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Improving Heat Treating Flexibility for Wind Turbine Gear Systems Through Carburizing, Quenching and Material Handling Alternatives

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Part handling and processes for heat treating large gears have created challenges for decades. Growth in wind energy technology has focused more attention on this issue in recent years. The vast majority of installations processing such large parts utilize conventional methods via pit furnace systems. Such equipment has inherent limitations with respect to quench flow and part handling, making true improvements in areas such as distortion control difficult due to physical limitations of this processing approach. This presentation will explain alternative methods for heat treating large components that allow part distortion to be minimized. Benefits will be quantified regarding cost savings to produce such gearing and quality.

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Introduction

Commercial size wind turbines shown in Figure 1 and their gearboxes Figure 2, are designed to survive in extreme environmental conditions, most notably high wind forces, desert heat and arctic cold. However robust the design and use of materials, the typical gearbox struggles to meet their design life. Studies by the National Renewable Energy Laboratory (NREL) [1] have shown that on average a gearbox's time to repair can be as short as five years give or take when the economic pay-back model requires 20 years. Many failures seem to occur first in the bearings, also outlined in the NREL report. Studies are continuing to identify the root causes for these and other failures. Other preliminary studies indicate that the gearbox and or planetary carrier systems are subjected to higher-than-anticipated stresses and that the materials

used may not have the strength to resist the stresses encountered. Contaminated lubrication has also been targeted as a potential problem area. Since ferrous alloys are the most economical choice for drive train components, heat treating is a major consideration when designing for material strength and fatigue resistance.

Historically pit furnaces and the pit quench have been employed to case harden these and other large gears because for treaters there just has been no other choice. They are used primarily because they exist and alternative equipment has not, and there is the comfort factor – we've always done it that way. There are some who will say that pit furnaces offer a higher quality product but that's not so, as data presented later will show. In addition, pit furnaces can be energy hogs especially when carburizing cycles of 35 hours and longer are common.



Figure 1. Commercial size wind turbine

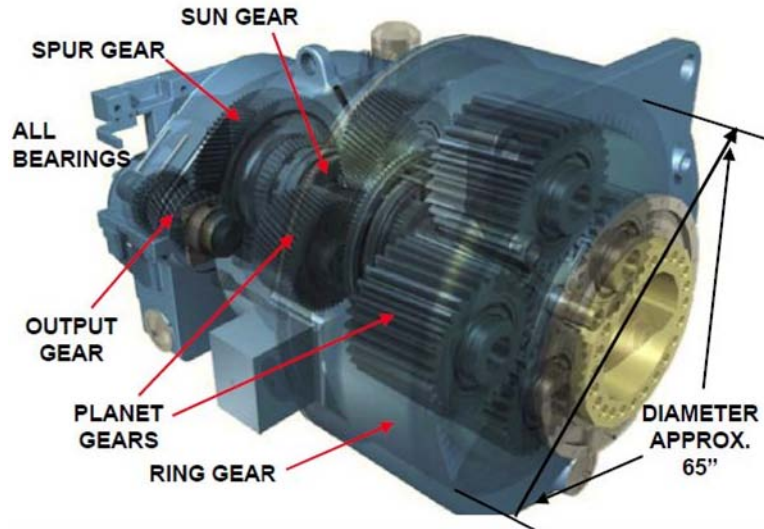


Figure 2. Heat treated parts of a typical wind turbine gearbox

Easy site preparation

Common sense suggests that eliminating the need for a pit is a very desirable concept, offering more freedom for heat treat site selection. Often the deep excavations needed for pit furnaces and quench tanks pose environmental issues in brown as well as green field sites. Further, if expanding an existing facility is contemplated, what facilities engineer hasn't experienced a flooded pit or power outage trying to install a pit? Who wants to accommodate an extra-high bay and additional large crane? Lower installation costs are achieved by reducing the overall furnace equipment height and using a pitless quench tank. Emerging economic realities for commercial as well as captive heat treaters dictate that the need for a more flexible and cost effective method of carburizing and quenching is overdue for large gears. Wind energy has attracted the attention of commercial heat treaters but they don't want to put all of their eggs in one basket, like a pit furnace; they need equipment flexibility if the wind turbine market fails to live up to expectations.

Cost effective material

Case hardening is necessary to achieve the tooth strength and wear resistance in ferrous alloys and the process allowing the most economical use of materials is carburizing. Adding carbon to the wear surfaces of bearings and gear teeth can be more cost effective than induction hardening where the entire part contains the alloy, even areas that play no role in the stressed application. Both processes require quenching to achieve the hardness necessary and both result in distortion that must be

corrected by grinding to bring the part to operating dimension.

