A Review on Design & Analysis and Remodification Pinion in Gear Drive used in Paper Mill Dryer

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Abstract- The pinion from the drive of the cement mill was failed; the teeth cracked and spall occurred on the sides of several teeth. The failure was only located on one side of the pinion. This type of failure is common with surface-hardened gears. Cracks initiated at the surface of case hardened gears may lead to typical life limiting fatigue failure modes such as pitting and tooth root breakage. Furthermore, the contact load on the flank surface also induces stresses in greater material depth which may lead to crack initiation below the surface if the local material strength is exceeded. With time the crack propagation below the surface may result in a gear failure referred to as "tooth flank fracture. This paper explains the mechanism of this subsurface fatigue failure mode and its decisive influence factors and gives an Overview of a new develop calculation model.

Keywords- *Tooth flank, Dryer, Spur Gear,Crack Propogation,Paper mill Dryer.*

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I. INTRODUCTION

Gear power transmissions have been the most common way to transmit mechanical power for decades. For this reason, thanks to years of investigations, many calculation methods are nowadays available, for example, in order to optimize the transmission against many failures like for instance tooth breakage, pitting, micro pitting, wear, scuffing... Many of these failure modes are strongly related to the tribology of the system. Which strongly depends on the lubricant properties which are, in turn, a function of the temperature. One challenge in the design of gear power transmissions is to find out how to accurately calculate the operating temperatures and the efficiency of the gearbox. Increasing the efficiency of power transmissions can bring a significant contribution not only in terms of pollutant emissions limitation and energy saving, but also for other aspects such as reliability, related to different (lower) thermal regimes, and allows the application of downsizing, weight reduction and system architecture simplification [1].

Case hardened gears are highly loaded machine elements used for power transmission in many field applications. One factor that can limit the life cycle of such highly loaded gears is the load carrying capacity. To ensure the safe operation of these gears reliable calculation and test methods are needed. With a variation of the material type and the heat treatment parameters it is possible to influence the flank load carrying capacity. Extensive theoretical and experimental investigations have been carried out in order to derive calculation methods and an optimized heat treatment, mostly for the fatigue failure mode pitting which occurs as a result of cracks initiated at or just below the flank surface[2]. Due to the fact that the crack propagates below the surface it is almost impossible to detect it in an early stage with visual inspections. Whether a failure occurs at the surface or in greater material depth, is influenced by the local contact load which depends on the gear flank geometry, in particular the equivalent radius of curvature, and by the local material strength. The in-depth strength of the material results primarily out of the heat treatment. To predict a failure the load curve has to be set in relation to the strength curve over the material depth. During the last years extensive theoretical and experimental investigations have been carried out in order to get a better understanding of the failure mechanism and to isolate the decisive influence factors on the failure mode of tooth flank fracture[3]

II. PHYSICAL MECHANISM OF DRYING

Drying does not mean only removal of the moisture but during the process, physical structure as well as the appearance has to be preserved. Drying is basically governed by the principles of transport of heat and mass. When a moist solid is heated to an appropriate temperature, moisture vaporizes at or near the solid surface and the heat required for evaporating moisture from the drying product is supplied by the external drying medium, usually air or a hot gas. Drying is a diffusion process in which the transfer of moisture to the surrounding medium takes place by the evaporation of surface moisture, as soon as some of the surface moisture vaporizes; more moisture is transported from interior of the solid to its surface. This transport of moisture within a solid takes place by a variety of mechanisms depending upon the nature and type of the solid and its state of aggregation. Different types of solids may have to be handled for drying crystalline, granular, beads, powders, sheets, slabs, filter-cakes etc. The mechanism of moisture transport in different solids may be broadly classified into (i) transport by liquid or vapor diffusion (ii) capillary section, and (iii) pressure induced transport. The mechanism that dominates depends on the nature of the solid, its pore structure and the rate of drying. Different mechanisms may come into play and dominate at different stages of drying of the same material[4]

