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# Selecting Inching Drives for Mill and Kiln Applications

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## Abstract

The inching drive, also known as a barring or auxiliary drive, is an important component of any mill or kiln installation. It is used for maintenance and inspection purposes, as well as an emergency auxiliary drive to keep kilns rotating when the main motor fails. This paper covers what data the end user needs to provide for proper selection of a drive as well as the different arrangements available to them. Also covered are descriptions of the different components and their associated service factors, as well as safety requirements and issues the end user should be aware of and use.

Inching drives in a cement plant have two possible applications that support the production of product. The first of which is the heart of any cement plant, the kiln. Based on their design, it is critical to keep the kiln in motion at all times when heated. The inching drive for this application is designed to operate whenever main power is lost for the rotation of the kiln. The second cement application for inching drives is the rotation of the horizontal grinding mills for maintenance. Here the inching drive provides positional accuracy and holding capabilities for mill shell liner replacement and other operations.

## Introduction

An inching drive is also referred to as a Sunday drive, barring drive, turning gear, jack drive, or auxiliary drive. It is a mechanical system used to turn the equipment at a slower than normal operating speed. The device normally utilizes an electric motor or a multi-cylinder internal combustion (IC) engine in conjunction with a speed reducer of the required ratio to achieve the necessary torque multiplication.

The inching drive components include a prime mover, speed reducer, and a connection - engaged by hand or automatically, between the inching reducer and the main drive. Also included in the system, is a brake or backstop to hold the equipment when it is stopped in an unbalanced position and other appropriate safety devices. Typical drive arrangements are illustrated in Figure 1 for kilns and Figure 2 for mills.

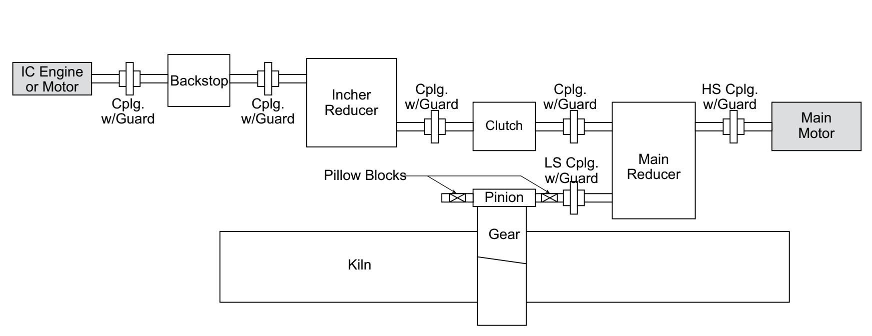


*Figure 1 - Typical Kiln Inching System*

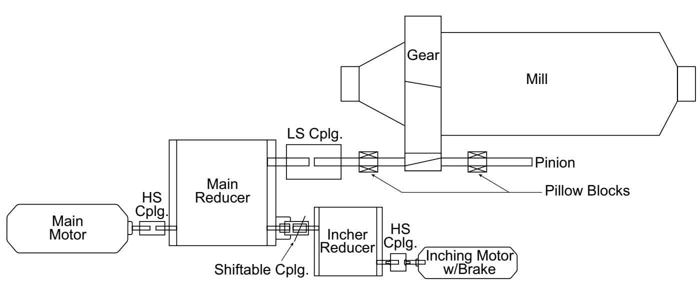


*Figure 2 - Typical Mill Inching System*

Source: *IEEE Standards Association*

Safety devices, such as coupling guards have been removed for illustration purposes. If the main reducers are not present, the inching drive can be connected via a through shaft in the main motor or the free end of the mill pinion.