Anyone associated with manufacturing and heat treating precision drive systems knows grinding is a necessary process required to obtain final size and surface finish after quenching. In addition, grinding remedies minor machining errors resulting from manufacturing very large gears. Grinding, although a critical requirement, is very expensive and can be minimized if quench distortion can be controlled and held to a minimum. If distortion can be predicted then designers can plan for it, thereby providing only the amount of material to be removed. Helical bevel gears are especially troublesome because of their tendency to "unwind". The unwinding if predictable can be accommodated in the design and machining.

Quenching options

Obviously quenching is a very difficult process to control and one that can ruin a perfectly successful carburizing process. Only recently with the development of sophisticated computerized fluid dynamics (CFD) has liquid quenching, specifically oil quenching, been targeted for investigation; maybe that's because most heat treaters wish it would just go away – no chance. Since heat treating ferrous material began eons ago, oil has no match for the range and control of quenching response. No other medium works better than oil when correctly applied knowing its limitations.

- Polymer has been tried and in some applications it can provide acceptable results in smaller

gears but concentration maintenance is an issue and it too has disadvantages, creating a need for more investigation into controlling distortion.

- Salt is a great quenching medium but has found almost no application with large gears. Historically, however, salt has been used extensively to reduce distortion in smaller gears.
- Helium high pressure quenching is very good at controlling distortion but cannot match the quench severity of liquid that's required for very massive parts.
- Press quenching with oil is the most accepted and practiced method for distortion control with gears and bearing cups & cones, but to date it has seen little if any application for smaller wind turbine gears.
- IntensiQuench® is a patented high intensity water quench method designed to impart compressive stresses onto the part surface in addition to allowing the use of lower alloy steels. Proprietary software computes the quench time to form martensite and the time required for the core heat to temper the martensitic case when the part is raised from the water then re-immersed into the water for final quenching.

Although diverse in their markets and application, all of the above quenching options can be implemented by AFC-Holcroft's modular heat treating system: EZ-Lynks.

Unlike smaller automotive drive trains, large gear components by necessity employ very high hardenability steels due to their size. However, high hardenability is a two-edged sword, easier to harden but at greater risk of distortion in quenching. Again, a better solution would allow several quenching techniques as documented above. Open pit oil quenching and the required fixturing offer little in the way of flexibility for quenching options. Many gears can be press quenched or otherwise individually quenched but not from pits where the awkward hanging fixture makes it impossible to remove individual parts.

Large is a relative term when applied to gears and for this paper is defined as 24" to 36" diameter planetary gears and up to 65" to 84" diameter spur gears. Quenching sun gears, shafts, pinions and planetary gears by their vertical orientation can be controlled somewhat easier but still requires attention to flow uniformity and velocity. In many applications, fairly large gears can be press

quenched with oil or water but only if the furnace type and material handling can provide the access for removal.

The IQ furnace has been the preferred furnace for commercial and captive heat treaters alike, primarily due to the flexibility offered in process, load size and efficiency. With electric as well as gas fired radiant tubes, the IQ furnace has provided unmatched utility and quality for all industrial, aerospace and military markets worldwide. AFC-Holcroft's UHQ series of IQ furnaces are the preferred product for many of the world's largest drive train suppliers. Today AFC-Holcroft's batch furnace as shown in Figure 3 is carburizing and quenching planet gears used by a major wind turbine manufacturer. Flame Metals Processing Corp. in Rogers, MN is a certified heat treat supplier meeting all of the AGMA and wind turbine quality requirements. Even though AFC-Holcroft has sold IQ furnace designed for very large loads, up to 72" (1829 mm) square and 12,000 lbs (5454 kg), they have not been applied to large gears probably because of rear handler (RH) capacity restrictions and the quench tank design. EZ-Lynks, AFC-Holcroft's alternative heat treating system shown in Figure 4a, Figure 4b and Figure 4c eliminates the pit disadvantage and overcomes the material handling concerns by separating the material handling from the furnace proper allowing more flexibility in the hot zone and quench tank designs.

