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Pellet mill design

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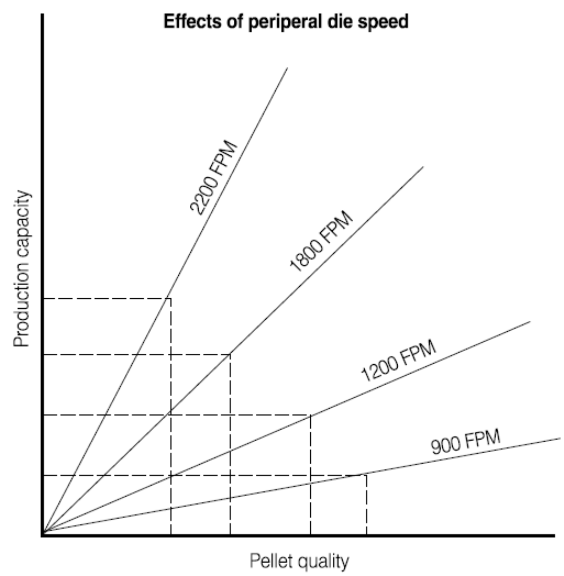
When considering at pellet mill design, there are some important aspects to study to achieve maximum efficiency of the machine. Maximum efficiency is defined as the ideal combination of producing the best pellet quality possible, at the maximum production capacity, for the least amount of energy being used. In order to achieve this ideal efficiency, both the pellet die speed and the ratio of the die working face area to the amount of power being used must be correct for each individual application.

Die speed is typically measured at the outside diameter of the die, which is either referred to as the "peripheral speed" or the "tip speed" of the die. For the majority of applications, the die speed that is generally used for maximum performance should be 9 meters per second for all easy-running materials being pelleted where small-diameter pellets are being produced. For hard-running materials, 6 meters per second is a typical die speed used to reduce the amount of vibration in the machine. The lower die speed is also used when pellet quality is of extreme importance, so as to reduce the amount of pellet breakage caused by the centrifugal force of the pellets leaving the die and hitting the inside of the pellet chamber door. Peripheral speeds exceeding 9 meters per second may result in deterioration of pellet quality, but an increase in production capacity. Conversely, peripheral speeds below 6 meters per second will typically result in an improvement in pellet quality, but a decrease in production capacity. If the peripheral speed of the die is too low, the die may be fed incorrectly and cause uneven wear on the die face and roller shell. **Figure 3-1** demonstrates the effects of peripheral speed on pellet quality and production capacity.

Figure 3-1. The effects of peripheral speed on pellet quality and production capacity (graphic representation only; not to scale).



Power

The ratio of power (kilowatts) to die working surface area is important to both ensure the machine has enough power to handle each application and prevent the main motor from being oversized. It is imperative that the machine has the correct size motor so motor power does not exceed the design limits of the machine being used. Each pellet mill is designed to utilize and accept a certain amount of maximum power, and the gears or belts and bearings are designed and selected to maximize lifetime use. A pellet mill is considered to be the type of machine that can be subjected to "shock loads", so there is typically at least a 2:1 safety factor built into the design of the main driving members and at least a 10-year life expectancy on the design of the bearings used to prevent premature part failure.

Table 3-1 shows the ratio of power to die working surface area. These values can be used as a general guideline for the applications listed, but may fluctuate due to the variation in feed ingredients and formulations, as well as to the pellet quality desired. The pellet mill manufacturer should be consulted as necessary for the ideal set-up regarding other applications or applications with non-typical ingredients.

Table 3-1. Die surface area to horsepower ratio.

Application	**Die area:horsepower, cm^2/kilowatt**
Broiler	25.95-27.68
Turkey	24.22-25.95
Swine	22.49-24.22
Fish/Shrimp	20.76-22.49
Dairy (high grain)	19.03-20.76
Dairy(high fiber)	17.30-19.03
Beef (high mineral)	12.98-14.71
Single ingredient (alfalfa, beet pulp, gluten)	12.11-14.71

The above recommended values may vary due to feed ingredient variation or desired pellet quality.

Drive arrangements

Historically, there have been two types of drive arrangements for a pellet mill: gears or belts. Depending on a variety of factors, one type of drive arrangement may be preferred over another in specific instances. For example, a single-reduction gear set with standard 1,800 or 1,200 RPM motors may be used to achieve the recommended die speeds for all different die sizes on a gear-driven pellet mill. Meanwhile, a belt-driven machine may require a double-reduction belt drive with the larger dies in order to maintain the peripheral speed of the die within acceptable limits. This is in part due to the size of the sheaves needed for these types of drives and requires the use of low-speed (900 RPM or 1,200 RPM) motors, which are more expensive than the normal high-speed (1,800 RPM) motors more commonly used with the gearbox design.

A typical gearbox is line bored on a machine so the gears are absolutely parallel to one another and have the correct center distance. This ensures correct meshing and contact of the gear teeth, thus allowing for nearly 100% of the motor load to be transmitted to the die. A large-power belt-driven machine uses a multiple number of v-belts, which must be perfectly matched set in order to transmit the power to the die. When belts are not perfectly matched, there may be a rollover of some of the belts when under load, causing the belts to break and resulting in a loss in overall efficiency.