The following term are commonly used in designing of drying systems. Moisture content of a substance which exerts as equilibrium vapors pressure less than of the pure liquid at the same temperature is referred to as bound moisture. Moisture content of the solid which enters an equilibrium vapor pressure equal to that of pure liquid at the given temperature is the unbound moisture. The moisture content of solid in excess of the equilibrium moisture content is referred as free moisture. During drying, only free moisture can be evaporated. The free moisture content of a solid depends upon the vapor concentration in the gas. The moisture contents of solid when it is in equilibrium with given partial pressure of vapor in gas phase is called as equilibrium moisture content. Similarly, the moisture content at which the constant rate drying period ends and the falling rate drying period starts is called critical moisture content. During the constant rate drying period, the moisture evaporated per unit time per unit area of drying surface remains constant and in falling rate drying period the amount of moisture evaporated per unit time per unit area of drying surface continuously decreases[5].

III. CLASSIFICATION OF DRYERS

Drying equipment is classified in different ways, according to following design and operating features. It can be classified based on mode of operation such as batch or continuous, In case of batch dryer the material is loaded in the drying equipment and drying proceeds for a given period of time, whereas, in case of continuous mode the material is continuously added to the dryer and dried material continuously removed. In some cases vacuum may be used to reduce the drying temperature. Some dryers can handle almost any kind of material, whereas others are severely limited in the style of feed they can accept.

Drying processes can also be categorized according to the physical state of the feed such as wet solid, liquid, and slurry. Type of heating system i.e. conduction, convection, radiation is another way of categorizing the drying process.

Heat may be supplied by direct contact with hot air at atmospheric pressure, and the water vaporized is removed by the air flowing. Heat may also be supplied indirectly through the wall of the dryer from a hot gas flowing outside the wall or by radiation. Dryers exposing the solids to a hot surface with which the solid is in contact are called adiabatic or direct dryers, while when heat is transferred from an external medium it is known as non adiabatic or indirect dryers. Dryers heated by dielectric, radiant or microwave energy are also non adiabatic. Some units combine adiabatic and non adiabatic drying; they are known as direct-indirect dryers[6].

IV. DRYING EQUIPMENT

IV.I Batch Type Dryers

IV.I.I. Tray Dryer

Schematic of a typical batch dryer is shown in figure 2.1Tray dryers usually operate in batch mode, Use racks to hold product and circulate air over the material. It consists of a rectangular chamber of sheet metal containing trucks that support racks. Each rack carries a number of trays that are loaded with the material to be dried. Hot air flows through the tunnel over the racks. Sometimes fans are used to on the tunnel wall to blow hot air across the trays Even baffles are used to distribute the air uniformly over the stack of trays. Some moist air is continuously vented through exhaust duct; makeup fresh air enters through the inlet. The racks with the dried product are taken to a tray dumping station.

These types of dryers are useful when the production rate is small. They are used to dry wide range of materials, but have high labor requirement for loading and Unloading the materials, and are expensive to operate. They find most frequent application for drying valuable products. Drying operation in case of such dryers is slow and requires several hours to complete drying of one batch. With indirect heating often the dryers may be operated under vacuum. The trays may rest on hollow plates supplied with steam or hot water or may themselves contain spaces for a heating fluid. Vapor from the solid may be removed by an ejector or vacuum pump. Freeze-drying Involves the sublimation of water from ice under high vacuum at temperatures well below 0^0C. This is done in special vacuum dryers for drying heat sensitive products[7]

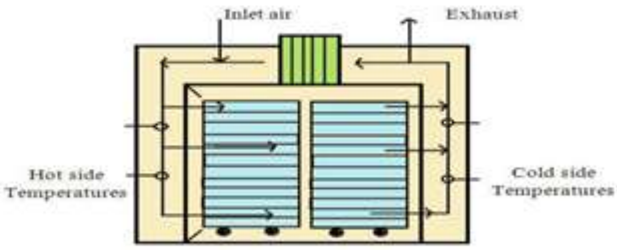

Figure 2.1: Tray dryer

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IV.I.II. PAN DRYER

The atmospheric pan drier has a jacketed round pan in which a stirrer or mill revolves slowly, driven from below. The slow moving stirrer exposes fresh surfaces and thereby raises the rate of evaporation and, hence, of drying. The pan drier is a batch machine and is limited to small batches. Pan driers may be used first to evaporate a solution to its crystallizing concentration and then can function as a crystallizer by sending cold water instead of steam into the jacket. The effect of the stirrer during crystallization prevents the growth of large crystals and promotes formation of small, uniform crystals. The mother liquor is then drained off and the crystals dried in the same apparatus[8].

