The Fundamentals of Gear Press Quenching

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Abstract: Most steel gear applications require appreciable loads to be applied that will result in high bending and compressive stresses. For the material (steel) to meet these performance criteria, the gear must be heat treated. Associated with this thermal processing is distortion. To control the distortion and achieve repeatable dimensional tolerances, the gear will be constrained during the quenching cycle of the heat treatment process. This type of fixture quenching is the function of gear quench pressing equipment.

Introduction

To understand press quenching, we must first understand the phenomenon of quenching and the resultant stresses within the gears that translate into dimensional changes or distortion. When we refer to the basic definitions of "press" and "quench," we see that:

Quench "is the immersion of metal into a liquid to extract heat"; and that

Press "is to exert a steady force or pressure on a component to achieve a desired shape."

Therefore, gear press quenching can be defined as "*heating a gear to the austenitic condition and then immersing the gear into a liquid to achieve metallurgical transformation, while at the same time constraining the gear to hold size and shape.*"

The most important thing to remember about gear press quenching is that its purpose is only to constrain the part and to use only enough force to counteract the parts' transformation stresses. Press quenching is not designed to reshape or forge gears into their final shape.

Causes of Distortions

Gear distortions can be caused by several factors and in any number of combinations. In the heat treating process, the gear is subjected to both thermal expansion and contraction. Non-uniformity in heating and cooling can cause stresses in a part, which, if large enough, can cause deformation. Consideration must also be given to the phase changes involved in hardening steel that result in expansions and contractions. Variations of this stress within the gear will cause deformation. Material composition variations resulting from the steel pro-

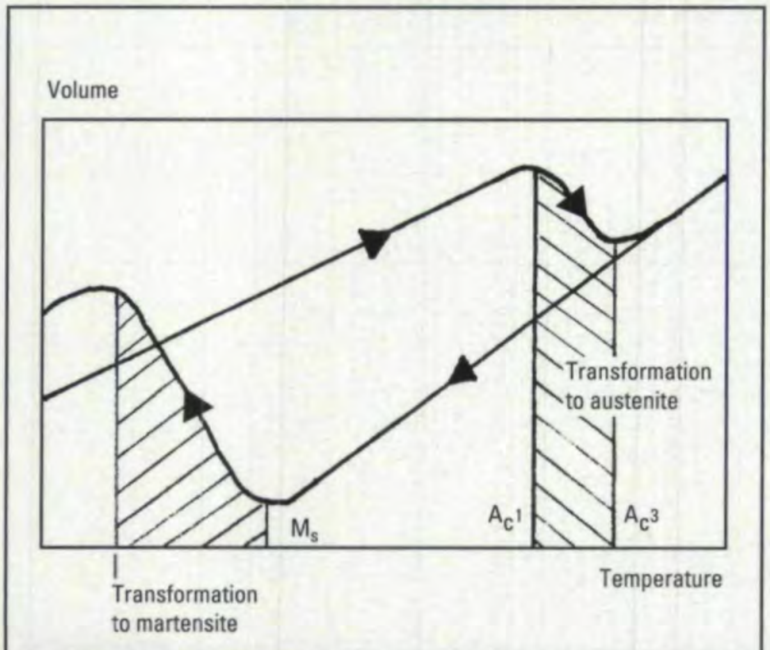

Fig. 1 – Volume changes due to structural transformation.

duction process, grain flow variations caused in forging, and stresses due to pre-heat treat machining can all affect the dimensional stability of a part during hardening operations.

The magnitude of the distortion in heat treating is affected by the cooling rate, method of cooling, transformation temperature and part geometry. To minimize distortion, it is best to use a slow cooling rate and a method that will maintain a uniform temperature throughout the part.

It is critical that the transformation temperature be consistent throughout the piece, so that during cooling the entire piece transforms at one time. However, a carburized and hardened gear that has a composition gradient and, hence, a transformation temperature gradient, is more susceptible to distortion. (See Fig. 1).

Finally, the shape of a part strongly influences the degree of distortion it may undergo. Parts that are large and thin are more susceptible to distortion than parts that are compact and massive. Therefore, a complex gear also is a more viable candidate for press quenching than is a simple one.

Review of Quenching and Systems

Fundamentally, quench systems, regardless of the quench media – oil, water, polymer or brine – are similar. Agitation, temperature control and quenchant contamination control are of primary importance. Since the primary quench medium used in gear press quenching is oil, the emphasis will be focused here.