Generally, both a single-reduction gear arrangement and timing belts will have a mechanical efficiency between 96-98%. Conventional v-belt drives will typically have an efficiency of 90-96% depending on the level of maintenance. If the recommended die speed requires a two-stage reduction belt drive, the efficiency of this type of drive will drop as low as 81-92%. When comparing the two types of drives, we see that a gear-driven pellet mill can be as much as 10% more efficient than a single-stage belt drive machine, and as much as 20% more efficient than a two-stage belt drive machine. This difference in efficiency will result in more or less energy being used, depending on which drive arrangement is being used. Generally speaking, a gear-driven pellet mill will be more efficient to operate than a belt-driven machine, thus resulting in lower energy costs for the gear-driven machine.

Drive loading

A pellet mill can be applied to a wide variety of many different applications, and the drive loading can vary from an easy, uniform load to severe shock loading. The power transmission should be designed for more severe conditions, safety, reliability and overall longevity. Generally, the gearing used in a typical gear-driven pellet mill is life and durability limited, not shock load limited. Therefore, the tooth design is more than adequate to handle any shock loading. In the case of belt drives, the shock resistance of the belts is limited by a combination of heat dissipation capacity, the tensile strength of the reinforced strands and the durability of the friction surfaces in contact with the sheaves. With belts, shock loading increases the heat being generated in the belts because of the shock energy absorption. Shock increases the wear of the friction surfaces because of the added movement against the sheave face, and loads can exceed the tensile limit of the reinforcing strands because shock loading can initiate a whipping action of the belts. Shock and overload conditions are better handled by a gear drive, thus providing longer overall service life than a belt drive.

The highly-variable loads which can occur in a pellet mill can generate overload conditions. Stalled conditions are usually caused by the die plugging and/or trying to start the mill under load. Gear drives can withstand overload conditions because the gear teeth are proportioned for durability or life conditions, and are designed to withstand these conditions. A properly-maintained belt drive can withstand overload or stalled conditions, but if the belt tension is below the design level, belt slippage can occur and the belts can be destroyed and need to be replaced completely.

Environmental considerations

Airborne dust occurs, to some extent, in all pellet mill installations. The composition of the dust will depend upon the materials being processed. Under the worst conditions, the dust can be corrosive or abrasive. A gear-driven pellet mill has a gearbox that is sealed to prevent any dust from entering, and is also usually fitted with a lubrication system that includes a filter and oil cooler to maximize the life of the components. A belt-driven pellet mill usually includes belt guards that have openings to provide adequate air ventilation. These openings will allow dust to enter the drive area and, under severe conditions, can result in accelerated belt and sheave wear.

Noise considerations

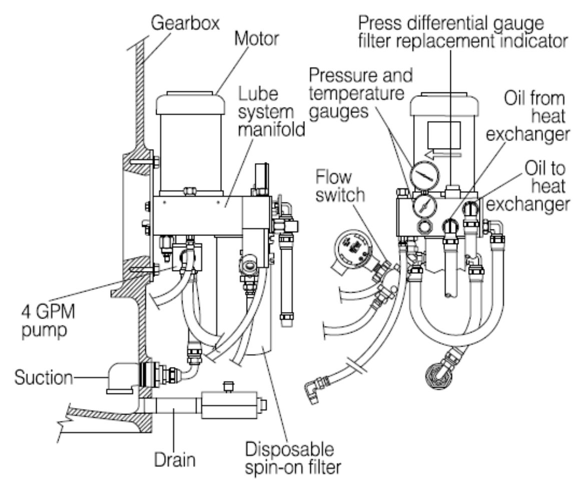
A pellet mill can contribute to the overall noise of a feed mill, and belt-driven pellet mills are usually quieter than a gear-driven machine; however, a correctly-designed gear drive is usually well within the required decibel sound limitations.

Heat

Pellet mills are usually exposed to heat in a typical feed mill environment when under operating conditions. An oil cooler is normally installed as part of the oil system on a gear-driven pellet mill and can use either water or air as the heat transfer medium, with the air cooler being the preferred method.

The oil system is normally fitted with a low-temperature switch which turns on the air cooler fan motor when the oil temperature is above 60°C. This allows the oil to continue to operate at the desired temperature. This system is also fitted with a high-temperature switch, which turns the pellet mill off if the oil temperature gets above 77°C, so as to protect the oil seals from deteriorating due to exposure to continuous high temperatures. The oil system is also usually fitted with a flow switch which turns the pellet mill off if there is no flow to the bearings. There is also a pressure-relief device in the system that is normally set to operate at approximately 4 Bar.

Figure 3-2. Circuit lube system in a gear-driven pellet mill.



Lubrication

Gear-driven pellet mills are now fitted with integrated circuit lube systems (see **Figure 3-2**), which not only cool and filter the oil, but also incorporate devices to control the temperature, flow rate and pressure. They also come equipped with simple spin-on disposable oil filters which are easy to replace. There is no low-temperature limitation to a belt drive, but high ambient temperatures can shorten the belt life because of the reduced ability of the drive to dissipate the heat generated by the power transmission. There is no practical way to cool a belt drive.

