FALL ISSUE

NITREX

NOVEMBER 2021

VACUUM FURNACE EDITION

VACUUM FURNACES:

KEEPING AN EYE ON THE BIG PICTURE

A WORD FROM IWO

When we first started in 1984, our mission was to invent a new concept that would break the mold in the heat treat world, redefining the concept of "turnkey systems" to an entirely new level in nitriding and nitrocarburizing processes. Fast-forward 37 years and our most recent investment is driving the growth of our Turnkey Systems division.

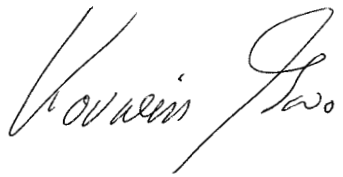
Through the acquisition of G-M Enterprises, a US-based vacuum furnace manufacturer, NITREX has a great potential to tap into the global heat treating market with a broader portfolio mix of turnkey systems for customers in aerospace, additive manufacturing, power generation, energy, MIM, and commercial heat treating industries. Besides being a reliable, safe, and clean process, vacuum heat treating like nitriding shares a common goal – to improve the customer's workflow and efficiency while maximizing the life span and performance of engineered components. These vacuum furnaces are very flexible and can handle a wide range of thermal processes, including annealing, brazing, sintering, quenching, and tempering.

As with any technology, "the devil is in the details"; and for nearly 40 years, our team has honed their expertise and know-how to design, build, and deliver with the highest quality.

We will gladly put our experience at your disposal should you wish to obtain more information or, even better, acquire one of our vacuum furnaces.

So it's fitting that the focus of our fall issue of NITREX magazine is on vacuum heat treating furnaces. Inside, our product engineering teams share several design initiatives that have increased the energy efficiency of our vacuum furnaces; discuss the role of aluminide coating for today's high-performance, high-efficiency jet engines; and give insights on what's next for vacuum furnaces as we scale AI and IIoT.

I hope you enjoy reading the articles we selected, and please do not hesitate to send any feedback my way. I look forward to communicating with you very soon.



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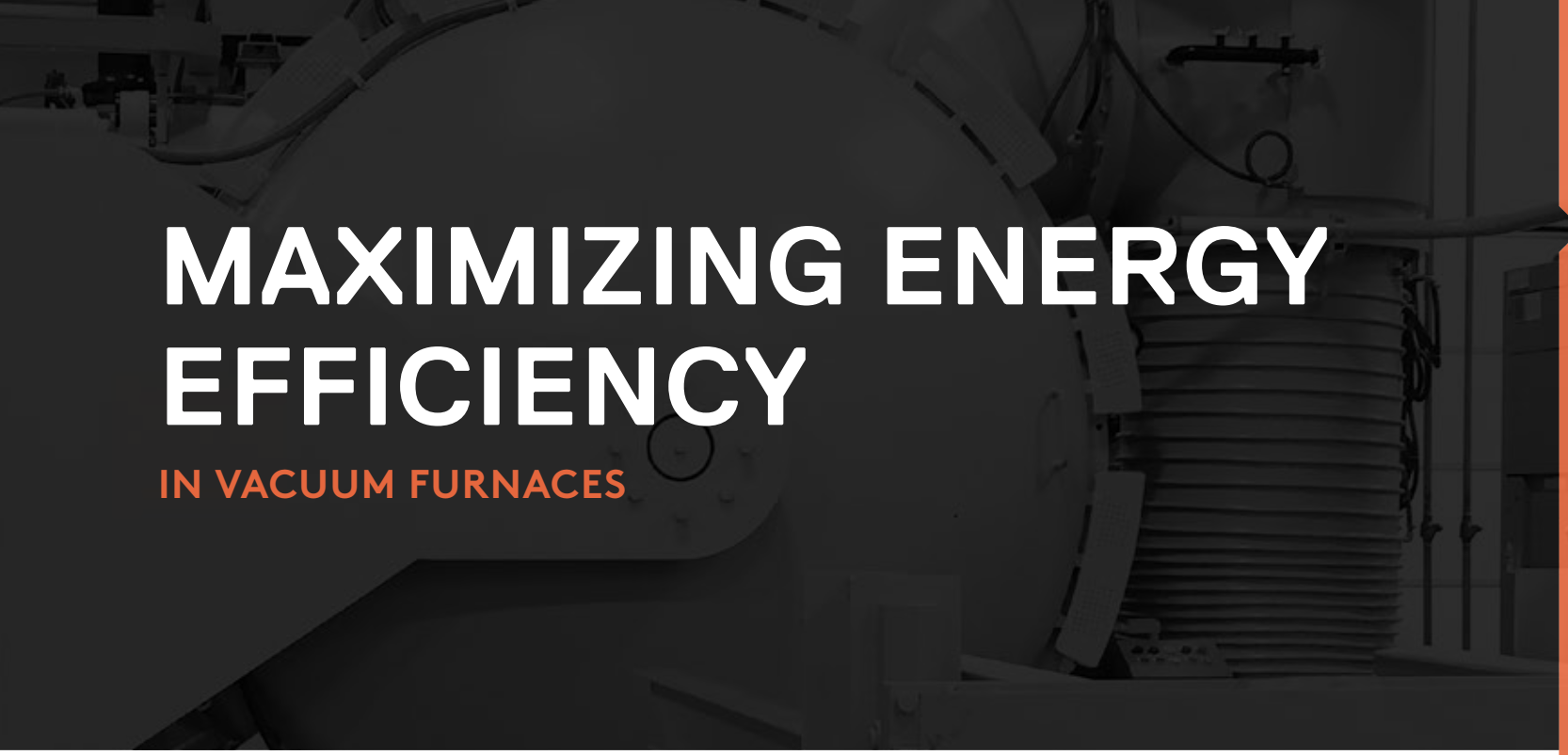


