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At the Intersection of Technology and Industry 4.0: A Look at Thermal Processing Technology in the Modern Age

Janusz Kowalewski, Director of Business Development for ARGOS

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Ipsen USA

Technology continues to advance at an accelerated pace, fueled by the development of lean manufacturing processes, the growth of the Internet of Things and the demand for integrated, automated systems. This intersection of technology and industry development has led to a turning point – a point where technology can now manage process variables, enhance productivity and contribute to seamless manufacturing operations. A point where technology drastically impacts the advancement and utilization of thermal processing systems and applications.

Integration of Lean Manufacturing and the Internet of Things

At this intersection between technology and the thermal processing industry is lean manufacturing. One of the primary tenants of the lean manufacturing movement is to increase productivity by reducing the work-in-process inventory. However, it is important to note that as the supply chain and manufacturing process become leaner, it is even more essential that production interruptions caused by equipment breakdowns are prevented. This is where the growth in the Internet of Things (IoT) and predictive maintenance come into play.

Take industrial applications, such as Aerospace manufacturing, for example. Currently, there are multiple steps and physical devices that make up the process of manufacturing a load of engine parts – machining, heat treatment, finishing, etc. However, with the application of the IoT, all of these processes and systems will become interconnected. One day, we will be able to start with a usable part that knows who the end customer is, and once it is put into a machine, any abnormalities or changes from the standard process will be recorded. The technology will move the part from one process to the next as part of an automated system, and each integrated machine will track the necessary information. All of this data will then be accessible in a central location so the IoT system can analyze the manufacturing process and determine ways to attain peak efficiency, lean manufacturing objectives, etc.

Predictive Maintenance Capabilities

An example of the ability to achieve enhanced control and operation of today's equipment is predictive maintenance technology, which is emerging as a powerful tool within the heat treatment industry for analyzing performance and efficiency.

By monitoring the furnace, its performance and other parameters, predictive maintenance provides key data that can be analyzed to determine when maintenance should be, or will need to be, performed. This data can then be used to augment the furnace's performance, efficiency and reliability. Predictive maintenance also allows for an all-encompassing planning of available resources, thus helping minimize unnecessary personnel, storage and spare parts costs. In addition, it is effective at identifying problems that occur between scheduled inspections.

PdMetrics™ Software Platform

Ipsen's PdMetrics™ software platform for predictive maintenance was developed as a way for companies to create value from the wealth of data that is generated by their equipment and processes ran in the furnace. With sophisticated monitoring and diagnostics, the PdMetrics software platform integrates with critical systems to provide insights never before seen in the thermal processing industry (Figure 1).

Figure 1: The PdMetrics software platform dashboard, where users can monitor the health and integrity of the hot zone, pumping system, cooling system and vacuum integrity

This innovative system securely connects to a network of integrated sensors on the furnace to gather data, analyze it and provide real-time diagnostics that improve the health and integrity of the equipment. The PdMetrics platform also provides several advantages, including the ability to:

- Leverage Ipsen's experience through automated analysis performed by the PdMetrics algorithms
- Experience real-time furnace visibility for faster, better decision making – from monitoring dashboards at the furnace, on the office PC, smartphone or tablet to sending urgent alerts by text or email
- Achieve smart factory integration with furnace fleet analytics, allowing operators to see the health of all furnaces at all facilities

PdMetrics is available as a retrofit or with the purchase of a new furnace, and it is not integrated with the PLC. It also functions as a furnace add-on, meaning it can be quickly retrofitted to the global installed base, including non-Ipsen brand furnaces.

Learn more about the power of predictive maintenance at bit.ly/IH-PdM816-2.

In the end, the integration of predictive maintenance provides a smart, connected furnace capable of monitoring in-service equipment to capture data that assists in refining furnace operations and reporting when service will be needed. Through analysis of the critical furnace data, predictive maintenance software can also identify maintenance trends, deteriorating conditions and more. This, in turn, helps companies plan ahead – whether that means scheduling someone to perform maintenance or ensuring the required furnace parts are in stock.

The Evolution of Low-Pressure Vacuum Carburizing

In addition to the use of technology and equipment that contribute to the achievement of lean manufacturing objectives, there has also been a substantial increase in demand for leaner and more environmentally friendly heat treatment processes that help streamline and shorten the production cycle. With this increase, there has been marked growth around low-pressure carburizing (LPC), and it is estimated that LPC technology has much more room to grow in the near future.