Static

Pellet mills can be installed in an explosion-proof environment where there is the possibility of static electricity being present and the possible generation of sparks occurring. Gear-driven pellet mills do not generate static electricity, but belt drives do have the potential of generating static electricity. This potential problem can be reduced by using static-free belts.

Covers

The gearbox on a gear-driven pellet mill is totally enclosed, protecting the operator from any moving components, thus any failure of the transmission will be contained within the gearbox enclosure. The rotating members of a belt drive are normally enclosed in sheet metal covers, offering protection to the operator in case of a failure. However, these covers do have openings to allow for air circulation, and these openings can provide opportunities for foreign objects to enter the moving belt drive. When these covers are removed for maintenance purposes, they must be reinstalled properly in order to prevent risk of injury to the operator.

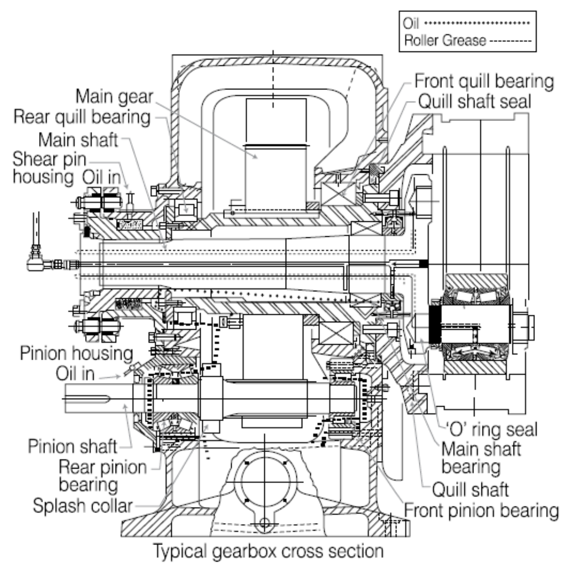
Maintenance

The main gear used within a gear-driven pellet mill is reversible, allowing it to be turned over when one side of the gear teeth is worn, thus doubling the operating life. When belts become worn on a belt-drive machine, an entirely new set of belts must be fitted. Though belts typically must be changed more often, it is a less intensive process than working within the gearbox of a gear-driven machine. Gear-driven pellet mills require using the correct lubrication recommended by the manufacturer, and the oil should be replaced at regular intervals, approximately every 2,000 operating hours. An oil filter is used within the lubrication system and should be replaced each time the oil is changed. A belt-driven pellet mill does not require changing oil, but requires regular lubrication at regular intervals with the recommended grease specified by the manufacturer. **Figure 3-3** shows a cross-section view of a typical single-reduction, gear-driven pellet mill showing the major components and lubrication system.

Quillshaft assembly

As seen in **Figure 3-3**, the quillshaft supporting the main gear and the die is made in two separate pieces. In earlier designs, the quillshaft was all one piece. It should be noticed that the quill flange, or die driving rim, is now bolted to an inner quillshaft which directly supports the main gear. This newer design allows for mounting different size dies onto the same gearbox, thus allowing the same gearbox components to be used with a number of different size dies. This modular concept not only allows the manufacturer to keep the parts inventory to a minimum, but it also means that the user can replace just the quill flange when it is worn and not have to completely disassemble the gearbox and replace the whole quillshaft assembly.

Figure 3-3. Typical single-reduction gear-driven pellet mill.

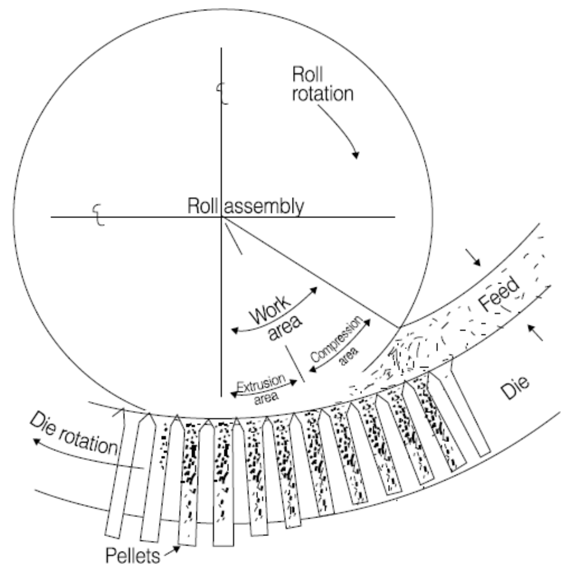


It should also be noticed that the quill flange is fitted with a die wear insert ring located directly between the quill flange and the die itself. This wear insert can easily be replaced, and it prevents wear from occurring directly to the surface of the quill flange. This new modular design minimizes replacement part costs and reduces the downtime necessary to rebuild the pellet mill. It also allows the user to convert an existing pellet mill to a larger die machine at a later date if and when production capacity increases while keeping the existing gearbox, base, motor, electrical wiring, etc., the same as before. Gear-driven pellet mills are fitted with a symmetrical main gear to allow use of both sides of the gear teeth. As mentioned above, this means that the main gear can be reversed when one side of the gear teeth is worn, doubling the overall life of the main gear and keeping replacement part costs to a minimum. The pinion shaft is heat-treated and ground, and is much harder and wear-resistant than the softer main gear, so its life is also prolonged. Both gears usually have helical cut teeth in order to reduce the noise and increase the overall face width and load bearing capacity.

