KILN FANS-FROM DESIGN TO OPTIMIZING PERFORMANCE

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Introduction

Dry kilns use air to transport heat to the lumber charge and moisture away from it. If the lumber has a uniform temperature, the air's temperature drop across the load (TDAL) is the result of the evaporation of moisture into the air passing through the sticker openings. As the airflow increases through the sticker openings, the TDAL will decrease and the drying rate will increase. If the air flow is not adequate to maintain a reasonable wet bulb depression across the load, then the evaporation rate will decrease and condensation could even occur. Therefore, airflow, along with heat and humidity, is an important factor in the rate of drying.

Fans increase the static and kinetic energies of the air flow. When air is moved through the kiln a certain pressure or head is required to start and maintain flow. Static pressure is the pressure which tends to collapse or burst the kiln walls and is used in part to overcome the frictional resistance of the air against the kiln walls, heating coils and the surface of the lumber in the sticker openings. The velocity pressure accelerates and maintains the movement, or velocity, of the air. The static pressure can be positive or negative and velocity pressure is always positive. Total pressure is the sum of the static and velocity pressure.

Propeller fans are most effective delivering high air flow against relatively low pressure, while centrifugal fans work better against higher pressure. Propellers are used as dry kiln fans because the pressure is usually low enough to make them the best choice. Reversible fans deliver equal air flow with the same power and efficiency whether rotating clockwise or counter clockwise. West coast dry kilns are batch drying chambers, so reversing the direction of air flow through the lumber charge is necessary to achieve uniform drying across the load. There are some kiln designs that rotate the entire fan housing to achieve reversibility and progressive tunnel kilns often use unidirectional fans. There are two basic approaches to making a propeller reversible. The first is to design fan blades that are equally efficient regardless of direction of rotation. The other way is to pitch every other unidirectional fan blade on a propeller to be efficient in one direction or the other. This method usually results in a substantial decrease of fan efficiency compared to pitching them all the same. Reversibility and Hand are sometimes confused with each other. Reversing the direction of rotation changes the direction that air is blowing. The fan's Hand determines which direction the air is blowing when rotating clockwise and counter clockwise. A Right Hand fan blows air in your face when it's rotating clockwise as you look at it, and a Left Hand fan blows it away from you. A Right Hand pitched fan blade at the 3 o'clock position lets your right arm rest flat against it, but cuts into your left arm at the 9 o'clock position. A Left Hand pitched fan blade at the 9 o'clock position lets your left arm rest flat against it, but cuts into your right arm at the 3 o'clock position. Right Hand fans are the norm, and Left Hand fans are used in combination with Right Hand fans on a common shaft to blow air toward or away from each other, such as in a line shaft kiln. Some cross shaft kiln designs position every other fan as a Right or Left Hand to counteract the helical rotation of the discharged air.

Fan blade design has evolved from flat paddle shapes that push the air, to airfoil shapes that create pressure drops across the blade surfaces similar to air plane wings. Airfoil blades are ineffective at very low fan speeds because they cannot generate the required pressure drop, but are very efficient at higher speed. Propellers with a few wide blades usually work well at low static pressure, and fans with more blades are more effective at higher pressure.

Most modern dry kiln propellers are made of cast aluminum, which is durable and light weight. The typical dry kiln has a hot, windy and humid internal environment. It requires high quality fan castings suitable for billions of revolutions and thousands of starts. Recent attempts to use reinforced fiber polyester blades in kilns have generally not been successful. While they work well in low temperature drying sheds and pre dryers, they do not hold up over time at elevated kiln temperatures. Steel kiln fans have been around for a long time, but their use is currently limited to slow speed line shaft kilns. Starting inertia, or WR^2, is an important consideration for fan system design, and aluminum construction reduces the WR^2 by over 50% of steel for a given fan.

Another consideration for kiln fans is the use of dissimilar materials at elevated temperatures. Aluminum expands at about twice the rate of carbon steel and 1.3 times the rate of stainless steel. A carbon steel fan shaft and a malleable iron bushing will expand at about the same rate, but an aluminum fan hub expands at about twice the rate of the bushing. This can cause the bushing to loosen its grip to the shaft and the axial thrust developed by the fan will cause it to move along the shaft. The thrust is the product of the total fan pressure and the area of the fan, and a 72" fan working against 1 inch w.c. of static pressure develops about 150 lbs. of thrust. Thermal expansion also affects the clearance between the tip of the blade and the fan ring. The fan opening and the fan diameter increase with temperature, but an aluminum fan will increase at twice the rate of a steel fan housing so the tip clearance will decrease with increased temperature. Good kiln design will ensure that the fans stay centered in the fan ring at any temperature.