IV.I.III. AGITATED VACUUM DRYER

The agitated vacuum dryer is one of the most versatile in the range and is similar in principle to a pan dryer. The dryer essentially consists of a jacketed cylindrical vessel arranged for hot water, steam or a suitable thermal fluid flow through the jacket for heating. Doors are provided on the shell, at the top for loading the feed material and at the bottom for discharging. The dryers are available in variety of sizes. The entire drying chamber is well machined to insure small clearance with the agitator blade. Thus ensures proper shuffling of the material and avoids localized overheating. Due to the agitation of the product in the agitated vacuum dryer the drying time is substantially reduced.

A choice of the agitator design which can be arranged with or without heating depends on the material characteristics and process requirements. While designing the shell one has to consider the external pressure and the shaft designing includes fatigue consideration. Designing the impeller needs consider ation of characteristics of the material before and after drying[9].

IV.I I CONTINUOUS DRYER

IV.I I.I ROTARY DRYER

The rotary drier is basically a cylinder, inclined slightly to the horizontal, which may be rotated, or the shell may be stationary, and an agitator inside may revolve slowly. In either case, the wet material is fed in at the upper end, and the rotation, or agitation, advances the material progressively to the lower end, where it is discharged. Figure (2.2) shows a direct heat rotary drier. Typical dimensions for a unit like this are 9 ft diameter and 45 ft length. In direct-heat revolving rotary driers, hot air or a mixture of flue gases and air travels through the cylinder. The feed rate, the speed of rotation or agitation, the volume of heated air or gases, and their temperature are so regulated that the solid is dried just before discharge[10].

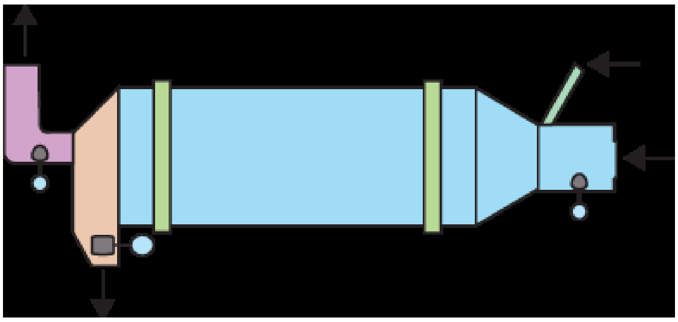

Figure 2.2: Counter current direct heat rotary dryer

IV.I I.II DRUM DRYER

In drum dryers (Fig 2.3a, b) a liquid containing dissolved solids or slurry carrying suspended solids forms a thin layer on the outside surface of a large rotating drum. For a single drum unit thickness of the film can be controlled by an adjustable scraping blade. In case of a double drum unit thickness can be controlled by the gap between the drums (figure 2.3a). A gas, normally air may be blown over the surface for rapid removal of moisture. The rotation of the drum adjusted so that all of the liquid is fully vaporized and a dried deposit can be scrapped off with the help of flexible or adjustable knife. This type of dryer mainly handles the materials that are too thick for a spray dryer and too thin for a rotary dryer. The solid collects on an apron in front of the knife and rolls to a container or to a screw conveyor. The operation of the drum drier is continuous. The drum is rotated continuously by a gear driven by a pinion that receives its motion through a belt, a chain, or a reduction gear from. The speed of the drum may be regulated by a variable-speed drive to adopt the speed to any slight variation in the feed quality. The speed of the drum regulated depending upon the nature of materials (i.e wet or dry), if the product material is wet/dry