Gearbox

A typical gearbox is fitted with a shear pin arrangement located within easy reach at the rear of the pellet mill, as shown in **Figure 3-3**. If a piece of foreign material enters the die cavity, these pins are designed to shear immediately, thus protecting the die, rolls and gears from premature failure. These pins also sometimes shear as a result of the die plugging with feed material; however, they can usually be replaced within minutes, keeping downtime to a minimum and preventing a major overhaul from becoming necessary. While large electric motors are more efficient than smaller ones in converting electrical energy into useful shaft work, some belt-driven pellet mills are equipped with two small main drive motors instead of one large one due to the power limits of the belt drives. Unfortunately, load sharing is difficult to balance with dual motor systems, potentially resulting in higher power consumption and cost. Non-identically matched electric motors results in the “push-pull” effect, with one motor always working harder than the other. The harder-working motor is then more liable to break down sooner. Start-up energy is essentially the same for one or more motors of the same total power and pellet mills of the same rotary inertia. The dual motor system is inherently more complex than the single motor system, with dual motors requiring additional electrical wiring, two motor mounts, and two drive connections. All of these factors point towards higher maintenance and operating costs when using dual motors instead of a single motor.

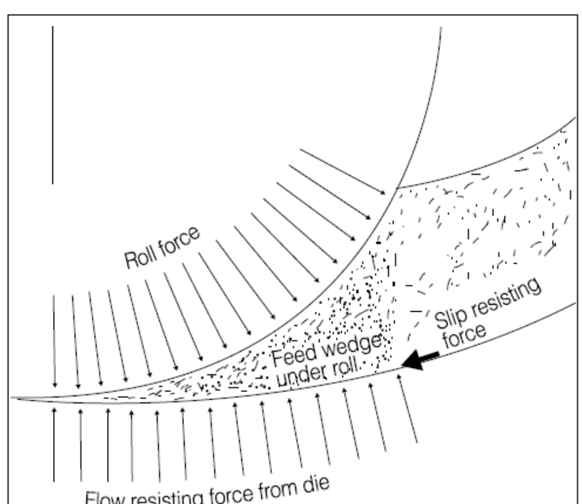
Figure 3-4. The die and roller assembly.



Inside the die cavity

Various factors affecting pelleting occur inside the die cavity. This area is the heart of the pellet mill, where the actual pelleting process occurs. This is where the pellets are being produced, at the nip point between the die and the rolls. **Figure 3-4** shows a close-up of one roller assembly and its relationship to the die. The die is driven by the gear drive, and the roller assembly depends on the frictional force from contact with the pad of feed material between the die and the roll to generate the driving force that causes the roll to rotate.

Figure 3-5. Forces acting on feed at the nip point.



The work area is comprised of the compression area where the feed is initially compressed; the extrusion area is where the feed is forced into and through the holes in the die. To fully understand how a pellet mill works, one must also become conscious of the forces and how they are applied within the die cavity. In particular, this involves the forces acting on the wedge of feed at the nip point between the die and the roll (see **Figure 3-5**).

The "roll force" is the force from the roll acting on the material, in relationship to the contact point with the die. It is this force that compresses the material to be pelleted on the die face, then extrudes it through the die to form pellets. The "radial force" is the force from the die that resists the flow of material through the holes of the die. The "tangential force" is the force along the face of the die that keeps the material from slipping along the face of the die in front of the roll. This force is related to the pressure exerted by the roll and the frictional characteristics of the feed material.

Figure 3-6. Feed rate versus roll force.

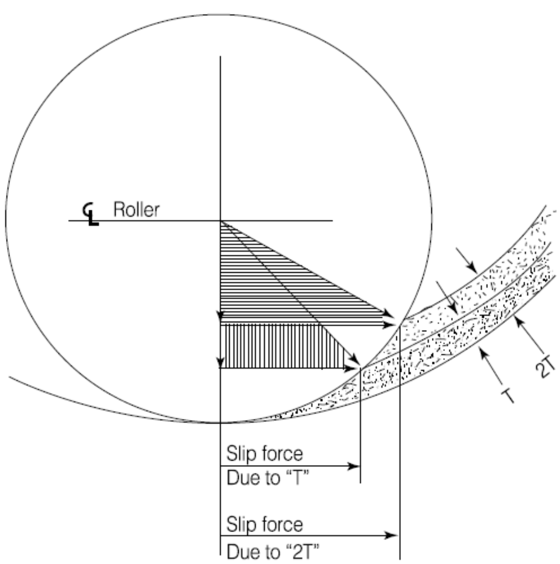


Figure 3-6 demonstrates what occurs when the feed rate is doubled and the pad of feed material in front of the roll is twice as thick. With the thicker pad, the roll tends to push the material forward instead of down into the holes. The slip force is what tends to cause the pad of feed material to skid along the die face, thus causing the die to plug or choke. From the simple force diagrams, it can be seen that the slip force caused by pad thickness "T" is much less than the slip force caused by pad thickness "2T." So, the larger slip force generated by pad thickness (2T) now overcomes the slip-resisting force. The material then ceases to pass under the roll, causing the pelleting process to cease, which results in the die cavity being filled with material until the die plugs.