### Data Requirements for Incher Selection

In order to design an optimal inching drive for a given application, the gear designer must have the endpoint defined. If the following basic information is not supplied, it becomes difficult if not impossible to design the system to ensure it matches the actual installation conditions and the desired performance. The following information is equired:

- Full load running torque required at the kiln or mill shell at normal operating speed when the main drive is operating.
- Full load running torque required at the kiln or mill shell at inching operating speed. Typically this is set at 120% of main drive operating torque.
- The desired output speed at the shell. Usually this is targeted at 0.1 RPM with a range of +50% / -10%
- Single or dual pinions driving the ring gear.
- Mill or Kiln type inching system
- The amount of space available at the equipment site to determine the basic type of arrangement (concentric shaft, bevel helical, or parallel shaft) and the location and type of connection between the incher and main drive that may be used.
- Single or multiple use installations of the inching drive. This will govern the type of mounting, disconnect, and type of safety devices required.
- The ambient temperature conditions (minimum and maximum), the altitude at the operating site, as well as the location (indoors or outdoors) are required for thermal calculations.
- Power available (50 or 60 Hz) to determine incher motor speed.
- Any other specifications regarding service factor on the drives, component life, cooling, or noise.

Given this information, one can begin the process to select the inching system components.

### Prime Mover Requirements

Typically prime movers for inching drives can be split into two categories, electric or internal combustion. Each has specific torque and starting characteristics that need to be reviewed during the selection process.

### Electric Motors

The standard inching drive motor is a NEMA or IEC frame typically foot mounted to a motor scoop or base plate. Typical motor speeds are either 4 or 6 pole, i.e. 1750 rpm or 1170 rpm for 60 Hz applications and 1450 rpm or 970 rpm for 50 Hz applications. The advantage of using a four pole motor allows for a smaller footprint and a smaller brake if required by the process. A six pole motor will be larger but will have a beneficial impact on thermal ratings of the gear reducer and noise.

Based on overall system costs, four pole motors should be the default choice. Only when the inching gear reducer needs more than four gear stages to achieve the required ratio should a six pole mote be used.

The size of the motor can be determined by the following formula:

$$P_{inch} = N_{o\_inch} \cdot \left( \frac{P_{mill\_motor}}{N_{o\_mill}} \right)$$

where

$P_{inch}$ is the incher driver power (HP *or* kW)

$N_{o\_inch}$ is the requested ouput speed of the mill gear in inching mode

$N_{o\_mill}$ is the actual output speed of the mill gear in normal running mode

$P_{mill\_motor}$ is the actual power of the main drive motor or 2 x main drive motor for dual pinion drives.

The power computed above is considered an output power of the inching system. Therefore an adjustment of 1% per mesh of the inching reducer drive can be added to reflect efficiency losses.

$$P_{inch} = P_{inch} \cdot (1 + (stage \cdot 0.01))$$

where

***stage*** is the number of reductions between the inching drive motor and the main drive input shaft (or mill pinion if direct driven)

Round up $P_{inch}$ to the next standard motor power. This standard motor power becomes the incher drive power

One can further optimize the power / output speed relationship by adjusting the inching output speed to more closely correlate to the inching drive power. Once the final drive train is designed, recheck for power loss at actual output speeds to ensure that the output torque of the inching system is equal to or greater than the output torque of the main drive system.

The key issue to keep track of is the amount of output torque generated by the main drive in main drive mode and the amount of torque generated by the inching drive train. Inching drive systems are traditionally designed to generate 120% of main drive torque while in inching mode. This torque comparison is the final arbiter between motor size and ratio in the inching reducer.

### Multi-cylinder internal combustion engines

Multi-cylinder internal combustion (IC) engines are used where the mill or kiln must be kept in motion during an electrical power outage. Engines, unlike electric motor prime movers, are not necessarily constant torque over their entire speed range. Since inching drives normally run at one speed, this variation is typically not a problem. Torque is influenced by both fuel source and environmental (air temperature and altitude) conditions. It is necessary to review the specific manufacturer's multiple cylinder rating definitions to properly size the engine for both starting and running loads.

Typical engine sizing is based on 2 x full load torque of a comparable electric inching system to account for the inherent starting capacity of electric motors. The Incher drive power $P_{inch}$ is defined as 0.5 * IC engine power. Speeds are normally 1800 rpm (exact) but can range from 1600 to 2500 rpm.

