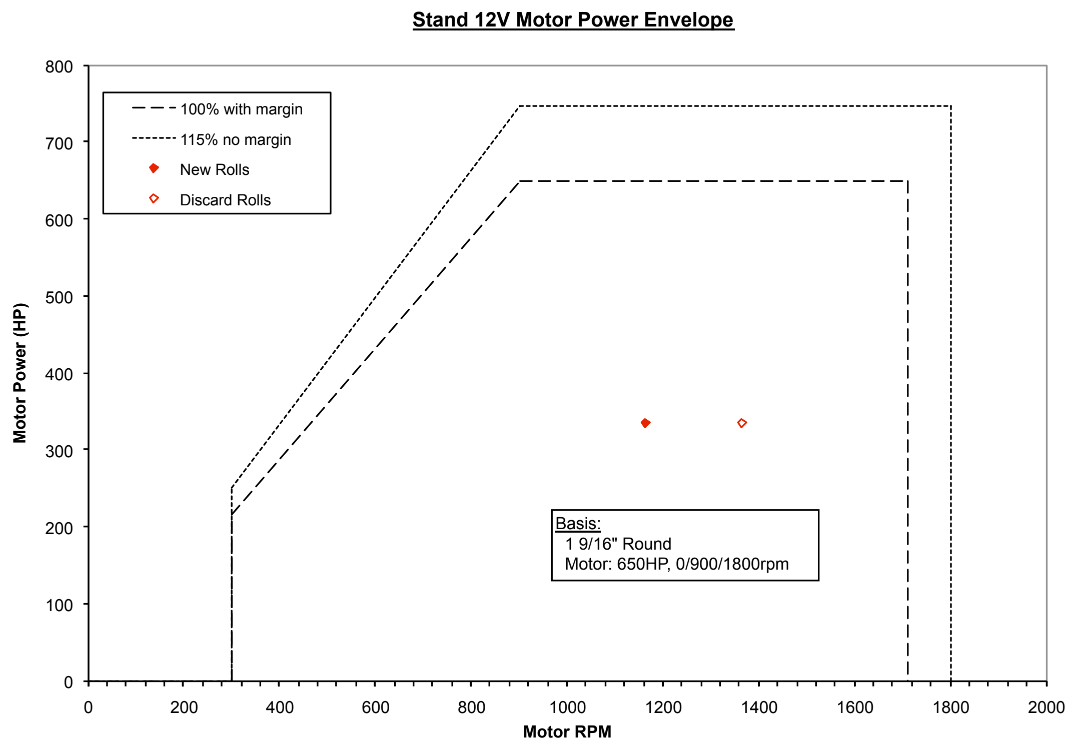

Figure 14 - 14

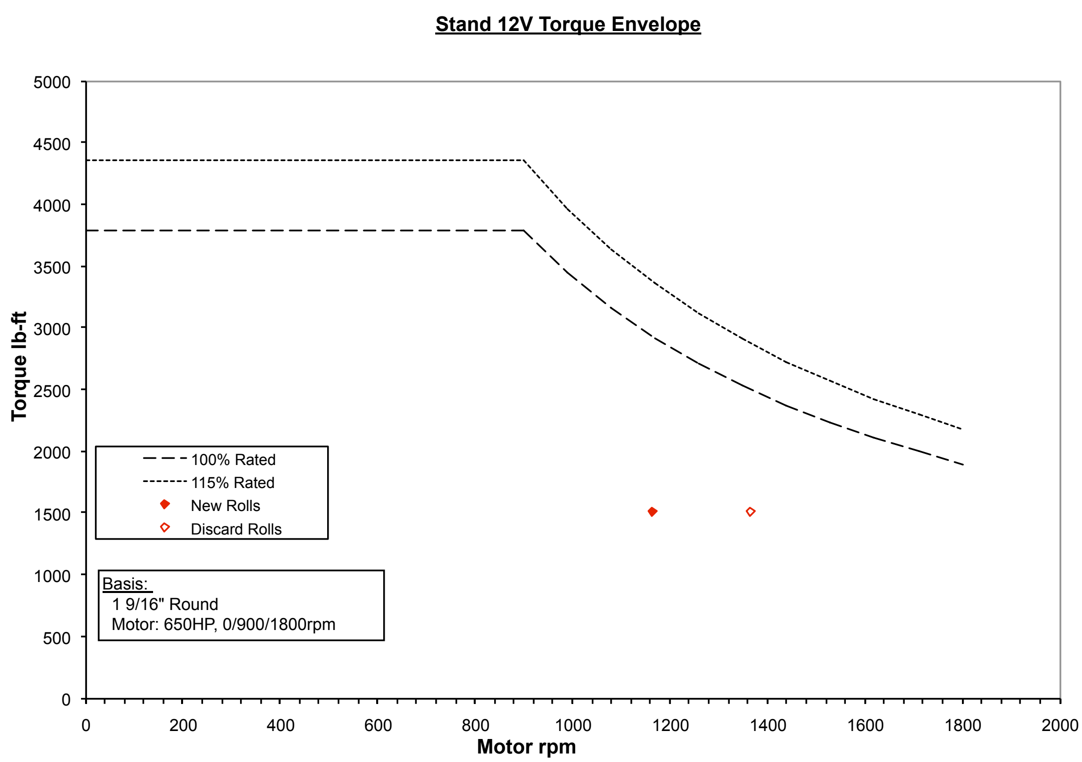

Figure 14 - 15

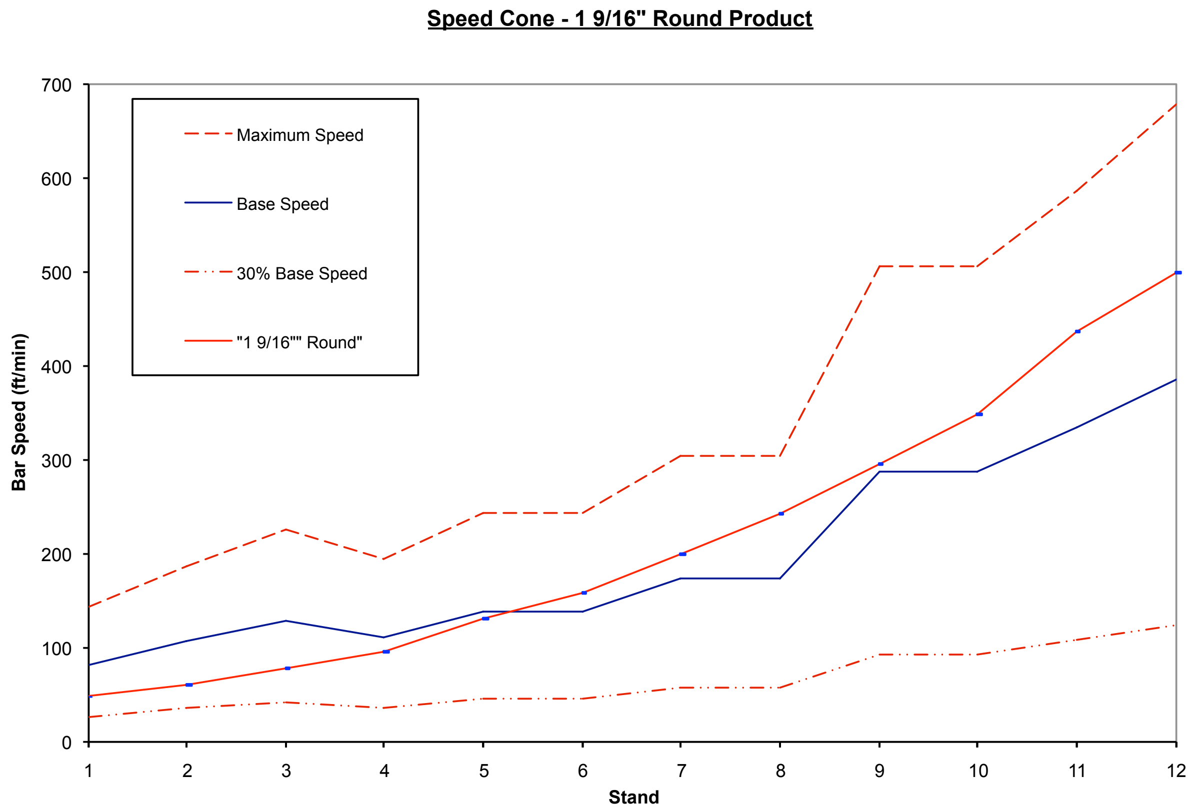

Figure 14 - 16

Mill Speed Setup Exercise

Input values for setting mill motor speeds are production rate, roll collar diameters, roll gaps, bar areas and widths, and gear ratios. Motor speed ratings will be checked against calculated speeds. Using the breakdown pass sequence for producing the 2.530" square out of stand 6 from a 5" x 5" billet in chapter 5, we will calculate the motor setup speeds to roll the roughing mill.