According to industry estimations, currently between 25 to 30 percent of gears are vacuum carburized. Assuming that the low-pressure vacuum carburizing market penetration reached that percentage in 2015, there is sure to be an exponential increase in demand for vacuum furnace systems with LPC technology. This not only applies to traditional automobile transmission components and fuel injection nozzles, but also to bearings, PM parts and tool parts. In the end, as LPC equipment and processes continue to be refined, companies gain the ability to further optimize the manufacturing process – which ultimately results in the production of high-quality parts with lower cost per part.

As technology has developed and evolved over the years, so has the LPC process. In the 1960s, development work began to provide an LPC technology that was fully competitive with gas carburizing. While at the time LPC offered a number of benefits with respect to process time, component quality and minimized fluid burnoff and heat emissions, it still had a high amount of soot forming in the furnace. In addition, there were high maintenance requirements when propane was used as a carburizing gas with relatively high partial pressures. However, in the mid-nineties, acetylene was discovered to have superior qualities as a reactive gas in vacuum carburizing.

To start, the AvaC® process (acetylene vacuum carburizing) produces twice the carbon availability as compared to traditional carburizing agents, resulting in excellent carbon transfer into the parts. AvaC also has the advantage of producing an oxidation-free surface microstructure while allowing complex geometry components to be evenly carburized. Wherever possible, it is used in combination with dry, high-pressure gas quenching as the hardening step. This provides the industry with a case hardening process that is safe, environmentally friendly, clean and flexible, which – when compared with oil quenching – also has a potential for reducing distortion and improving case-depth uniformity.

Understanding the AvaC Process

The AvaC process involves alternate injections of acetylene (boost) and a neutral gas, such as nitrogen, for diffusion. During the boost injection, acetylene will only dissociate when in contact with metallic surfaces, thus allowing for uniform carburizing. At the same time, it almost completely eliminates the soot and tar formation problem known to occur from earlier propane carburizers.

One of the most important advantages of this process, though, is the high carbon availability. This helps ensure extremely homogenous carburizing – even for complex geometries and very high load densities. Overall, AvaC is a fairly diverse process that is capable of processing parts with simple and complex geometries; wrought and powder metal materials; dense loading arrangements; variations in section size; and shallow, medium and deep case-depth requirements.

As shown in Figure 2, once the carburizing temperature is reached, the first carburizing step is initiated by injecting acetylene into the furnace to pressures between 3 and 5 Torr. The carbon transfer is so effective that the limit of carbon solubility in austenite is reached after only a few minutes. As a result, the first carburizing step must be stopped after a relatively short time by interrupting the gas supply and evacuating the furnace chamber.

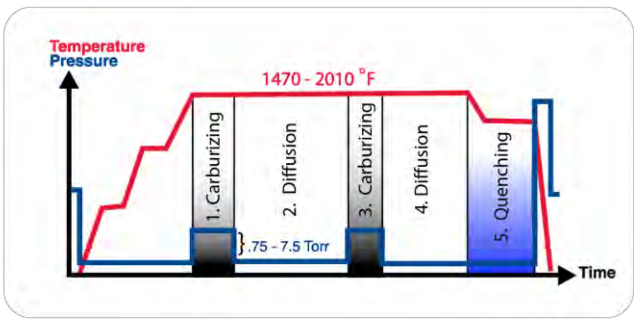

Figure 2: Typical low-pressure carburizing cycle with temperature and pressure curve

Deactivation of the boost event and evacuating the furnace chamber initiates the first diffusion step. During this segment, the carbon transferred into the material, as well as the surface carbon content, decrease until the desired surface carbon content is reached. Depending on the specified material case depth, further carburizing and diffusion steps may need to follow. Once the specified case depth has been obtained, the next step applied is quenching. This typically involves reducing the load temperature and quenching the load in the same chamber.

In the end, control of the AvaC process for LPC involves an understanding of the variables that influence carbon transfer and diffusion. These include time (total boost or carburizing time, total diffusion time and the number/duration of carburization and diffusion steps); temperature; and gas parameters (type, pressure and flow rate). Depending on the part's surface area, geometry and steel chemical composition, the parameters listed above are determined as constants resulting in homogeneous carburization.