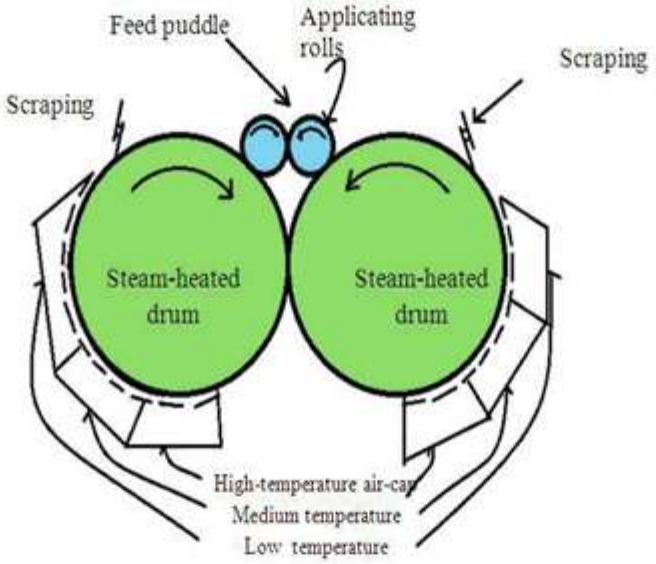

Figure 2.3b: Double drum dryer

quite a distance before the knife is reached, the speed should be decreased/increased. The design of the components is similar to that of drum filter. The knife may be held just against the surface. It may be brought closer by turning the adjusting wheels. The knife supports may be turned through part of a circle so that the angle of the blade of the knife relative to the drum surface may be selected for the greatest shearing effect. In recent years, double drum dryers have replaced single drum dryer in several applications (figure 2.3b), due to their more efficient operation, wide range of products and high production rates[11].

IV.I I.III Flash Dryer

The flash driers (figure 2.4), also called pneumatic dryers, are similar in their operating principle to spray dryer. The materials that are to be dried (i.e. solid or semisolid) are dispersed in finely divided form in an upward flowing stream of heated air. These types of dryer are mainly used for drying of heat sensitive or easily oxidizable materials. The wet materials that are to dried can be passed into a high-temperature air stream that carries it to a hammer mill or high-speed agitator where the exposed surface is increased. The drying rate is very high for these dryers (hence the term *flash dryers*), but the solid temperature does not rise much because of the short residence time. A flash dryer is not suitable for particles which are large in size or heavy particles. The special advantage of this type of dryer is that no separate arrangement is required for transporting the dried product. The fine particles leave the mill through a small duct to maintain the carrying velocities (drying gas) and reach a cyclone separator. A solid particle takes few seconds to pass from the point of entry into the air stream to the collector. The inlet gas temperature is high and varies from 650oC to 315oC, for example, in 2 seconds, or from 650oC to 175oC in 4 seconds. The thermal efficiency this type of dryer is generally low. A material having an initial moisture content of 80 % may be reduced to 5 or 6 % in the dried product[12].

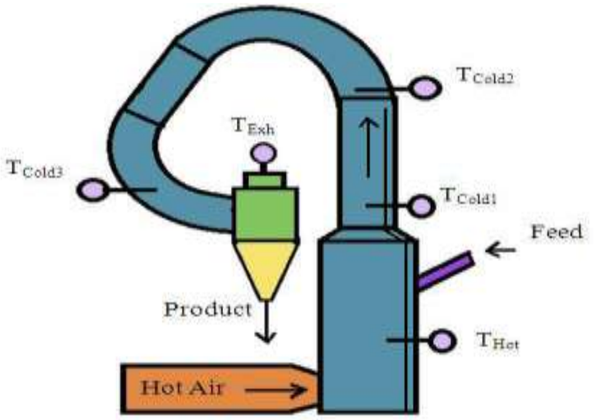

Figure 2.4: Flash dryer

IV.I I.IV FLUIDISED BED DRYER

Fluidized bed dryer consist of a steel shell of cylindrical or rectangular cross section. A grid is provided in the column over which the wet material is rests. In this type of dryer, the drying gas is passed through the bed of solids at a velocity sufficient to keep the bed in a fluidized state. Mixing and heat transfer are very rapid in this type of dryers. The dryer can be operated in batch or continuous mode (figure 2.5). Fluidized bed dryer are suitable for granular and crystalline materials. If fine particles are present, either from the feed or from particle breakage in the fluidized bed, there may be considerable solid carryover with the exit gas and bag filters are needed for fines recovery. The main advantage of this type of dryer are: rapid and uniform heat transfer, short drying time, good control of