Bar Speed

Using the production tonnage rate for the product a mill constant will be used to find the bar speed at each stand.

We will calculate the setup data for the 2.530" square bar using a box pass design we developed in chapter 5. The pass design data is shown below in table 14 - 8 and the stand information from table 14 - 7.

Stand	Shape	Width	Thickness	Draft	Spread	Area	Roll Gap	Reduction
1V	Box	3.762	5.330	1.238	0.330	20.050	0.500	19.7%
2H	Slab	4.165	3.944	1.396	0.403	16.430	3.944	18.1%
3V	Box	2.957	4.344	1.209	0.400	12.845	0.500	21.8%
4H	Slab	3.338	3.128	1.216	0.381	10.440	3.128	18.7%
5V	Box	2.146	3.604	1.192	0.476	7.734	0.500	25.9%
6H	Slab	2.531	2.530	1.074	0.385	6.403	2.530	17.2%

Table 14 - 8

Given a tonnage rate of ________ tons/hour and an area at stand 6 of 6.403 in^2 we have a bar speed at stand 6 of:

(_______ tons/hour x 1 hour/60 minutes) x 2000 lbs/ton =

_____________ tons/min x 2000 = ____________ lbs/min

____________ lb/min ÷ (_______ in^2 x 12 in x 0.283 lb/in^3) =

____________ lb/min ÷ (___________ lb/ft) = ___________ ft/min

Mill Constant

Using the delivery speed out of stand 6H and the bar area we construct a mill constant to find the bar speed at each stand.

Mill Constant = Bar Area x Speed at 6H:

____________ in^2 x ____________ ft/min = ____________ (in^2 - ft/min)

Then to find the bar speed at each stand we divide the Mill Constant by the bar area:

Bar Speed = Mill Constant ÷ Bar Area

At stand 5V:

____________ (in^2 - ft/min) ÷ ____________ in^2 = ____________ ft/min

At stand 4H:

____________ (in^2 - ft/min) ÷ ____________ in^2 = ____________ ft/min

At stand 3V:

____________ (in^2 - ft/min) ÷ ____________ in^2 = ____________ ft/min

At stand 2H:

____________ (in^2 - ft/min) ÷ ____________ in^2 = ____________ ft/min

At stand 1V:

____________ (in^2 - ft/min) ÷ ____________ in^2 = ____________ ft/min

Groove Factor

Using the bar area width and roll gap, we can develop a Groove Factor that we will use to find the Working Diameter given the roll end collar diameter.

Groove Factor = (Bar Area ÷ Bar Width) - Roll Gap

At stand 6H:

(____________ in^2 ÷ ____________") - ____________" = ____________"

At stand 5V:

(____________ in^2 ÷ ____________") - ____________" = ____________"

At stand 4H:

(____________ in^2 ÷ ____________") - ____________" = ____________"

At stand 3V:

(____________ in^2 ÷ ____________") - ____________" = ____________"

At stand 2H:

(____________ in^2 ÷ ____________") - ____________" = ____________"

At stand 1V:

(____________ in^2 ÷ ____________") - ____________" = ____________"

This value is then subtracted from the roll end collar diameter to find the Effective Working Diameter.

Effective Working Diameter

Using groove factor and the roll diameter provided we calculate the Working Diameter by subtracting the Groove Factor from the end collar diameter. For this example we will assume all new roll diameters (maximum) from table 14 - 7.

At stand 6H that is:

_____________" - _____________" = _____________"

At stand 5V that is:

_____________" - _____________" = _____________"

At stand 4H that is:

_____________" - _____________" = _____________"

At stand 3V that is:

_____________" - _____________" = _____________"

At stand 2H that is:

_____________" - _____________" = _____________"

At stand 1V that is:

_____________" - _____________" = _____________"

Roll RPM

Calculating the roll circumference at the Working Diameter (WD) and dividing that into the bar speed gives us the roll RPM:

(WD / 12) x π = Circumference (feet)

Bar Speed (ft/min) ÷ Circumference (ft) = Roll RPM (/min)

At stand 6H that is:

(_____________" / 12) x π = _____________'

_____________ ft/min ÷ _____________' = _____________ / min (RPM)

At stand 5V that is:

(_____________" / 12) x π = _____________'

_____________ ft/min ÷ _____________' = _____________ / min (RPM)

At stand 4H that is:

(_____________" / 12) x π = _____________'

_____________ ft/min ÷ _____________' = _____________ / min (RPM)

At stand 3V that is:

(_____________" / 12) x π = _____________'

_____________ ft/min ÷ _____________’ = _____________ / min (RPM)

At stand 2H that is:

(_____________” / 12) x π = _____________’

_____________ ft/min ÷ _____________’ = _____________ / min (RPM)

At stand 1V that is:

(_____________” / 12) x π = _____________’

_____________ ft/min ÷ _____________’ = _____________ / min (RPM)

Motor RPM

The Motor RPM is the Roll RPM multiplied by the drive ratio.