The Use of Low-Pressure Carbonitriding

In addition to LPC, the AvaC-N process (low-pressure carbonitriding) is also commonly used in the heat treatment and machining of gears. For vacuum carbonitriding (AvaC-N), an ammonia gas train is incorporated into the process gas system. In vacuum carbonitriding with acetylene and ammonia, carburizing pulses with acetylene alternate with diffusion/nitriding phases with ammonia (Figure 3). The partial nitrogen pressure is not required in vacuum carbonitriding as the diffusion phases are run with ammonia as the nitriding gas.

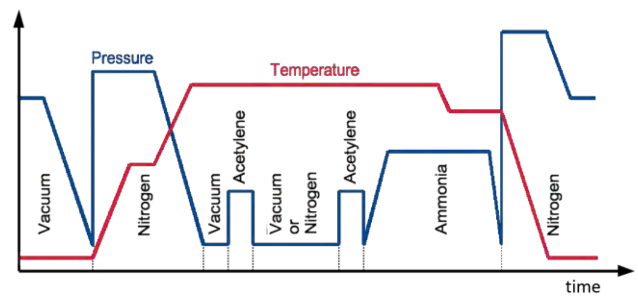

Figure 3: Typical low-pressure carbonitriding cycle with temperature and pressure curve

Overall, LPC and low-pressure carbonitriding are marked by their ability to provide precise process control, which in turn, helps result in uniform part microstructures, process repeatability and a reduction in manufacturing and maintenance costs. For example, precise process control leads to minimized distortion, and as a result, a reduction in the grinding process; in turn, this contributes to a decrease in hard machining costs.

Refining Operations with LPC Technology

The use of advanced LPC equipment and technology also has a significant impact on refining operations and allowing manufacturers to reduce unnecessary processes and actions. With an increased focus on using the IoT to optimize operations through data collection, data computation and production maximization, this mode of operation increasingly requires the use of sensors to adjust the furnace's operational parameters.

Accompanying this shift in operation requirements is a need for vacuum heat-treating systems that are able to bridge this intersection by providing an equipment design that incorporates integrated technology and meets these new criteria. This need has contributed to the development of new technology for multi-chamber LPC; specifically, a modular furnace design that allows the heat treatment process to be seamlessly incorporated into the overall production process. It is important to note that the heat-treating equipment used with LPC plays a significant role in achieving precise process control.

Achieving Exceptional Hardness Results with Nitrogen Quenching

The ARGOS heat-treating system represents a significant milestone in the growing trend to operate LPC lines in combination with inert gas quenching. Using LPC (AvaC) in combination with 20-bar nitrogen quenching, ARGOS provides metallurgical properties never before seen in gas quenching systems – even those utilizing 20-bar helium quenching.

The Great Helium Debate

In the industrial sector, helium is still widely used even as it increases in scarcity. Not only is this noble gas in finite supply as its lightweight composition results in it escaping into space, but it is also essential to have in supply for key industries and practices – such as the performance of MRIs by the Medical industry.

Helium is also commonly used with thermal processing equipment for cooling. As we must consider the environmental and ethical impacts of continuing to use helium for industrial applications, the use of other cooling gases must be considered. The ARGOS heat-treating system was developed to only use nitrogen for the cooling processes, which has resulted in excellent cooling speeds that are comparable to helium. Overall, nitrogen provides uniform quenching results with a higher turbulent flow around the 'dark side' of the load.

The other advantages of using nitrogen, as compared to helium, include the fact that it is an abundant, easy-to-make resource, as well as offers lower operating costs with no expensive recovery or purification necessary.

An initial test was performed on a vacuum carburized component that is one of the most difficult to quench: layshafts for large gears. Until now, helium gas, which is both expensive and declining in availability, was required to fully transform parts with very high cross-sectional thicknesses. Test outcomes showed that the shafts processed in the ARGOS system with 20-bar nitrogen quenching achieved surface hardness and core hardness values comparable to shafts processed in existing vacuum heat-treating furnaces that use 20-bar helium quenching.