Propellers with adjustable pitch blades have some type of clamping device to attach the blade to the hub, and choice of materials can affect the service life of the hub. If carbon steel or stainless steel clamping bolts are used with aluminum hubs, the bolt tension will increase with temperature and can cause cracks in the hub. The increase with carbon steel bolts is 50% greater than with stainless steel.

The blade angle on adjustable pitch propellers can be set to match the fan speed to many operating points, while fan speed controls the range of operating points for a fixed pitch model. The only on site assembly usually required for fixed pitch propellers is attachment to the drive shaft, while the blades may also have to be attached to the hub for adjustable pitch fans. Adjustable pitch models can be shipped knocked down, which is convenient for shipping and maneuvering onto the fan deck in the kiln. Fixed pitch fans can be spin and static balanced, while most knocked down adjustable pitch propellers are statically balanced.

Some adjustable pitch propellers have two piece hubs that sandwich the blades between the halves, while others use shank caps and U-bolts to clamp individual blades. Assembly and installation instructions should be followed carefully. Fastener torque values and orientation of parts are important. Fasteners must be tightened enough to secure the connection or part, but over tightening can cause breakage or excessive stress that leads to failure in the future. Parts must be properly positioned to ensure correct balance of the propeller, and blades should be pulled all the way outward in the hub sockets. Shank caps may not clamp the blade properly if not oriented as shown in the instructions.

Most fans used in West coast dry kilns use split taper bushings to attach the propeller to the drive shaft. They should be attached to the fan hub with bolts that pass through the bushing flange and the hub and nutted with lock nuts suitable for kiln temperatures. Propellers should be mounted to the fan shaft with the bolt flange of the bushing accessible for using back out screws to remove the propeller from the shaft. Through bolts can be nutted at the bushing flange to minimize the clearance required between the fan and motor. If the fan shaft must be cleaned up, dress it carefully so it doesn't become undersized. Do not dress a spinning shaft using an abrasive, like emery cloth. Anti seize compounds and other lubricants should never be used for assembling a propeller or mounting it to the shaft.

Most occurrences of fans walking on the shaft happen during the start up of a newly installed fan. It's important to retorque all fasteners and check the blade pitch angle after the fan has run at operating temperature for 24 hours or so. For kilns operating above 200 ^{0}F, it's best to heat up the assembled fan on the shaft to the typical drying temperature before it is run, and then let it cool down to where the metal is still hot, but the air is cool enough for people to safely work, and tighten the fasteners to the recommended torques. Set collars can be located on the fan shaft near the fan to limit the distance it can walk, and a retaining washer is often attached to the end of the shaft to prevent the fan from walking completely off the shaft.

There are several methods used to set the blade pitch angle. From a performance viewpoint, each angle setting defines a new fan. There are fan laws that predict a fan's performance characteristics for change of speed, fan diameter, air density, etc., but none for change of blade pitch. Fan performance is determined for each blade pitch angle by testing it in an air flow test laboratory. Performance between tested pitches can usually be reasonably estimated by interpolation. The proper blade pitch angle matches the available power to the fan speed and the operating pressure. The pressure that a propeller can efficiently work against decreases as the blade pitch increases.

It is important to use the manufacturer's prescribed method to set the blade pitch angle because it corresponds to the angle setting of the test data. Checking the pitch angle with a protractor level at the blade tip will not necessarily correspond to the manufacturer's fan curve. Setting all the blades to the same pitch angle is important to realize maximum fan efficiency.

A fan curve is a graphical representation of the data collected from air flow testing. The basic data are static pressure, fan volume or CFM and brake horsepower. The test arrangement should be as similar to the field arrangement as possible. Fan curves are used to select the best propeller model for an application, and to determine the power requirement and fan speed. They are also necessary to select the proper blade pitch setting for a specific kiln.

Kiln fan systems are usually designed to deliver sufficient air to achieve a desired sticker velocity. The required fan volume is calculated as feet per minute of air through the area of total sticker openings plus bolster openings and the open areas around the lumber packages that air can pass through. The sticker velocity will also affect the static pressure that the kiln fans have to work against, and the pressure drop across the load of lumber is usually the greatest pressure drop in the kiln. Typical West coast kiln static pressure is between .25 and .75 inches w.c. depending on the load configuration and sticker velocity. Some lumber species can be dried effectively with very high air flow and static pressure can be as high as 2 to 3 inches w.c. Propellers with more blades running at high speeds do best against high static pressure, while a slower speed might be more efficient for lower duty operating points, and these decisions are made using fan curves.