Figure 3-7. Determining nip angle.

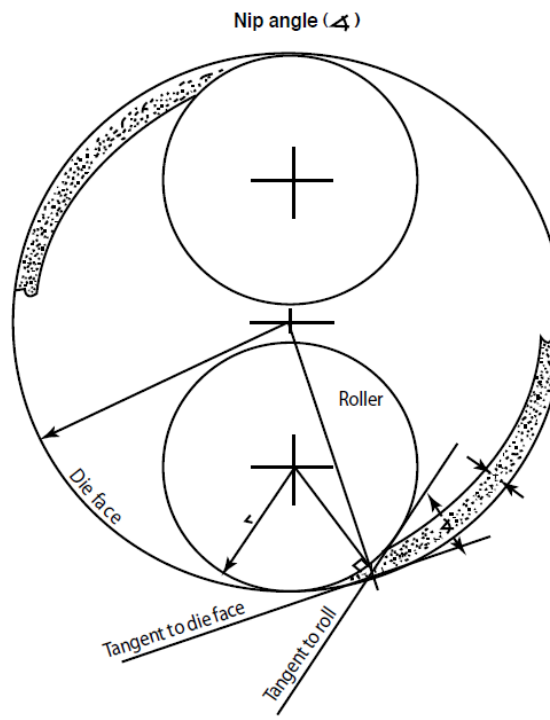
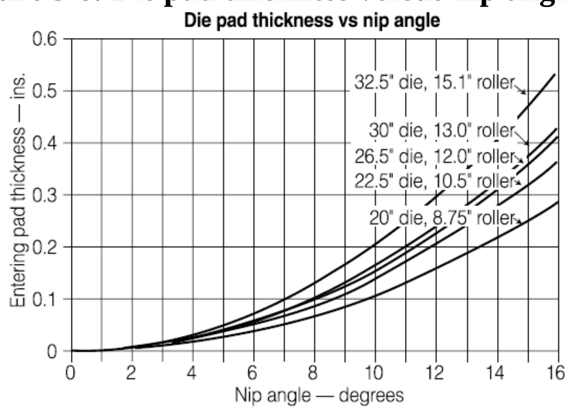


Figure 3-7 shows how the nip angle is determined between the die and roll. This is the angle formed by a line tangent to the die radius and a line tangent to the roll radius, measured at a point where the pad of feed material on the die face meets the roll.

Figure 3-8 shows the relationship between the nip angle and the pad thickness for different sized dies and rolls. As can be seen from the graph, the smaller die and rolls can only tolerate a much thinner pad thickness than the larger die and rolls for the same nip angle. Because a pellet mill with a larger die and rolls can operate with a thicker pad, it is much more energy efficient than a mill with smaller ones—leading to greater production capacity and reduced energy usage.

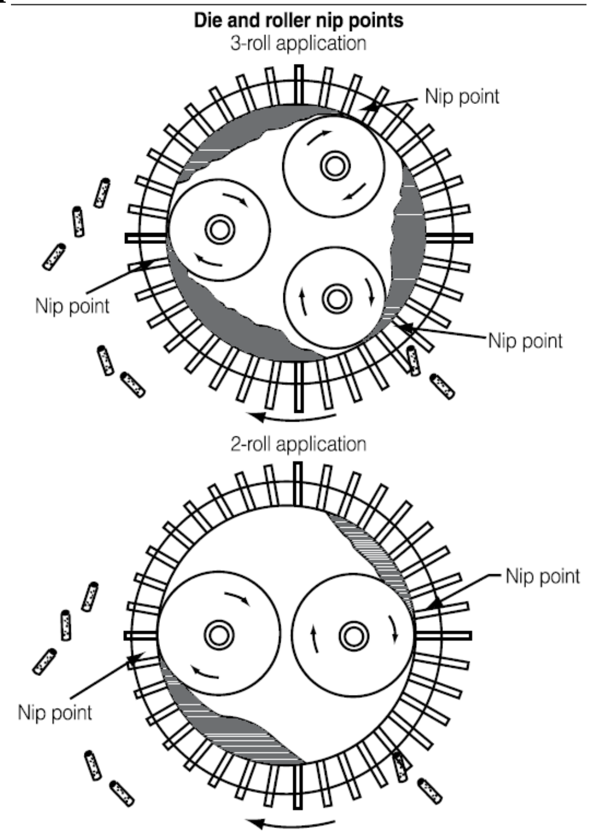
Figure 3-8. Die pad thickness versus nip angle.