The quenching of steel provides the rapid cooling that is required to convert the austenite to hard martensite. The prime factors that determine the quench speed required are steel chemistry, part geometry and designed function of the part.

Too low a quench rate will result in soft parts. Too high a quench rate may result in excessive distortion and cracking.

Quenching has three distinctive stages:

1. *Vapor blanket stage* – Delta temperature creates an insulating vapor in slow cooling.

2. *Vapor transport stage* – Liquid breaks through the vapor barrier; rapid heat transfer takes place.

3. *Liquid stage* – Cooling is taking place by conduction and convection. At this stage, the part temperature is above the boiling point of the quenchant, but the rate of flow prevents the quenchant from boiling. (See Fig. 2).

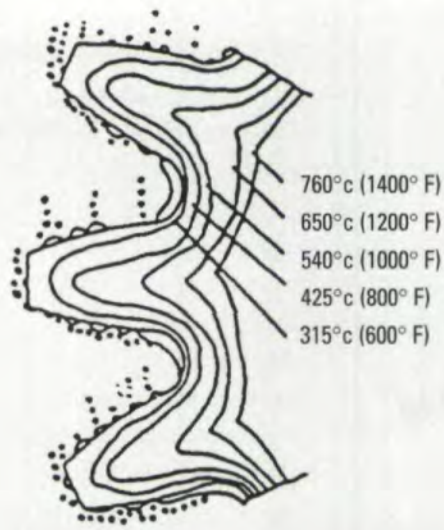

Fig. 2 – Temperatures during quenching.

The control of the vapor blanket stage is critical to the control of a consistent cooling rate for uniform heat extraction from the gear. Therefore, proper agitation or rapid movement of the quenchant is essential to prevent formation of vapor bubbles around the gear which insulate it and would result in irregular surface hardness and excessive distortion. As a rule of thumb, proper quenchant movement is defined as a volume flow of oil equal to two to three times the surface area of the gear in a one minute period.

To summarize, a proper quench system must have control of the temperature of the quench media, adequate quenchant movement, and consistent quenchant chemistry.

The Mechanics of the Press Quench

There are several manufacturers of quench presses, such as QPS, Inc., Gleason Works, Inc., Klingelnberg, Oerlikon and Jenny Presses, to name just a few. All quench press designs must incorporate a sufficient quantity of quench oil, variable quenchant flow rate, quenchant flow direction, die holding pressure, die contact points, and cyclic flow and pressures. The various press designs either use pneumatics or hydraulics for the pressure systems.

Our focus on a typical press quench operation will feature a press that uses hydraulics for mechanical movements and pressing force. (See Fig. 3).

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Basically, this type of quench press consists of a very rigid rectangular-box type construction. The base is a tank which acts as a reservoir for the quenching oil. It also serves as a support for the lower die. The upper portion of the machine contains the upper die ram assembly, hydraulic units, and the electrical panel. The opening at the front allows full access for changing the upper dies; the lower die table moves outward and inward for loading and unloading.

During operation, the component to be quenched is removed from a furnace (usually a pusher-type continuous or rotary-hearth-type), and placed onto the lower die in the "out" position. The automatic cycle moves the loaded lower die assembly into the center section of the machine and centers the die location. Next, the upper ram assembly descends, with an expander centering the part just prior to the inner and outer dies' location on their respective pressure points. The inner die, outer die and expander have completely independent pressure controls. (See Fig. 4). A circular guard completely encloses the upper dies to form a quench chamber which is affixed to the upper ram for movement. The chamber fills with oil flow from the lower die once the dies are in position. A variation in oil flow is controlled by three solenoid valves. Another unique feature is the ability to pulse the various die components (that is, maintain die contact on the component and cycle the pressure every two seconds or so). Also, the lower die is cam-adjustable, so the die rings can be raised or lowered to compensate for a predetermined amount of component dishing or camber. (See Fig. 5).