### Selection of Inching Drive Characteristics

Gear reducers are typically parallel shaft type, concentric shaft type or bevel helical combinations. Reducers utilizing worm gears are normally not selected due to the risk of self-locking, i.e. preventing reverse rotation, in back driving applications and efficiency considerations. Standard catalog ratio reducers can be used based on the speed tolerance of +50% / -10% while in inching mode. Ratio selection is established to obtain the required mill speed in conjunction with open gear set ratio, and main drive gear reducer ratio where applicable.

The normal duty of an incher is intermittent. Therefore lower service factors can be specified since the expected 25 years life of the mill / kiln, the inching system would operate infrequently. **Tables 1** and **2** summarize the expected number of starts and the total hours of operation for inching drives for mills.

**Table 1 Mill Number of Starting Cycles**

| Event | Installation | Inspection | Relining |
|---|---|---|---|
| Number of starts | 25 | 10 | 50 |
| Frequency per year | 1 | 52 | 1 |
| Number of years | 1 | 25 | 25 |
| Number total cycles | 25 | 13000 | 1250 |
| **Grand Total** | | **14275 cycles** | |

**Table 2 Mill Hours of Operation**

| Event | Installation | Inspection | Relining |
|---|---|---|---|
| Hours | 20 | 4 | 36 |
| Frequency per year | 1 | 52 | 1 |
| Number of years | 1 | 25 | 25 |
| Total hours | 20 | 5200 | 900 |
| **Grand Total** | | **6120 hours** | |

For kilns only, warm up or cool down will require continuous operating for up to 5 days, 3-4 times per year. Thus the number of starts and hours of operation are increased.

**Table 3 Kiln Number of Starting Cycles**

| Event | Installation | Inspection | Relining | Warming/Cooling |
|---|---|---|---|---|
| Number starts | 25 | 10 | 50 | 2 |
| Frequency per year | 1 | 52 | 1 | 4 |
| Number of years | 1 | 25 | 25 | 25 |
| Number total cycles | 25 | 13000 | 1250 | 200 |
| **Grand Total** | | **14475 cycles** | | |

**Table 4 Kiln Hours of Operation**

| Event | Installation | Inspection | Relining | Warming/Cooling |
|---|---|---|---|---|
| Hours | 20 | 4 | 36 | 120 |
| Frequency per year | 1 | 52 | 1 | 4 |
| Number of years | 1 | 25 | 25 | 25 |
| Total hours | 20 | 5200 | 900 | 12000 |
| **Grand Total** | | **18120 hours** | | |

For this reason, kilns require higher service factors due to the increased number of load cycles. See **table 5** for recommended service factor values. These service factors would multiply the Incher drive power $P_{inch}$ and be used to select the gear reducer from a manufacture's catalog. The table is based on the assumption that the inching drive motor was selected based on 200% starting torque. Higher starting torque capacities will require large service factors. Consult the gear drive manufacturer for additional information.

**Table 5 Reducer service factors**

| Electric Motors | IC Engines |
|---|---|
| 1.00 on mills | 1.25 Mils |
| 1.25 on kilns | 1.50 on kilns with 0.5 de-rate on IC power |

In general use, few applications of gear drives in industrial applications are selected on the basis of 1.0 service factors. Normally service factors are 1.25, 1.42 or greater. Mill drive inchers can use this low value of service factor based on the limited operation over the twenty five year expected life.

Regular inspections of the gear drive, control of moisture and dust ingress, and regular lubricant sampling and changes are required to have the expected life match the actual life of the drive system.

The thermal rating of the gear reducer should be selected based on the maximum ambient temperature in the area of the drive, the altitude above sea level to account for the difference in heat transfer due to air density changes, and the location of the drive (indoors or outdoors) to account for air velocity across the drive. Although inching drives operate intermittently throughout their life, when they are operating for warm up or cool down of kilns, the duty cycle is 100% per hour. Therefore no increase in thermal capacity should be assumed based on their intermittent use.