Roll Configurations

Figure 3-9 shows the comparison between a pellet mill having three rolls to one having two rolls using the same size die. The rolls used on the two-roll machine are much larger than the rolls used on the three-roll machine, indicating that the two-roll machine has a much smaller nip angle between the die and roll than exists on the three-roll machine. This allows the two-roll machine to run with a much thicker pad of material on the die face than that which is possible on the three-roll machine. There is also more open area to allow the feed material to enter the die cavity on the two-roll machine than there is on the three-roll. Generally, a two-roll machine uses a simple feed chute that utilizes gravity to feed material into the die cavity and evenly distribute it between the two rolls. Successfully getting the feed material into the die cavity of a three-roll machine, and distributing it evenly, however, may require the use of a motorized force feeder instead of a simple feed chute. Comparative tests have shown that a pellet mill with two large rolls will produce up to 15% more capacity than a mill with three small rolls (when using the same size die and running the same material)—making the two-roll machine much more efficient than the three-roll machine. The use of three rolls is meant to decrease the load on the die and reduce the amount of die deflection when in production; however, correct die design enables the die to withstand the loads experienced during full production when using two rolls and keeps die deflection to a minimum.

Figure 3-9. Die and roller nip points three-roll application.

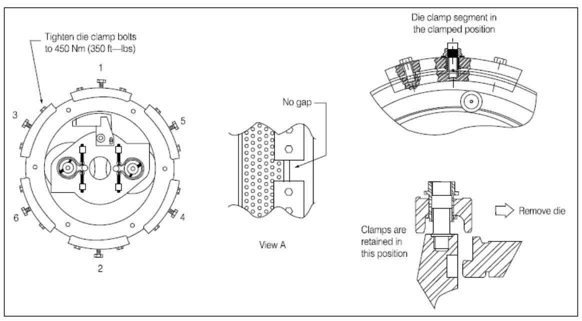


Mounting dies

There are basically two methods for mounting a die onto a pellet mill. One is to bolt the die on using a number of high tensile steel bolts which are directly screwed into the rear of the die. The other method is to clamp the die on by using a die clamp with tapered contact areas (see **Figure 3-10**). Die clamps come with different numbers of segments depending on the size of the die being used. The larger dies usually have more die clamp segments than the smaller dies. This is in order to keep the weight of each segment down, allowing easier installation and providing the best clamping action possible to hold the larger dies securely in place. One example is a design in which each die clamp segment is held in place with one spring-loaded fastener located in the center and two regular fasteners located at the outside.

When changing or mounting a die, the two regular fasteners are removed and the spring-loaded fastener is loosened to the point where the die clamp backs away from the quill flange, allowing clearance. The two regular fasteners can also be used as jacking screws to pry the die clamp loose if necessary. With this design it is not necessary to remove the die clamp segments completely, as they remain in place while the die is being removed or mounted. Dies that are bolted on usually take longer to change than those that are clamped on, as the bolt-on dies usually require a stiffening ring to be bolted to the front of the die. Dies that are clamped on have a stiffening ring incorporated into the front of the die, which is integral with the die design, thus eliminating the need to be replaced or refitted each time.

Figure 3-10. Die clamps.

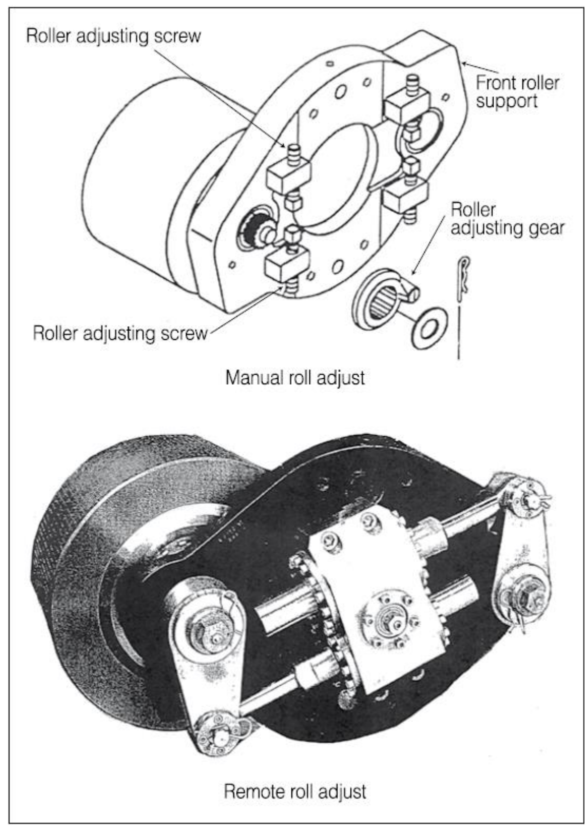


Roll Adjustment

All pellet mills have roller assemblies that need to be repositioned and adjusted to allow for the correct running clearance between the rollers and the die face. This is one of the most critical adjustments made on a pellet mill to guarantee maximum performance and allow for the longest die and roll life possible. The correct adjustment allows for a minimum clearance between the die face and the roll—often referred to as a "skip-touch"—and reduces metal-to-metal contact, which would cause damage to the die face and the rolls. There are basically two methods for adjusting the rollers on a pellet mill. One is to adjust them manually, the other is to use a remote roll adjust system, as shown in **Figure 3-11**.