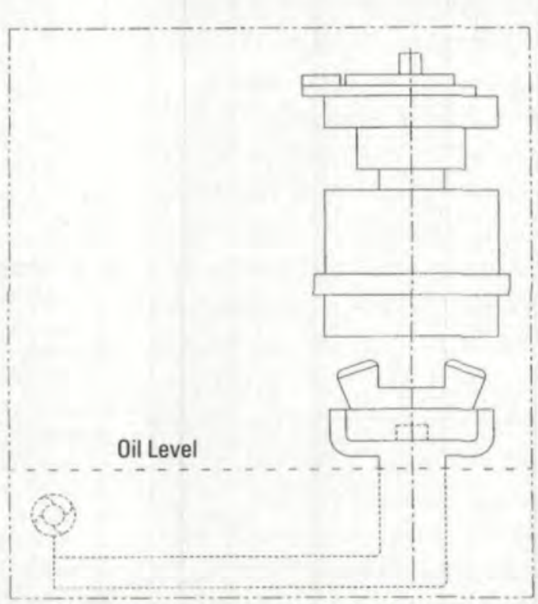

Fig. 3 – Schematic – Typical quench press.

The loading of the hot components can be either manual or robotic. The transfer mechanism is critical to assure a minimum of part heat loss from the furnace to the die. The temperature of the gear at the time of entering the quench is a determining factor of the final gear size.

The press quenchant system typically consists of the holding tank within the press, an external oil reservoir, circulation pump, heat exchanger, and internal heating source. The oil reservoir typically holds one and one-half to two times the holding capacity of the press itself. (See Fig. 6).

Within the quenchant system, oil temperature is maintained within 5°F plus or minus during operation. The operating oil temperature for most gear press quenching operations is between 130°F and 145°F.

Control of the Gear Press Quenching Process

This review of the control process will focus on carburized, case-hardened gears due to their high susceptibility to distortion. When examining a press quenching operation, consideration must be given to part geometry, chemistry of the component and the volumetric change resulting from the hardening process. Also, it must be remembered that the quench pressing operation will only round up and flatten the hot plastic gear, but will not change tooth shapes. With this in mind, it is imperative that the gear's prior manufacturing operations are closely controlled to assure consistent press quench results. The gear coming out of the press operation can only be as good as the gear going in. The variables that must be controlled before heat treatment are:

- Gear material composition,
- Grain direction and size,
- Prior thermal processing (normalizing),
- Machine stock removal,
- Cold work stresses,
- Tolerances and sizes of reference surfaces.

Once the gear enters the heat treat process, the procedures employed must be consistent, repeatable and closely controlled. The vari-

ables that must be controlled in carburizing are:

• Furnace temperature uniformity for heating rates and temperature distribution,

• Control surface carbon content and repeatable diffusion gradients,

• Gear fixturing during carburizing,

• Cooling rates after carburizing,

• Repeatability of temperature, uniformity, time at temperature and control cooling rates if annealing operations are used.

The reheating operation requires close control of:

• Temperature uniformity,

• Time at temperature,

• Fixturing and furnace loading,

• Atmosphere control or consistent stop-off procedures for surface integrity,

• Gear handling from the furnace to the press: Pickup contact and transfer time.

To successfully operate this type of press quench, the factors must be regulated:

• Quality of quench oil supplied,

• Duration of quenching,

• Quench oil temperature,

• Direction of quench oil flow,

• Pressure applied to hold the component,

• Location of component holding points.

In setting up this kind of press quench machine for operation, it is well recognized that the actual pressures and time settings must be developed for each component by trial and error. The following are general guidelines:

1. A fast quench or high oil flow is favored in the first stage to reduce the temperature of the part to the transformation range as quickly as possible. However, the flexibility available in the choice of duration and amount of oil flow permits a compromise between the need for a fast quench to ensure satisfactory hardening response and the desirability of a slower quench to minimize distortion.

2. The low flow rate in the second stage allows the temperature through the various cross sections to equalize. Thus, further cooling and martensitic transformation takes place with reduced internal stresses.

3. The third state returns to high oil flow when the component has nearly completed transformation. The high quenchant flow rate cools the part for operator handling.

4. In setting the pressures for the inner and outer dies, it is recommended that minimum levels be used. Use only the amount of pressure necessary to true up the component (high pressure settings can result in excessive distortions).