MAXIMIZING ENERGY EFFICIENCY

IN VACUUM FURNACES

Energy efficiency is an important issue not only in the USA, but throughout the world where energy costs are higher.

Over the years, G-M Enterprises, a NITREX company, has pursued, developed, and implemented energy-efficient initiatives in its furnace design to reduce the total energy consumption and to help the environment.

These important upgrades to our vacuum heat treat furnaces benefit the customer and the environment:

- → **A high-efficiency diffusion pump** and the use of variable frequency drive (VFD) motors on the vacuum blower pump
- → **Extra thick graphite felt** to retain heat more heat efficiently at higher temperatures
- → **An AC/DC transformer system** that saves power over a traditional variable reactance transformer (VRT) by:
  - Achieving 30% power savings during steady-state soak temperatures
  - Maintaining a power factor close to 1.0 during all inductive heating operations
  - Reducing peak power demand
  - Reducing premium power surcharge that the utility companies charge for running under a 1.0 power factor and higher peak power usage

3 WAYS TO SAVE:

VARIABLE FREQUENCY DRIVES

Variable frequency drives (VFD) are the most common energy-efficient improvements.

Variable frequencies allow the ability to control the starting current of equipment, which reduces power usage on start-up.

Applying this technology to our cooling blowers and mechanical pumps not only helps to conserve energy but also to control the cooling/quenching cycle. The addition of a special PID loop when used in conjunction with the VFD updates to real-time data and adjusts the cooling fan's RPM accordingly to eliminate energy waste.

Equally important when it comes to VFD is the fact that vacuum furnaces achieve a higher degree of process control for better mechanical properties of heat-treated parts.

HIGH-PERFORMING INSULATION

Improvements in insulation materials are also contributing to greater energy efficiency of vacuum furnaces.

Most furnaces on the market today use a 1" (25.4 mm) graphite board with bonded Grafoil (similar to a very dense Styrofoam but made from graphite), plus two layers of graphite felt. **The insulation performance of a 1" (25.4 mm) graphite board is about 25% less efficient than a 1" (25.4 mm) graphite felt.** In cases where the customer's process requires high operating temperatures, typically over 2,200°F (1,204°C), we recommend an all-graphite felt 2" or 2.5" thick (50.8 mm or 63.5 mm), to minimize heat loss inside the hot zone.

Efficiency can improve as much as 25% over the typical 1" (25.4 mm) board and 1" (25.4 mm) graphite felt insulation and can achieve even higher values at higher operating temperatures. These thicker all-graphite felt insulation configurations are typically covered with a carbon fiber composite (CFC) sheet about 0.050" (1.27 mm), thick to protect the graphite felt from mechanical damage and localized compression.