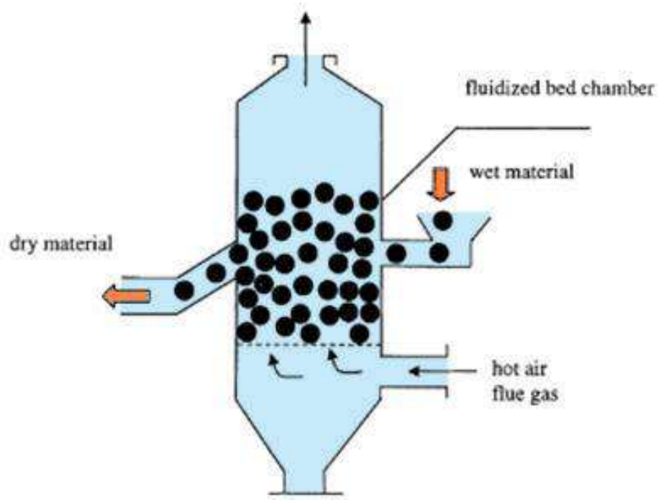

Figure 2.5: Continuous fluidized bed dryer

the drying conditions. In case of rectangular fluid-bed dryers separate fluidized compartments are provided through which the solids move in sequence from inlet to outlet. These are known as *plug flow dryers;* residence time is almost the same for all particles in the compartments. But the drying conditions can be changed from one compartment to another, and often the last compartment is fluidized with cold gas to cool the solid before discharge[13].

V. FAILURE MECHANISM OF TOOTH FLANK FRACTURE

Gears with tooth flank fracture show characteristic features that differentiates them from gears failed due to pitting, micro-pitting or tooth root breakage for example. In Figure 1 are shown two gears failed by pitting and tooth root breakage, which have in common that the crack was initiated at or close to the surface. Figure 2 shows two example gears, a test and a turbine gear, with tooth flank fracture. These are only two examples, among many others, showing that

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subsurface fatigue failures, such as tooth flank fracture, can occur in almost every field application. Failures due to tooth flank fracture are reported in wind and steam turbines, truck gearboxes, bevel gears for heavy machinery and test gearboxes.

Typical for the failure mode of tooth flank fracture is that the crack initiation is normally located below the flank surface in an approximate depth of the case-core transition (see Figure 3a) and b)) in the active flank area. The primary crack is often initiated at non-metallic inclusions that have significantly different Young's modulus compared to the normal material structure. Such imperfections below the surface act as stress risers during the roll off of the flank because of the notch effect. If the material strength is locally exceeded, a crack with growth potential could be initiated in the material which can lead to tooth flank fracture later[14].

After a crack has been initiated below the surface, it slowly propagates during operation in an angle of 40° to 50° relative to the flank surface, but without direct connection to the surface. During the crack propagation a so called "fish eye" can occur due to relative microscopic movement of the cracked surfaces. The primary crack propagates from the crack starter towards the surface of the loaded flank and into the tooth core towards the opposite tooth root section. The crack propagation rate towards the loaded flank is smaller in comparison to the core due to the higher hardness. After the primary crack has grown enough so the tooth stiffness is reduced, secondary cracks may occur under load. Distinctive feature of these cracks is that they normally start at the flank surface and propagate parallel to the tooth tip into the material.