The variables within the actual press operation are:

• Die contact,

• Die oil flow,

• Oil flow rate and Delta temperature,

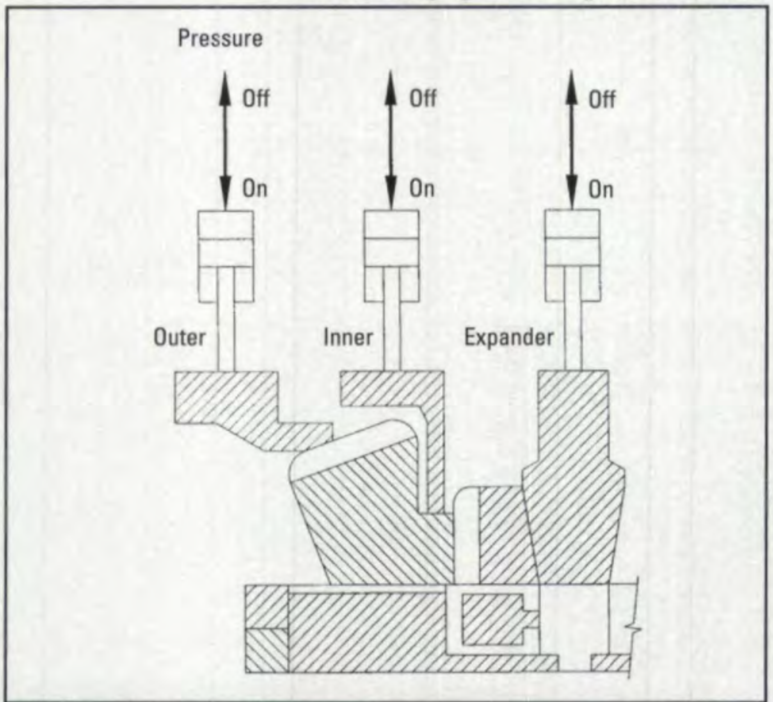

Fig. 4 – Die systems and ram pressure.

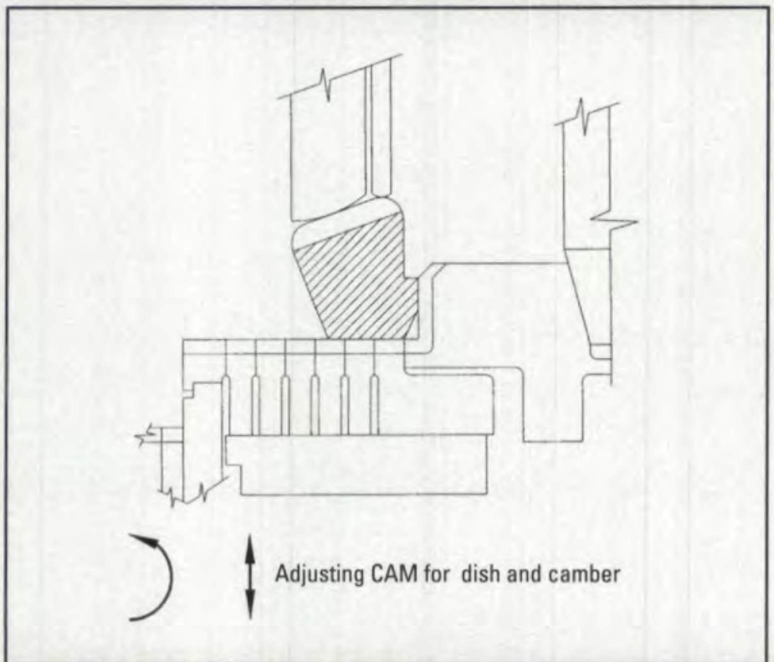

Fig. 5 – Lower quench die systems.

• Smooth movement of lower table,

• Die closure rate,

• Consistent ram pressure on all die rings,

• If pulse pressure is used, repeatable time for on and off cycles,

• Tooling care – nicks, burrs, scale or dirt *should be avoided so not to interfere with the* mechanical truing.

The control of gear press quenching operations cannot be isolated for control of gear distortion. The final results of the process are dependent on all prior operations. Therefore, if the gear manufacturing process is well documented, and the overall process is in control from the raw material stage to press quenching operation, repeatable results will be achieved with predictable size changes.

Gear Press Quench Instrumentation

As the demand on today's industrial quality systems and the need for system documentation and repeatability increase, more interest in press instrumentation systems is being generated. To date, development of instrumentation systems for press quenching has ranged from mechanical gauges to complex computer integrated systems. However simple or complex the instrumentation is, the information collected must be analyzed and correlated to the overall prior manufacturing process to gain control of the quench press operation.