3 WAYS TO SAVE:

ENERGY-EFFICIENT HEATING SYSTEM

An area that demands a huge glut of energy is the heating system. Its power supply is by far the biggest draw of amperage in a vacuum furnace system.

AC TO DC TRANSFORMERS

Using existing technology in new ways, specifically applying AC to DC transformers, has allowed significant energy savings. Most systems use alternating current as the primary source, which fluctuates output during each half cycle. If direct current is used, the heat pattern does not fluctuate. Using AC to DC transformers limits fluctuations, resulting in a reduction of the amount of energy used.

This technology is called IGBT/MFDC – Insulated Gate Bipolar Transistor/Mid-Frequency 1,000 hertz to DC voltage power transformer. Transformers operate at optimal efficiency when under a reduced load – i.e., less than 70% output in steady-state heating, not when ramping up to the full operating temperature. Specially designed inverters allow for full control of cycles.

In a typical heat treat cycle, controlled ramping means that it is unlikely that the controller will be at 100%. During a soak cycle, the controller is at reduced output. For AC to DC transformers, this works to their strength.

LESS KILOWATTS REQUIRED

A study found that approximately 30% FEWER KILOWATTS were consumed during a soak segment compared to an AC transformer or a variable reactance transformer (VRT). The longer the soak cycle is, the higher the energy savings.

LOWER PEAK DEMAND

Reduced energy consumption is not the only benefit – a reduction of peak demand is just as important. The same study found that peak demand was reduced by 14%, driving higher efficiency gains for furnace users.

Another benefit of the DC-type transformer is that the operating power factor is very close to 1.0, which reduces the utility company's calculation of peak demand surcharges.

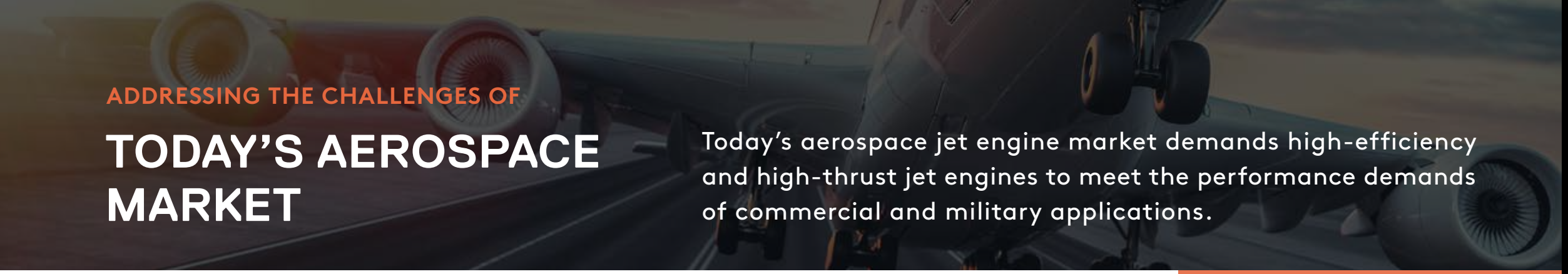
SMALLER FOOTPRINT

Standard transformers are bulkier and require cooling cables from the transformers to the power feedthroughs (PFT) on a vacuum furnace. With AC to DC transformers, no more need for cooling cables or replacement due to degradation of cables. The design makes it compact in a small footprint and lighter weight, allowing the transformers to be mounted closer to the PFT and connected simply with a busbar.

JET ENGINE BLADES & VANES

INCREASING STRUCTURAL DURABILITY WITH ADVANCED ALUMINIDE COATING

IN A SEALED ATMOSPHERE RETORT OR VAPOR PHASE ALUMINIDE RETORT COATING FURNACE



ADDRESSING THE CHALLENGES OF

TODAY'S AEROSPACE MARKET

Today's aerospace jet engine market demands high-efficiency and high-thrust jet engines to meet the performance demands of commercial and military applications.

THEN...

Jet engine technology was developed and applied to commercial and military jets during the 50s and 60s. The power and efficiency of early jet engines were limited by the temperature that the jet engine blades and vanes could withstand before degradation.