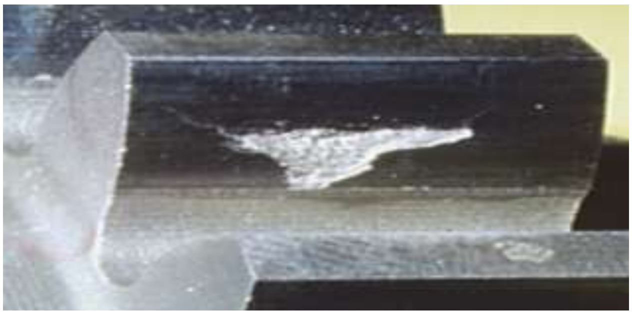

Figure 1: Typical surface gear failure examples – Pitting

VI. INFLUENCE FACTORS ON THE FAILURE TYPE TOOTH FLANK FRACTURE

The induced stresses inside the loaded tooth are shown in Figure 5. Considering an ideal smooth flank surface the general stress condition inside the tooth is composed of following components:

- stresses due to the normal force resulting from the transmitted torque
- shear stresses on the flank surface due to friction
- thermal stresses caused by the thermal gradient bending stresses and shear stresses due to shear load caused by the normal force
- residual stresses[15].

VII. DESIGN CONSIDERATION OF DRIERS

Design of a rotary dryer only on the basis of fundamental principle is very difficult. Few of correlations that are available for design may not prove to be satisfactory for many systems. The design of a rotary dryer is better done by using pilot plant test data and the full scale operating data of dryer of similar type if available, together with the available design equations. A fairly large number of variables are involved such as solid to be dried per hour, the inlet and exit moisture contents of the solid, the critical and equilibrium moisture contents, temperature and humidity of the drying gas. The design procedure based on the basic principles and available correlations is discussed below. In this case we assume that the solid has only unbound moisture and as shown in fig 2.7 in stage II the solid is at the wet bulb temperature of the gas.

1. Heat losses from dryer surfaces are neglected.
2. Once the capacity of the dryer is known, the drying gas flow rate, its temperature and humidity are decided considering a number of factors. And the following moisture & enthalpy balances need to be satisfied.

Gs (Y1 - Y2) = Ms (X1 – X2) Gs (Hg2 – Hg1) = Ms (HS2 – Hs1) Here, Gs = flow rate of air (dry basis, kg/h), Ms = flow rate of solid (kg/h, dry basis), Hs = humidity of air (kg/H2O/kg dry air)

3. The gas and solid temperatures at the stage boundaries are obtained by moisture and energy (enthalpy) balances. The number of heat transfer unit for each zone is calculated. for the stage II. The number of heat transfer units is given by

(NtG)h,II × ΔTm = (TGB – TGA)

4. The total length of dryer is given by

L = (LT)1 (NtG)1 + (LT)II (NtG)II + (LT)III (NtG)III

5. The shell diameter is calculated from the dry gas flow rate (from step I) and suitable gas flow velocity or gas mass flow rate

Some useful correlations for the design of a rotary dryer are given below. Volumetric gas-solid heat transfer coefficient. Ūa = (W/m3.K) = 237 (G‟)0.67/d

Here, G‟ = gas mass flow rate (kg/m2.h) and d, dryer diameter Length of transfer unit LT = G‟CH / Ūa LT = 0.0063 CH . d. Here, cH = average humid heat, and d = dryer diameter 0.84 S G

Solid retention time: (+ve sign is for counter flow; –ve sign is for parallel flow of the gas and solid) Where, θ = retention time (min); L = dryer length (m) S = slope of the dryer (m/m); N = speed (rpm) G‟ = gas mass flow rate (Kg/m2.h) F = feed rate (Kg/m2. h) dry basis B = 5 (dp)-0.5 dp = weight average particle diameter ' 0.9 0.23 L B L G θ = 1.97 S N d F

VIII. CONCLUSIONS

Tooth flank fracture is a sub surface fatigue failure mode observed on case hardened gears. One characteristic feature of tooth flank fracture is that in comparison to pitting and tooth root breakage the initial crack can be found below the loaded surface, in greater material depth. Tooth flank fracture leads in almost all cases to the complete breakdown of the gear set. When the primary crack reaches the surface the upper tooth part is separated within a short time due to overload breakage. Both the crack propagation and the overload breakage can be observed on the fracture area, which is typical for tooth flank fracture. Extensive experimental investigations have shown that the gear geometry, operating conditions, gear material and heat treatment are the decisive factors that influence the risk of tooth flank fracture.

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