The manual system requires untightening and re-tightening of the roller adjustment screws in order to reposition the roller adjusting gear. This rotates the roller shaft, which has a built-in eccentric, and causes the roll to move closer to or further away from the die surface. This manual system requires the machine to be shut down and locked out during the adjustment procedure, as the adjustment must be done with the pellet chamber door in the open position. The remote roll adjust system is either hydraulically operated or mechanically operated, with the mechanical design being preferred over the hydraulic system. The mechanical system results in a positive positioning of the rolls, whereas the hydraulic system can experience leakage, causing the rolls to back away from the die and cause roll slippage.

Figure 3-11. Remote roll adjust system.



The mechanical roll adjust system incorporates a lineator gearbox mounted to the front roller support, which is driven by a small shaft that runs through the center of the mainshaft. This small shaft is driven by an air motor mounted on the rear end of the mainshaft, which is operated by remote control. By pressing the positive or negative push buttons on the control cabinet, it is possible to adjust the rolls while the pellet mill is in operation. With this system, it is not necessary to stop the pellet mill in order to adjust the rolls except when a new die and rolls are fitted. Then it is necessary to adjust the rolls manually in order to establish the initial set-point. Not having to shut the machine down during production is an obvious advantage, as the roller position should be readjusted as necessary to maintain the correct running clearance. Because the remote roll adjust system allows the operator to adjust the rolls while the pellet mill is in operation, it is possible to adjust the feed material pad thickness on the die face, thus applying more work to the feed material, and resulting in higher pellet quality in some cases.

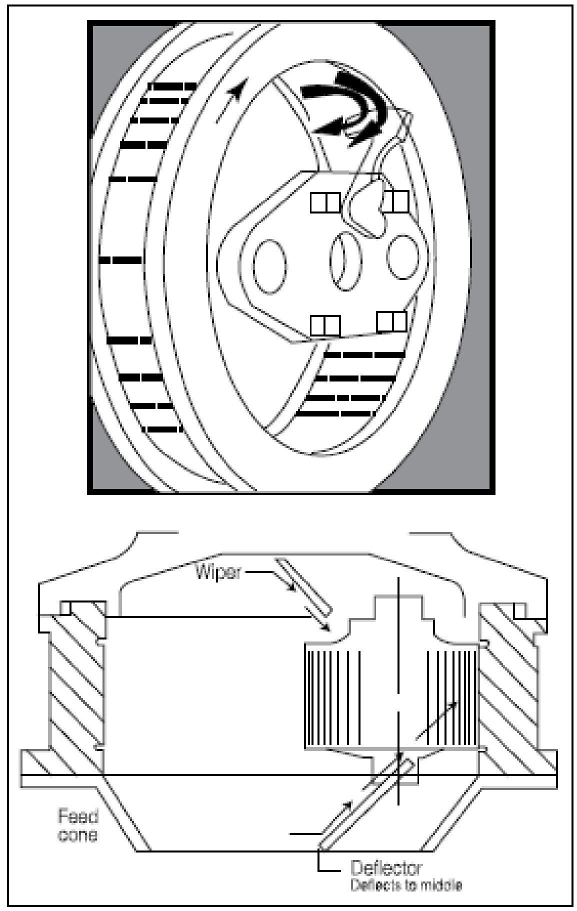
Die plugging

In the case of a die plugging during operation, remotely adjusted rolls can be backed away from the die face, allowing the plug to clear and the rolls to be brought back into their original position, all while the pellet mill is running without having to shut down. Should it be necessary to shut the pellet mill down in order to clean out the die cavity, the rolls can be quickly backed away from the die face, so the die can be re-started easily and the rolls returned to their original operating position. This is extremely useful when operating a machine having a large die and motor fitted, as these large motors are usually set up with a reduced-voltage starter, and the machine will not start at the low-voltage setting if any feed material is present between the die and rolls. This system allows a person to adjust the rolls from a remote location without having to open the pellet chamber door and adjusting the rolls by hand—making it much safer for the operator.

Feeding the Die

Feed material is brought into the die cavity using a typical die feeding system, as shown in **Figure 3-12**. If the machine has two rolls, the feed material is free-flowing and has a heavy bulk density, a feed chute is normally used. In a feed chute, gravity carries the material into the die area. Gravity forces half of the material into the first roll, while the other half is carried around to the second roll using centrifugal force to hold the material to the inside face of the feed cone. A deflector is positioned close to the second roll, deflecting the material off the feed cone face into the path of the roll and into the nip point. A wiper is positioned at the rear of the die cavity to clean feed material off the quill flange face and direct it back into the path of the rolls.