Early engineers had to develop unique high-temperature resistant metal alloys to fabricate the blades and vanes, given that exposure to high-temperature gas tended to erode and destroy the blades. After many years of development and experimentation, single-crystal high-temperature aerospace alloy materials were developed, capable of withstanding the high-firing temperatures of jet engines. But jet engineers were determined to push the thrust and efficiency of the jet engines considerably further, which meant increasing the firing temperature of the gas hitting the blades and vanes. Even with these advanced single crystal materials, the higher burn temperatures culminated in shorter engine life. This led to the development of the aluminide coating process to help blades resist the higher burn temperatures. As burn temperatures continued to rise, additional coatings were developed.

...& NOW

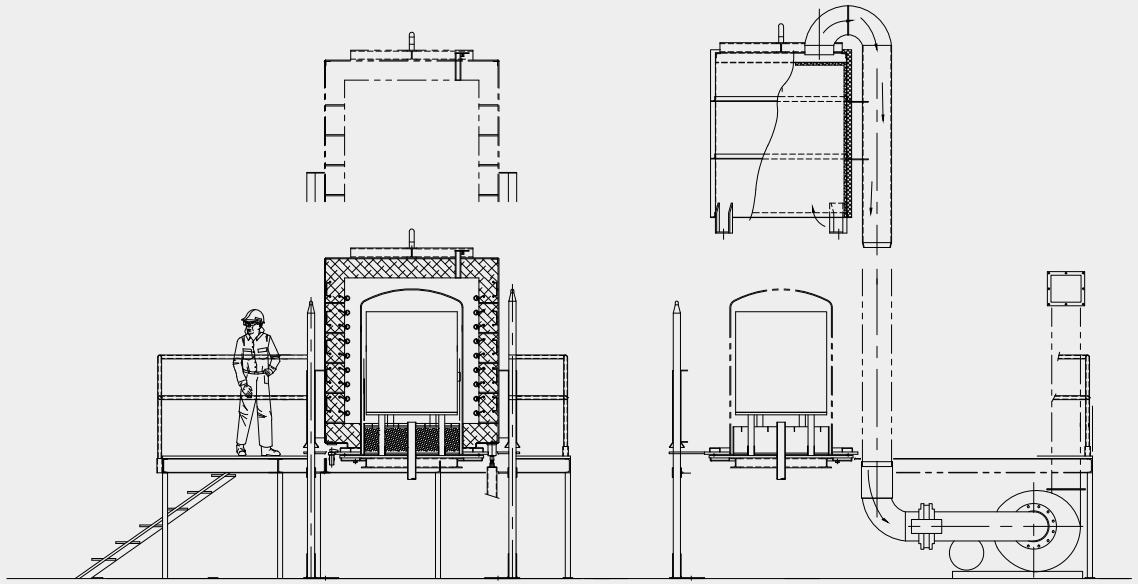
THE HIGHEST PERFORMING HEAT-RESISTANT COATING TODAY IS A COMBINATION OF A PLATINUM ALUMINIDE & CERAMIC TOPCOAT (EVPVD).

It's a triple coating layer that substantially increases the durability and resistance of blades and vanes against high-burn temperatures and erosion.

UNDERSTANDING THE FUNDAMENTALS

SAR/VPA FURNACE

Now that we have an understanding of why aluminide coating is important to the aerospace market, let's discuss how an SAR/VPA furnace works and why a G-M Enterprises SAR/VPA furnace is the right choice.



Fixed-based SAR/VPA Furnace

The design of an SAR/VPA furnace consists of an exposed hearth where the load is built up on top of the hearth. A typical SAR/VPA coating load has one to four coating cans where parts are loaded into a graphite or alloy coating can. Parts are fixtured inside the can so that they do not touch one another. Within the coating can are doner baskets containing aluminide pellets – the source of aluminide for the VPA process. An activator, typically a chloride or fluoride-based powder, is distributed inside the can over the aluminide pellets. With the coating can loaded and covered, it is stacked onto the open hearth, with up to four coating cans forming a load. The retort is then lowered over the load cans on the hearth. Clamped and secured, the retort and coating cans are vacuum purged; once the purge is complete and the leak up rate passes, the retort is positively pressurized for a positive pressure purge and leak down rate test. If both purge tests pass, the load is ready to be heated and coated. The heat chamber is lowered down on top of the retort and hearth assembly.