### Coupling Considerations

For safety and equipment protection, one must ensure that the inching drive system is not mechanically connected to the main drive system when the main drive is operating. For example, if the main drive motor runs at 1170 rpm and the inching reducer output shaft remains coupled to the main drive input shaft, the high speed shaft of the inching reducer can run at 232,830 rpm (but not for long). Therefore, for mill inching systems, the inching drive is connected to the main drive using a shiftable coupling with a manual operating shifting lever for engagement and disengagement, and a locking method to maintain positive engagement or disengagement during any operation. This disconnection method allows for the engagement and disengagement to be made without physically touching the high torque carrying members that could be in a loaded condition. In addition a method to interlock the powering of the main motor when the inching reducer is engaged is required.

Kiln inching drive to main drive connections must be permanently installed to drive immediately if there is a loss of main motor power. The connection method should only allow the incher drive to transmit torque in the forward direction and the main drive will "overrun" and not transmit motion back into the incher drive train as long as it rotates in the forward direction. This is normally accomplished with an overrunning clutch or a jaw clutch for manually activated systems.

Suggested service factors for the motor - reducer connection is 1.00 and 1.25 for the reducer main drive connection.

### Brake Considerations

Brakes are used on inching systems to prevent rotation of the drive train after power is removed from the system. This is typically used for maintenance purposes when the mill must be held in a fixed position for liner replacement. They also prevent backdriving of the system if the mill while inching is stopped in an unbalanced position. A third reason for systems without a clutch connection is to protect the drive train in case the main drive is started while the inching drive train is still connected. It has been industry practice to size the brake based on 1.50 x incher drive power increased to the next brake torque size. This ensures that when the brake is applied, the inching drive will not move. However, this brake torque can exceed the class 1 rating (1.0 service factor on catalog rating) of the inching drive reducer when selected based on the service factors typically used in industry.

Traditionally this brake overload has been addressed by reviewing the performance of the gear teeth, shafting, and couplings in the system at this load and comparing it to 75% of the material yield stress. In ANSI / AGMA 2001-D04 *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth* published by ANSI in conjunction with The American Gear Manufacturers Association (AGMA) a method is presented to calculate the strength rating of the gear teeth. Using convenation units and symbols:

$$fsyield = 0.75 \cdot s_{ay} \cdot \frac{F \cdot J \cdot K_f}{W_t \cdot P_d \cdot K_{my}}$$

where

***fsyield*** is the factor of safety for 75% of yield

$s_{ay}$ is the yield stress of the material (lbs/in$^2$)

*F* is the face width of the pinion or gear (in)

*J* is the J factor of the pinion or gear

$K_f$ is the stress correction factor for pinion or gear

$W_t$ is the tangential load (lbs)

*P* is the transverse diametral pitch (in$^{-1}$)

$K_{my}$ is the load distributionfactor at yield conditions

Using SI units and symbols:

$$fsyield = 0.75 \cdot \sigma_s \cdot \frac{b \cdot m_t \cdot Y_J \cdot K_f}{F_{max} \cdot K_{Hs}}$$

where

**fsyield** is the factor of safety for 75% of yield

$\sigma_s$ is the yield stress of the material (N/mm$^2$)

**b** is the face width of the pinion or gear (mm)

$Y_J$ is the J factor of the pinion or gear

$K_f$ is the stress correction factor for pinion or gear

$F_{max}$ is the tangential load (N)

$m_t$ is the transverse metric module (mm)

$K_{Hs}$ is the load distribution factor at yield conditions

The yield stress of the gear tooth material is defined as

$$s_{ay} = 482 \cdot H_B - 32800$$

$$\sigma_s = 3.324 \cdot H_B - 226.2$$

where

$H_B$ is the surface hardness for thru-hardened parts (HBW) and the core hardness for surface hardened parts

The tangential load is defined as

$$W_t \cdot \frac{24 \cdot T}{d}$$

Where

*T* is the torque on pinion being analyzed in (lbs ft)

*d* is the pinion operating pitch diameter (in)

$$F_{max} = \frac{2000 \cdot T}{d_{w1}}$$

where

*T* is the torque on pinion being analyzed in (N m)

$d_{w1}$ is the pinion operating pitch diameter (mm)

The load distribution factor at yeild conditions is defined for straddle mounted pinions as:

$$K_{my} = 0.0144 \cdot F + 1.07$$

$$K_{Hs} = 0.000567 \cdot b + 1.07$$

The ***fsyield*** must be greater than 1.00.