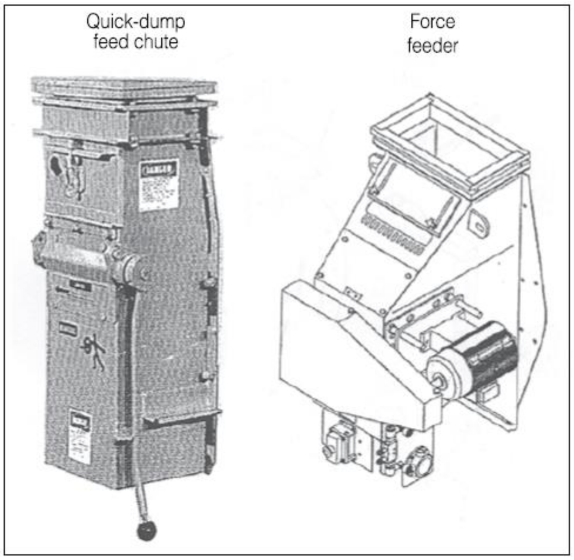
Figure 3-12. Typical die feeding system.



If the machine has three rolls and/or the feed material is not free-flowing, and it has a light bulk density, a force feeder is normally used. This feeder throws the feed material out centrifugally into the feed cone, carrying the material around to the three rolls, where each roll has a deflector to direct the material into the die cavity and into the path of the rolls. **Figure 3-13** shows a typical quick-dump feed chute and a force feeder.

As mentioned previously, a feed chute uses gravity to cause the material to flow into the die feeding area. The chute is a simple mechanical device with an inspection door to view the die cavity if necessary. The quick-dump feed chute has a flap built into the lower portion of the chute. This can be opened and closed manually with a lever mounted on the side of the chute, or remotely by using an air

Figure 3-13. Quick-dump feed chute and force feeder.

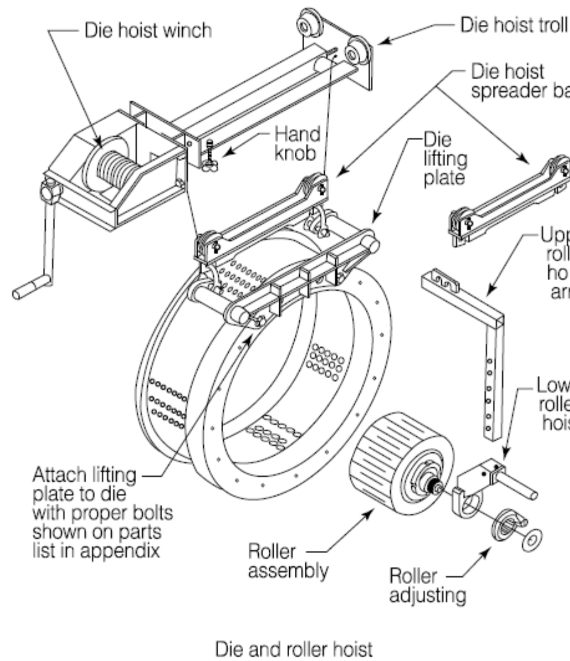


cylinder which is built into the feed chute assembly. The chute with the air cylinder can be connected to an automatic device which controls the pellet mill. Here, the flap can open if the die begins to plug and close when the potential plug clears itself. The quick-dump feed chute can be designed so that when the flap opens, the feed material either discharges onto the floor in front of the pellet mill, or it can be diverted directly into the cooler situated below the pellet mill, thus bypassing the die until the flap is closed again for normal operational use.

A force feeder is a motorized device with a rotating shaft that has paddles mounted to it. The feed material falls into the force feeder inlet and is conveyed along towards the die area. When the material reaches the force feeder discharge, centrifugal force throws it out into the feed cone where it is held onto the feed cone face until it is directed into the die cavity by the deflectors. It is necessary to use one deflector for each roll with this type of device, and all deflectors must be identical and of the same length.

Figure 3-14 shows a typical pellet mill die and roller hoist arrangement used on machines that have dies and rolls too heavy to handle by hand. These are available with either a manual or a pneumatic hoist or winch. The manual hoist is generally used for the smaller, light dies, whereas the pneumatic hoist is used for the larger, heavy dies. The pneumatic die and roll hoist are sometimes used together with the quick-release die clamp along with a pneumatic-powered wrench and the remote roll adjust to provide a quick die change. A die lifting plate and roller attachment match the size of die and rolls being used on a particular machine.

Figure 3-14. Typical pellet mill die and roller hoist arrangement.



A typical pellet mill base and drive coupling is used with a gear-driven pellet mill. The fabricated base has pads welded to it for mounting the pellet mill and the main motor. These pads are precision machined to allow for correct alignment of the pellet mill input shaft and the motor shaft, which are normally connected through a flexible coupling arrangement. Alignment of these shafts is critical in order to eliminate any possible vibration that can occur through any misalignment.

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This content was edited and reviewed by Dr. Adam Fahrenholz, Assistant Professor of Feed Milling at North Carolina State University, Dr. Cassandra Jones, Assistant Professor of Feed Technology at Kansas State University, and Dr. Charles Stark, Jim and Carol Brown Associate Professor of Feed Technology at Kansas State University.