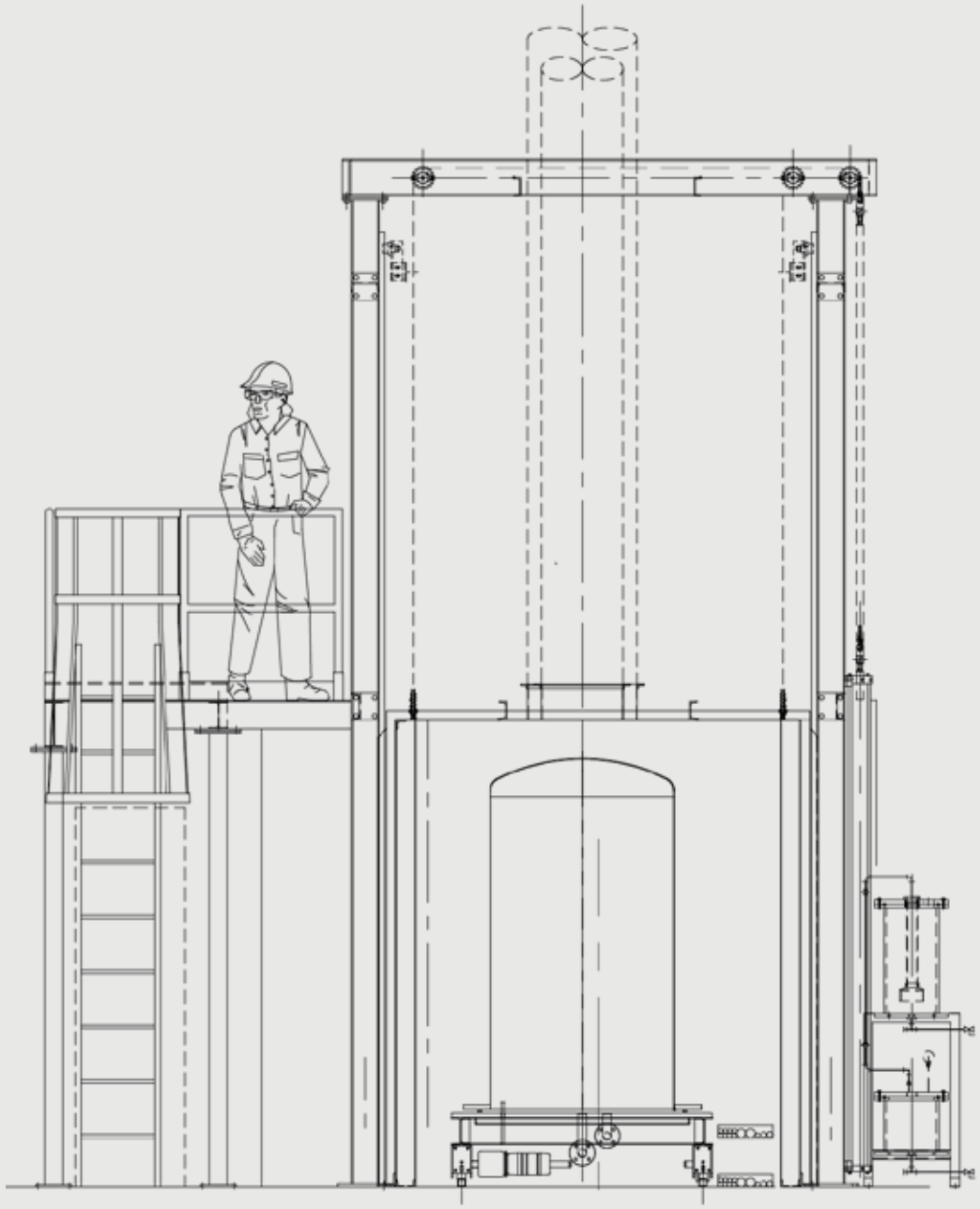
UNDERSTANDING THE FUNDAMENTALS

SAR/VPA FURNACE

AVAILABLE IN 2 CONFIGURATIONS

A G-M Enterprises SAR/VPA furnace comes in 2 configurations:

- → **The first has the hearth in a fixed position.**
- → **The second is a vertical furnace heat chamber with the hearth or load base on a bottom platform moving on rails to a different load, unload, heating and/or cooling station within the furnace.**



Moving-based SAR/VPA Furnace

SAR/VPA FURNACE

FIXED-BASED

PERFECT FOR LOW TO MEDIUM PRODUCTION, our fixed-based SAR/VPA furnace eliminates the need to extract the furnace room air and exhaust it outside.