At stand 6H that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

At stand 5V that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

At stand 4H that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

At stand 3V that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

At stand 2H that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

At stand 1V that is:

_____________ Roll RPM x _____________ = _____________ Motor RPM

Carrying these calculations back to stand 1, using the Mill constant gives Roll and Motor RPM settings for zero tension rolling.

Table 14 - 9 shows the results of our calculations.

Stand	Area in^2	Width in	Gap in	Groove Factor in	Roll Dia. in	Work Dia. in	Mill Con-stant	Bar Speed ft/min	Roll RPM	Drive Ratio	Motor RPM
1V											
2H											
3V											
4H											
5V											
6H											

Table 14 - 9

Measuring Mill Performance

Several common benchmark measurements of mill performance can be used to track historical mill performance and for mill to mill and plant to plant comparisons. These are yield, utilization, and cobble rate.

Yield

Yield is the measurement of production loss from furnace charge to bundled or coiled finished product. The factors that influence yield are scale loss, crop loss, cobble loss, and any other factor that reduces the weight of the finished product. When the billet is charged into the reheat furnace, it is either weighed or assumed to have a nominal weight based on its cross section and grade. As is progresses through the furnace scale is formed that is removed at the descaler or fall off during rolling. This can amount to 1.5% of the charged weight. A more normal figure is 0.85%. Shears that remove the malformed front end of the bar as it progresses through the mill can remove up to 1 foot of material at each shear. After dividing the bar onto the cooling bed, a cold shear or saw cuts the bar to sell lengths, cleaning up the variations in length. Structural mills often take an additional saw cut on stacked and bundled material. All the removed material contributes to yield loss. Good figures for yield are around 98% for bar and rod mills, 92% for structural mills, and 101% for rebar mills. The last figure is the result of selling to nominal weight, calculating that weight based on rolled length, and actually rolling the product at 97% of nominal.

If a mill rolls 750,000 tons per year of sold product, and has a 95% yield, 5% of the product is lost. It must therefore charge 750,000/0.95 or 789,474 tons of billets to create the sold tons. That is 39,474 tons of lost production. If the yield can be improved by just

1%, the extra finished steel is 750,000/0.95 - 750,000/0.96 = 8224 tons. If the average selling price is $950/ton that is 8224 x 950 = $7,812,800 of increased sales. If the profit margin on sales is 15%, that is $1,171,920 of increased profit.

Annual tonnage: ______________________

Present yield: ________________________

Charged tons = Annual tons / Present yield

______________ / ______________ = _____________

Improved yield: _______________________

Extra finished tons = Annual tons / Present yield - Annual tons / Improved yield

______________ / ___________ - ______________ / ___________ = _____________

Average selling price: _______________

Increased sales = Extra charged tons x Average selling price

_______________ x _________________ = _____________

Profit margin: __________________

Increased profit = Profit margin x Increased sales

_____________ x ____________ = ___________

Utilization

Mill utilization is a measure of the percentage of time that the mill is rolling steel. The truest measure of performance is as a percentage of calendar time. Factors that influence utilization are maintenance outages, scheduled and unscheduled, vacation outages, downtime for cobble clearing, roll and pass changes, excess billet gap, and other factors that create time when a billet is not in the mill. Good figures for rod and bar mills is 90 to 93%, for structural mills 75 to 78%.

If a mill rolls 80% of the calendar year, that is 365 x 24 x 0.80 = 7008 hours. If the mill rolls 789,474 tons per year, it runs at 112.6 tons/hour. If the utilization can be improved by 1%, the available rolling hours is 365 x 24 x 0.81 = 7096.6, creating 87.6 extra rolling hours. At 112.6 tons/hour that is an additional 9863.8 tons rolled. At the above mentioned 95% yield that is 9370.6 additional finished tons. If the average selling price is $950/ton that is 9370.6 x 950 = $8,901,500 of increased sales. If the profit margin on sales is 15%, that is $1,335,225 of increased profit.