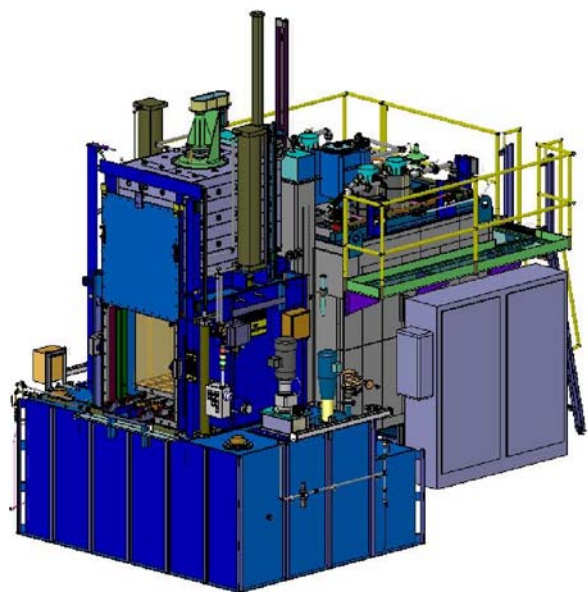


Figure 3. UHQ integral quench batch furnace

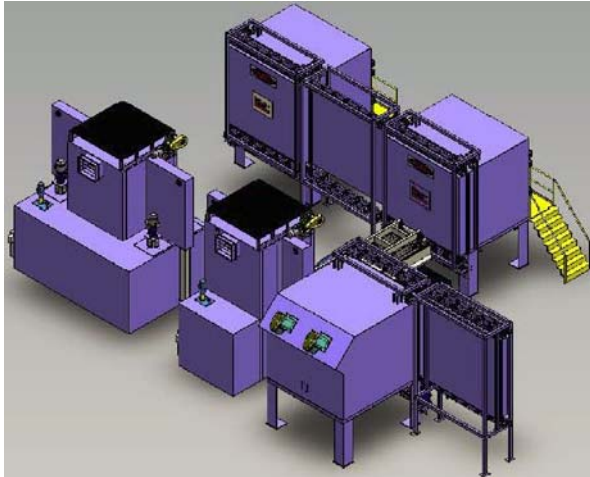


Figure 4a. EZ-Lynks modular heat treating system



Figure 4b. EZ-Lynks modular hot zone

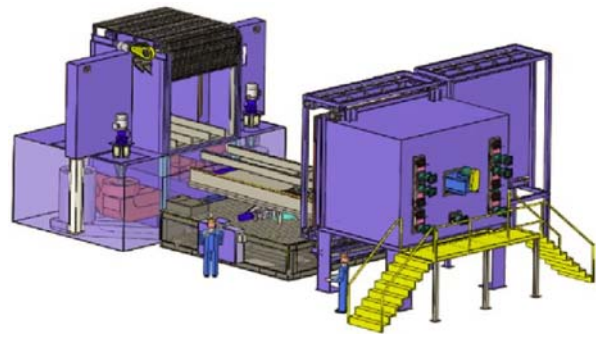


Figure 4c. EZ-Lynks modular system can be located anywhere and easily expanded as needed

The EZ-Lynks cell illustrated in Figure 5a and Figure 5b consists of multiple hot zone modules, enclosed floor mounted oil quench tank, wash, temper and transfer shuttle. All equipment is rated to 16,000 lbs (7,272 kg). A manufacturer or heat treater with an existing facility does not have to invest in a pit or extra high bay to accommodate EZ-Lynks. Doors can be designed to open sideways, radiant tubes can be removed from the rear and quench tanks can rest on the floor. Process flexibility is the result of a traversing and rotating transfer car, Figure 6, capable transferring loads automatically throughout the cell according to a preconfigured recipe.

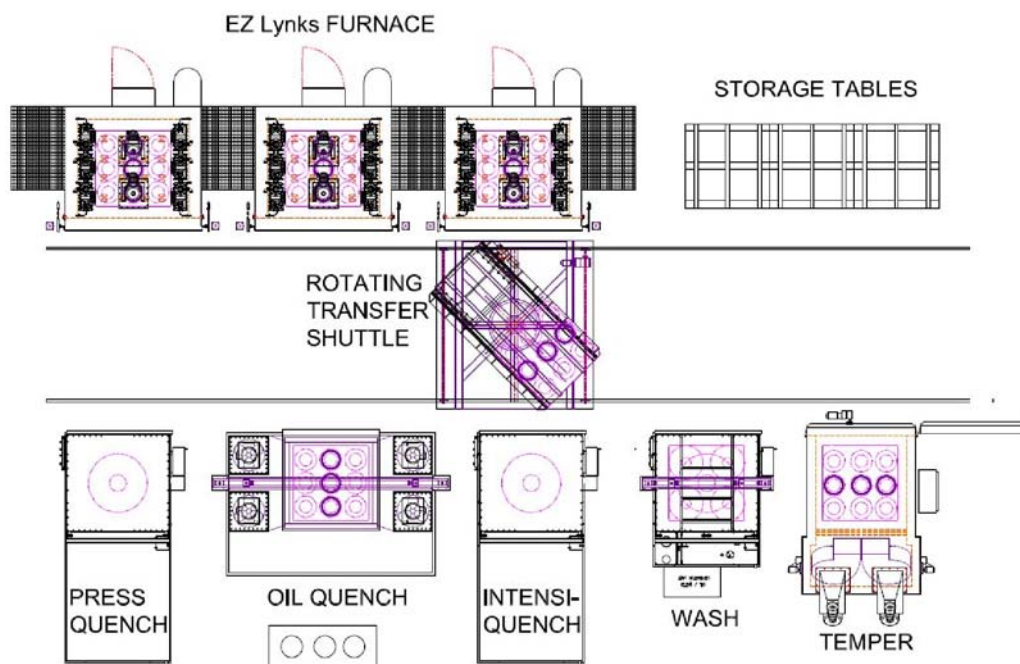


Figure 5a. EZ-Lynks modular heat treat floor plan