BENEFITS

The fixed-based furnace design reduces the load on the air conditioning system in the furnace room, saving a considerable amount on energy costs. Moreover, placing the exhaust fans outside of the building is an effective way of reducing the noise level in the furnace room for a quieter and safer workplace – a system feature not typically found in competitive SAR/VPA furnaces.

HOW IT WORKS

The simple fixed-base SAR/VPA furnace requires an overhead crane or gantry crane depending on how the furnace is configured. The coating cans, the retort, the heat chamber, and the cooling chamber are lifted separately or moved manually via a crane. After a coating cycle is finished, the heat chamber is lifted off the retort, placed on the rest station, and the cooling chamber is placed on top of the retort. With the cooling chamber in position, the automatic cooling in/out louvers are opened, allowing the cooling chamber to be ported to the cooling supply and the exhaust fans outside the building. High-velocity air is forced into the cooling chamber over the retort via the spiral flights inside the cooling chamber, while a balance draft exhaust fan removes the hot gas from the cooling chamber.

Each cooling chamber has a set of balanced draft supply and exhaust fans located outside on the roof of the furnace building. Fans are sized to provide a balanced supply of outside air and exhaust air, so the furnace room conditioned air is not exhausted out of the building.

SAR/VPA FURNACE

MOVING-BASED

Our automated moving-based SAR/VPA furnace is the **BEST CONFIGURATION TO SUPPORT HIGH OR CONTINUOUS VOLUME** as well as 24/7 production runs.

BENEFITS

The biggest advantage G-M Enterprises brings to the competitive market is a moving-based configuration, consisting of a common bottom loading heat chamber with two moving bases and two fixed cooling chambers that allows for high and continuous volumes and 24/7 production runs.

Operating at optimal performance and with minimal maintenance, our SAR/VPA furnace enables exceptionally high availability, increasing uptime well over 95%.

With employee safety and the running costs of air conditioning being a huge concern for most companies, the moving-based VPA furnace keeps the hot retort away from the operator and air conditioning costs in check.

HOW IT WORKS

Once the load bases are on the hearth and the retort is secured to the moving load bases, there is no intervention required by the operator. The operator is free to clean and inspect parts and build the next set of loads. Technically, one operator can tend to two SAR/VPA furnaces in this automated arrangement.

The furnace allows for two loads to be built and placed on standby for automatic loading with minimal operator involvement during a run.

Depending on the coating cycle, the typical process time for load 1 from start to finish is approximately 12 hours. After completing the first coating cycle load, the cool retort is unclamped and removed from the load base and the coating cans are removed from the hearth and unloaded.

While the second load is running, the next load for base 1 can be built with another set of coating cans or boxes. The next set of coating cans is ready to clean and loaded with parts along with the pellet baskets and activator medium, then covered and loaded onto the hearth; the retort is automatically clamped to the moving load base, ready to start the vacuum and positive pressure purge, prior to heating.

IIOT, AI, AND MORE

WHAT'S NEXT FOR VACUUM FURNACES?

FIRST STEP IN THE EVOLUTION – AI AND MACHINE LEARNING TO UNLOCK INSIGHTS

HEAT TREATING: A BLACK ART

Heat treating of steels and other metals, such as nickel-based and titanium-based alloys, is still considered a black art compared to other production steps in metal-fabricated parts.

While this is obvious when talking about case hardening in a pit furnace with open flames, where the yellow-red hot load is taken out of the furnace and moved to an oil quench by an overhead crane, it is not so apparent for processes performed in clean vacuum furnaces where the load is fast cooled or quenched internally.

HEAT TREATING:

A BLACK ART

One of the predominant reasons for this assumption stems from the fact that parts are loaded into a process chamber without the means of directly measuring what is happening to the parts during the process. Typically, we can only measure the surrounding environment, and even in a vacuum process where we control the temperature close to the parts using load thermocouples, we cannot directly observe what is happening to the parts from a metallurgical point of view.