Present utilization: ______________________

Current rolling hours = 365 days x 24 hours/day x Present utilization

365 x 24 x ______________ = _____________

Current annual tons: _____________

Current rolling rate = Annual charged tons / Current rolling hours

Improved utilization: _______________________

Improved rolling hours = 365 days x 24 hours/day x Improved utilization

365 x 24 x ______________ = _____________

Extra rolling hours = Improved rolling hours - Current rolling hours

______________ - ______________ = _____________

Extra rolled tons = Current rolling rate x Extra rolling hours

___________ x ___________ = ___________

Current yield: ___________

Extra finished tons = Extra rolled tons x Current yield

______________ x ______________ = ______________

Average selling price: _______________

Increased sales = Extra finished tons x Average selling price

_______________ x _________________ = _____________

Profit margin: __________________

Increased profit = Profit margin x Increased sales

_____________ x ____________ = ___________

Excess billet gap can be an unaccounted for loss of rolling time. If a mill rolls 789,474 tons per year using 1.5 ton billets, it rolls 526,316 billets per year. That is 526,315 billet gaps. If the average billet gap is 5 seconds, that is (5 sec x 526,315) / 3600 sec/hour = 731 hours of billet gap. If the average billet gap is reduced by 1/2 second that would be (4.5 sec x 526,315) / 3600 sec/hour = 658 hours of billet gap, creating an additional 73 hours of rolling time. At 112.6 tons/hour that is an additional 8,212 tons rolled. At the above mentioned 95% yield that is 7,809 additional finished tons. If the average selling price is $950/ton that is 7,809 x 950 = $7,418,370 of increased sales. If the profit margin on sales is 15%, that is $1,112,755 of increased profit.

Current annual tons: _____________

Average billet weight: _____________

Number of billet gaps = Current annual tons / Average billet weight - 1

_____________ / _____________ - 1 = _____________

Current billet gap: ____________ sec

Current total billet gap time (hours) = (Current billet gap x Number of billet gaps) / 3600

_____________ x _____________ = _____________

Improved billet gap: ____________ sec

Improved billet gap time (hours) = (Improved billet gap x Number of billet gaps) / 3600

_____________ x _____________ = _____________

Extra rolling hours = Current billet gap (hours) - Improved billet gap (hours)

______________ - ______________ = _____________

Extra rolled tons = Current rolling rate x Extra rolling hours

____________ x ____________ = ____________

Current yield: ____________

Extra finished tons = Extra rolled tons x Current yield

_______________ x _______________ = _______________

Average selling price: ________________

Increased sales = Extra finished tons x Average selling price

________________ x __________________ = ______________

Profit margin: ___________________

Increased profit = Profit margin x Increased sales

______________ x _____________ = ____________

Cobble Rate

Cobble rate is the measure of the percentage of charged billets lost to cobbles. If the cobble rate is 0.75%, then 0.75% of all billets charged are lost to cobbles. If a mill rolls 526,316 billets per year that would be 3947 billets lost. At 1.5 tons per billet that is 5921 lost tons. At $750 per ton selling price that is $4,440,750 in lost sales, at 15% profit margin, that is $666,113 in lost profit.

If the cobble rate can be improved by 0.25%, it saves 3947 - 0.5/100 x 526,316 = 1315 billets per year. At 1.5 tons each, that is an additional 1973 tons rolled. At 95% yield, that is 1874 finished tons. At $950 per ton and 15% profit margin, that is an additional $1,780,300 of sales and $267,045 in additional profit.

Current annual tons: ______________

Average billet weight: ______________

Annual number of billets = Current annual tons / Average billet weight

______________ / ______________ = ______________

Current cobble rate: _____________ %

Current lost billets = Annual number of billets x Current cobble rate

______________ x ______________ = ______________

Improved cobble rate: _____________ %

Improved billet gap time (hours) = (Improved billet gap x Number of billet gaps) / 3600

______________ x ______________ = ______________

Extra rolling hours = Current billet gap (hours) - Improved billet gap (hours)

_______________ - _______________ = ______________

Extra rolled tons = Current rolling rate x Extra rolling hours

____________ x ____________ = ____________

Current yield: ____________

Extra finished tons = Extra rolled tons x Current yield

_______________ x _______________ = _______________

Average selling price: ________________

Increased sales = Extra finished tons x Average selling price

________________ x __________________ = ______________

Profit margin: ___________________

Increased profit = Profit margin x Increased sales

______________ x _____________ = ____________