Maximizing Vacuum Furnace Gas Quenching Performance

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There are many critical factors that engineers must consider when designing a new, high-performance gas-quenching vacuum furnace, including:

- Proper fan design to achieve maximum gas flow
- Creating a minimal flow-resistance path for the recirculating gas
- Consideration of the types of cooling gases to be used
- A method to optimize the cooling system’s available power

Most vacuum furnaces are designed to operate at maximum pressure for a specific gas type (nitrogen, argon, helium, hydrogen). This approach sacrifices system performance at pressures lower than the optimal pressure as specified by the design. It also lengthens cycle time and creates extreme performance limitations when implementing other gases. To compensate for the change in gas density, quench pressure and/or fan speed decreases. Since using argon as well as nitrogen is often a requirement in many heat-treating facilities, these issues are a cause for concern.

Synchronous Design Concept

In order to overcome many of the disadvantages that exist on current vacuum furnaces, Solar has implemented a synchronous design concept in its new high-pressure-quench furnace. Key components of this design include:

- Utilizing a variable-frequency drive (VFD) to “over-speed” the cooling-fan motor
- Selecting a specially designed motor that can withstand the “over-speed” conditions
- Designing an appropriately sized fan to operate across the entire pressure range

Comparing Synchronous to Conventional Design for Two Gases

As opposed to traditionally designed vacuum furnaces, the synchronous approach allows the cooling system of the furnace to operate at the high motor-speed range.

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Applying the Synchronous Design to New 20-Bar Vacuum Furnace

The synchronous design with its VFD was recently incorporated into Solar’s newest 20-bar Super Quench vacuum furnace (SSQ). This recently manufactured and installed system has gone through an extensive testing program to fully compare its performance to prior conventional designs.

This furnace has a work zone that measures 36 inches wide x 36 inches high x 48 inches deep with a gas cooling system incorporating a 300-HP motor. The test load in Figure 1 was selected to represent its performance to prior conventional design.

Equating the relative performance of the two systems shows:
- Nitrogen: 7,200/7,200 = 1
- Argon: 6,468/5,220 = 1.24

This illustrates the improved relative cooling (24% better) when using argon in the synchronous system as compared to the conventional system.

Using nitrogen and at a slightly reduced speed with argon while maintaining the same pressure. Full horsepower can be utilized because the operating speed is still above the synchronous motor speed. Table 1 is normalized to compare the relative performance of each system when using nitrogen and argon gas.

Equating the relative performance of the two systems shows:
- Nitrogen: 7,200/7,200 = 1
- Argon: 6,468/5,220 = 1.24

The two systems provide equal relative cooling for nitrogen at this pressure.

- Operating at or above synchronous motor speed maximizes system performance.
- The synchronous design concept allows using the largest possible fan to maximize efficiency across the entire pressure range.
- The SSQ furnace will allow gas quenching to replace oil quenching on certain materials, thus greatly improving part stability and any need for further post-process operations.

The synchronous design cooling at 4-bar backfill pressure produced the same cooling performance as the conventional design cooling at 10-bar backfill pressure. That means the same results were achieved using 60% less gas.

Table 2 shows the unique varying components of the synchronous design as pressure increases.

Testing SSQ-5748 at Various Gas Pressures

The next series of tests involved processing the same test load across various gas pressures ranging from 2 to 20 bar (Figure 3). Table 2 shows the unique varying components of the synchronous design as pressure increases.

**Conclusions**

Based on this comprehensive test data, the resulting conclusions are:
- Incorporating a VFD into a gas-quenching system allows for excellent versatility regarding gas cooling at different pressures and when using different gas types.
- Operating at or above synchronous motor speed maximizes system performance.
- The synchronous design concept allows using the largest possible fan to maximize efficiency across the entire pressure range.
- The SSQ furnace will allow gas quenching to replace oil quenching on certain materials, thus greatly improving part stability and any need for further post-process operations.
When “just good enough” isn’t good enough for you.

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