Let's take a look at a typical process applied on hot work tool steels. First, we heat up the parts above austenitizing temperature in the corresponding phase diagram. Then, we hold the parts at this temperature until the desired temperature equalizes

throughout all parts, which is a matter of mass and dimensions. Once this is achieved, we quench the parts well below martensite start temperature to ensure transformation, only to heat up the parts again to a tempering temperature, then equalize, and cool. Tempering might be performed up to three times in order to create the desired structure with finely dispersed chromium carbides.

BEING ABLE TO PERFORM SUCH A PROCESS SUCCESSFULLY REQUIRES A LOT OF KNOWLEDGE & EXPERIENCE – AND THIS IS EXACTLY WHERE MACHINE LEARNING (ML) & ARTIFICIAL INTELLIGENCE (AI) KICK IN.

DATA & DEEP LEARNING: SEIZING THE POTENTIAL VALUE

Imagine model-driven vacuum equipment with additional sensors besides the typical furnace and load thermocouples, pressure gauges, and flow meters.

Using these data points together with the chemical composition and geometries of the parts, the AI will drive the vacuum heat treat process to meet the given specifications. By comparing the heating energy with the temperature readings of a permanently installed specialized temperature sensor that displays the propagation and distribution of heat throughout a test piece, the process controls will automatically operate the required heat treat stages fitting to the workload (stress relief, preheating, austenitizing, quenching, and tempering).

DATA & DEEP LEARNING:

SEIZING THE POTENTIAL VALUE

DEPLOYING A PREDICTIVE PROCESS MODEL TO DETECT ANOMALIES

By analyzing the sensor readings such as temperatures, output power to heaters, gas flows, pressures, pumps, etc., we can create a pattern representing a Model Process and use it for comparison with active runs. Any deviation will be detected as an anomaly indicating an unexpected behavior. This will then trigger a set of rules that identifies the most probable root cause and initiates optimal countermeasures.

USING ANOMALY DETECTION TO OPTIMIZE PROCESS PERFORMANCE

Here's a good example to illustrate this point:

Humidity is one of the most influential factors for fast evacuation to a required pressure level. While any gaseous species can be extracted by the pumping system, condensed water is more easily removed by an active flow of nitrogen. If the AI observes that pumping down takes longer than usual and that the furnace door has been open for a longer period prior to the process, it will assume that the reduced pumping efficiency is not caused by the pumping system itself but most likely due to the fact that a high amount of humidity has settled on the cooled furnace walls. In this case, the AI will invoke an active nitrogen or argon flow.

The anomaly detection will be used for both, predicting the asset health and validating and directing the process. If both worlds come together, it is possible to predict and ensure product quality in order to create the desired structure with finely dispersed chromium carbides.

NEXT STEP IN THE EVOLUTION: AI-DRIVEN CONTROLS

Enabling AI to interpret asset health, processes, and product quality requires a holistic and transparent view of the data.

This not only includes machinery data provided by the manufacturer, sensor readings, maintenance records, production schedules, parts' specifications, and materials, but it also includes environmental influences, such as temperature and atmospheric pressure. Managing this high amount of data needs to be properly orchestrated – documented, abstracted, normalized, and easily accessible. And creating models out of this vast data pool eats up a whole lot of computing power, which nowadays is only possible in a cloud environment.

NEXT STEP IN THE EVOLUTION:

AI-DRIVEN CONTROLS

Looking at the Gartner Hype Cycle, a methodology that is used to capture how a technology will evolve over time, would suggest that one of the next developments will be to bring the power of embedded AI to the controls.

The implementation of AI models to control hardware will shift data-processing from the cloud directly to end devices and provide near real-time, low-latency processing.

The future is bright with the ever-increasing use of smarter technologies – ensuring vacuum furnaces and operations run more smoothly and efficiently, providing real-time diagnostic support and corrective actions, adapting easily to dynamic manufacturing conditions, and keeping pace with new and changing demands.

THE FUTURE IS BRIGHT WITH THE EVER-INCREASING USE OF SMARTER TECHNOLOGIES

BEAT THE WINTER SHUTDOWN RUSH.

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