Shafting and couplings should also be reviewed under this braking load condition. Consult the manufacturer of the component for guidance on selection methods.

### Holdbacks / Backstops

When a continuous mechanical connection (i.e. no shiftable couplings) is required between the inching motor and the kiln system, a holdback / backstop is employed. It is used to prevent reverse rotation via braking and to allow for controlled reversal of the mill system. It will also prevent over speed of the drive train while reversing. This holdback is direct connected utilizing couplings between the inching prime mover and the inching reducer. Consult the manufacturer of the component for guidance on selection methods.

### Interlocks

A sufficient number of mechanical interlocks should be provided to insure that a main mill motor cannot be turned on while the incher is connected. This is relevant only to systems that do not use an overrunning clutch. For example, a single pinion drive in a single mill installation will have a pair of single interlocks, one each on the main motor control and the connection between the incher and the main reducer. Therefore the incher cannot be conneted until the main motor is turned off.

### Audit of drive train capacity

During inching mode, the main drive train may see a significant increase in the torque load running through it compared to the torque from running in main drive mode. Care must be taken on dual drive installations in that one can only mount a mechanical inching system on one of the driving pinions. The entire drive train must be sized to ensure that, in inching mode, the mill gearing, main drive reducer, shafts, and couplings can carry the full inching torque. For dual pinion applications the inching drive load must be designed for twice the main motor power. This increase in torque may exceed the torque capacity of the main drive components since they are initially size based on one main motor.

When the drive train is in inching mode, the input speed to the main drive can be only 0.6% of normal speed. This low speed requires adjustment to either the oil level, addition of oil dams and wipers to lubricate the bearings and gearing, and / or the addition of a motorized lubrication system. Increasing the oil level to ensure that all gears in the main drive are lubricated can cause overheating problems in main drive mode or compromise the use of labyrinth seals. Inching drives using an IC prime mover indicate that power may not be available for operating auxiliary pumps. Some main drives are mounted at a slope in relation to horizontal; these may need pumps to ensure lubrication to the upslope bearings. At slow speeds, pump flow rates must be reviewed to insure adequate flow to all lubricated items.

Once all the components have been selected, a final check should be made to ensure that the inching drive output torque at the mill or kiln shell is greater than the main drive output torque at the same location.

### Conclusions

The importance of complete and accurate load and application data is critical to the proper selection and design of an inching drive. It is imperative that the drive user or original equipment builder detail this information to the inching drive designer / manufacturer. Torque requirements, speed, type of installation, and infrastructure all play a role in optimal selection.

Two kinds of prime movers can be used depending on power availability and disaster recovery needs. Based on the method of selection, power selection is conservative in that the minimum power required is always rounded to the next larger motor size. This allows for sufficient capacity for operating a fully loaded mill or kiln in inching mode while using gear reducers sized for this highly intermittent service. Installation and regular maintenance including contamination and lubricant review is necessary to ensure operation of the drive when it is most needed.

A positive system is required to ensure that the inching drive is not mechanical connected to the main drive when the main drive is energized. A shfitable coupling with safety interlocks or a clutch can prevent equipment failure.

Brakes for mill drives are sized conservatively but since they can exceed the reducer rating, care must be taken in their selection. A review of the yield strength of all component subjected to brake loading is one method of ensuring success.

The controls of the main drive motor and inching package should be interlocked to prevent the main drive operating when the inching drive is connected.

Once all components are selected, one must make sure that the final selections have not overloaded the remaining members of the drive train, namely the main drive, low speed coupling and the ring gear set. This is especially critical on dual drive applications when the inching drive system must deliver 2 x the normal running torque through one power path from the main drive to one of the pinions meshing with the bull gear.

Through proper selection and application, an inching drive can be developed to meet the needs of maintenance of the mill and kiln system for the expected life of the installation.

### Reference

ANSI / AGMA 2001-D04 Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth. Alexandria VA: American Gear Manufacturers Association, 2004.





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