A complete instrumentation system will document the following:

• The location of the lower table,

• Time measurement of the cycles indicating travel time, air lockup, cycle delay, stroke, cycle quench on, pulse on and off,

• Linear measurement of stroke movement,

• Quenchant flow rate,

• Quenchant oil temperature control,

• Quenchant Delta temperature through the die chamber,

• Hydraulic system pressure,

• Die position indicators,

• Non-contact temperature sensing of part temperature on transfer,

• Hydraulic sensitivity for dimensional measurement of the gear,

• Contact sensing device for measurement of part cooling rate.

With tabulation of the above data and immediate analysis, adjustments to the press quench operation can be made on-line, thus reducing rejected parts and increasing the predictability of the final as heat treat size. ■

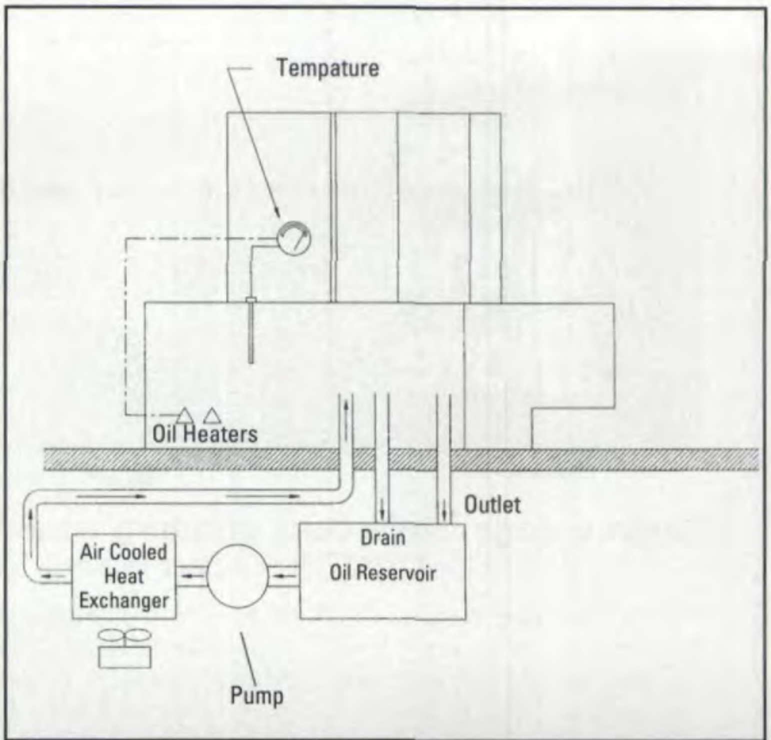

Fig. 6 – Quenching recirculation system.

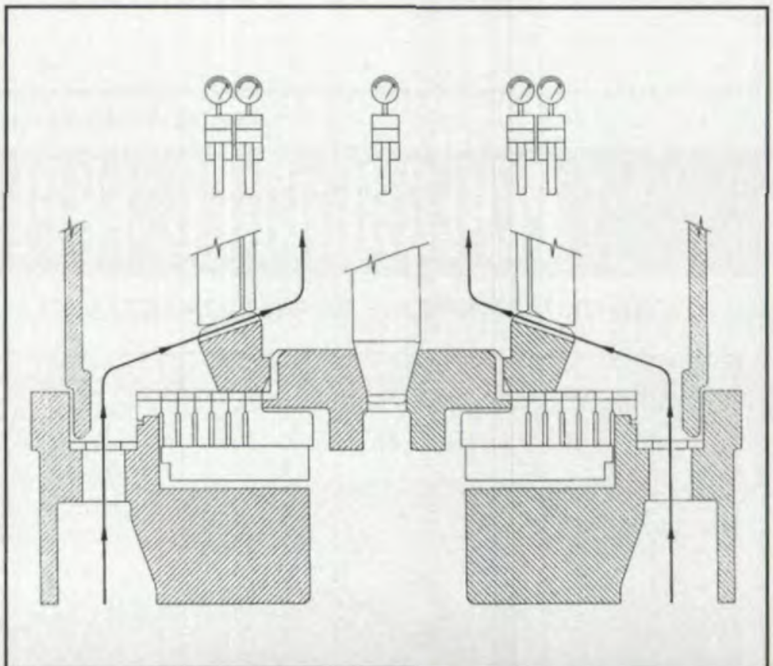
Fig. 7 – Typical die and quench chamber.

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