The propeller is only one component of the fan system, and other major components include the orifice ring, motor, drive shaft and bearings and structural supports. Fan systems are designed for specific mechanical loads, and their design must be analyzed before increasing fan speed, power and fan size. Care should be taken not to place obstructions near the fan that cause the fan pressure to change as the blades pass it. This can cause the load on the fan motor to fluctuate and lead to metal fatigue in the fan blades.

Orifice rings can be as simple as rolled flat sheet or as complex as a spun wide mouth bell shape. Since the air accelerates and contracts as it enters the ring and expand as it exits, some losses will occur. The magnitude of the losses depends on the shape of the entrance and discharge and the velocity pressure at the ring. Entrance loss coefficients range from .9 for rolled flat sheet to .5 for rolled channel to .05 for a wide mouth bell inlet. The rolled flat sheet is never a good choice, but the benefit of other shapes should be determined by the actual pressure loss. The velocity pressure is about 0.2 inches w.c. for 50000 CFM passing through a 72" diameter ring, so the rolled flat sheet orifice would have a loss of 0.18 inches w.c. while the rolled channel would have a loss of 0.1 inch w.c. and the bell mouth 0.01 inches w.c. For 100,000 CFM, the velocity pressure is about 0.78 inches w.c., so the rolled flat sheet orifice would have a loss of 0.7 inches w.c. while the rolled channel would have a loss of 0.39 inch w.c. and the bell mouth 0.04 inches w.c. The value of a sophisticated orifice ring is greater at higher airflow through the fan and that's why some very high performance kilns are using spun wide mouth bell shaped orifices. While most kilns can get good fan performance with a rolled radiused edge ring, they cannot get by with letting the blade tip run outside the flat throat of the ring. Even a slight overhang can have significant negative impact on fan performance.

A newer component of some fan systems is the Variable Speed Drive which changes the motor speed by increasing or decreasing the frequency, or Hertz, of the motor's input power. VSD's give great flexibility for matching the fan's performance to the drying schedule requirements and overcoming cold start conditions. The cold start condition causes an across the line starting motor to be sized to run within its ampere limits when the fan runs in dense air at start up rather than the less dense air after the kiln warms up. This means that all the available power may not be used when most of the wood drying is occurring. VSD's are often programmed to follow a speed ramp determined by motor amp load, which allows the fans to run at less than full speed while the kiln air is dense. The power consumed by a fan is proportional to the cube of the change in fan speed and directly proportional to the change of air density. So as the humidity and temperature in the kiln increase and air density decreases, the fan speed can also increase and constant power to the fan is maintained. It's also possible to program timed motor speed steps or ramps that stay within the motor's available power, but don't maintain constant amp load.

The drying rate decreases significantly for most wood species when fiber saturation is reached, and VSD's are often programmed to slow the fans down to match the drying rate and save power. Because of the "cube" rule, running the fans at 80% speed saves about 50% of fan power. VSD's can be used similarly to control the drying rate to match the kiln conditions to the drying schedule. One concern that VSD's have raised at the dry kiln is operation at harmonic frequencies, or resonance. All objects have natural frequencies that they vibrate at when bumped or otherwise excited. Rotating equipment like fans have excitation forces present as they rotate, and these will be amplified when running at the natural or harmonic frequency of the system. Sometimes the magnitude of the resonance is great enough to make the kiln shake, but often it is not even detectable without a vibration meter. Fortunately, most VSD's have "skip frequency" functions or drying schedules can be programmed to skip a band around the harmonic frequencies. It is best to not run at even small magnitude harmonic frequencies because metal fatigue is cumulative in aluminum where infinite fatigue life is not the rule.

Fan curves are very useful for selecting the proper fan and setting it up for optimum performance. Running the fan motor at Full Load Amps doesn't necessarily mean that you're operating at maximum efficiency. It is important to determine the static pressure and the fan characteristics at the operating conditions in the kiln. Once this is determined, fan curves are used to select the best propeller model, blade pitch and fan speed for that operating point. Fan efficiency is usually better for median pitch angles and if your operating on the "back side " of the curve the fan will be very inefficient. The opportunity for further optimization is expanded greatly if the fans have VSD's. The airflow at the most effective drying temperature can often be increased 5% to 10% by adjusting the fan's blade pitch to fully load the motor at full speed when the kiln air has reached an effective drying temperature, rather than at ambient temperature.

In conclusion, kiln fans have significant impact on drying rate and it's important to select propellers designed for the duty and performance needed for effective drying of specific products in a specific kiln. Fan design including materials, blade count, diameter and orifice ring construction should be matched to available fan power by adjusting the fan speed and blade pitch angle to deliver air efficiently at the required operating point. Fans can be further tuned to take maximum advantage of VSD's for energy savings and increased drying rates, and fan curves are important for making the best selections and choices.