Increasing Production Flexibility

With the demand to meet lean manufacturing objectives, reduce cycle times, increase process flexibility and maximize furnace up-time, it becomes clear that production flexibility is also an essential component of thermal processing equipment. The modular structure and software flexibility of multicell systems, such as the ARGOS furnace line, make them adaptable to a variety of plant configurations and changing production processes (Figure 4). To start, it is possible to selectively isolate modules using Ipsen's AutoMag® lights-out automation system, thus allowing for the performance of maintenance work on individual modules without affecting the entire production process. It is also easy to set up and take down individual modules without affecting the operation of the plant as a whole. As such, the production capacity can be easily expanded or minimized as needed.

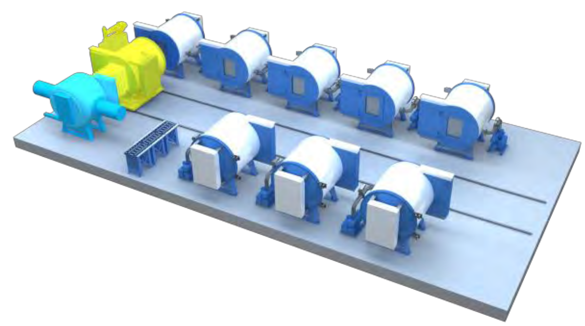

Figure 4: The ARGOS furnace line's modular structure and multicell systems make it adaptable to a variety of plant configurations and changing production processes

Based on specific process and industry needs, available modules can include nitriding, subzero and/or high vacuum chambers, as well as a washer, pre-oxide furnace, LPC furnace, tempering furnace, etc. This new generation of multi-chamber furnaces also offers several distinct operational advantages in manufacturing. With synchronized movement between each process and real-time sensors implemented in each process stage, the intermediate buffers between heat treatment operations can be eliminated and the transfer of loads between different modules (e.g., washing, carburizing, hardening, tempering) can be monitored. As a result of this flexibility, the ARGOS heat-treating system provides several solutions that address a diverse range of user needs and easily integrates with technology that aligns with the Industry 4.0 and lean manufacturing movements.

The ARGOS Heat-Treating System

The multi-chamber ARGOS furnace line is designed for several heat treatment processes, including hardening, LPC (AvaC®) and low-pressure carbonitriding (AvaC-N). It can also be used with oil quenching or high-pressure gas quenching using nitrogen at pressures up to 20 bar (absolute).

One of the ARGOS heat-treating system's special features is its modular principle, which allows users to create a precise solution for their specific requirements. The furnace offers various modules for carburization (e.g., hardening, austenitizing, carbonitiriding) with the flexibility to adjust the number of carburization modules to suit requirements. It also features modules for the transport system, washer, pre-oxidization, tempering and high-pressure gas quenching. With its modular plug-and-play principle, the furnace system can be quickly installed and easily commissioned. These modules can then be assembled on one or two sides, depending on users' requirements, or they can be added to as needed for any increased production in the future.

In addition, today's request of adapting the quenching intensity to the needs of different components – specifically hardenability and minimization of distortion – have also led to the increased, repeatable production of quality components. The flow-optimized design of the ARGOS furnace's gas distribution system, as well as its program-controlled reversing flow direction helps ensure a uniform flow over the load's entire surface area. The gas quenching module also minimizes the consumption of cooling gas with the incorporation of a compact housing design.

The ARGOS heat-treating system offers additional advantages, including:

- Flexible installation with a selectable number of carburizing, nitriding, subzero and high vacuum process chambers with a nitrogen gas and/or oil quench module
- Excellent temperature uniformity during heating and cooling
- Minimal and controllable distortion due to temperature homogeneity throughout the entire load and the reversible gas flow during cooling
- Extremely high gas velocity and volume due to Ipsen's unique cooling system design

Learn more about the ARGOS heat-treating system at bit.ly/IH-ARGOS816.

Conclusion

As the demand for leaner, more streamlined operations continues to grow, thermal processing systems and applications will increasingly intersect with the latest advancements in technology if they are to provide the necessary solutions. Bridging this gap between the new generation of multi-chamber LPC heat-treating systems and the integration of furnace operations with the entire manufacturing process is Industry 4.0. As companies utilize the IoT in the form of sophisticated software that analyzes key data, manufactures can continue to work toward meeting lean manufacturing objectives, as well as enhancing overall production speed and process quality.

For more information and insight into recent advancements in thermal processing equipment and processes, contact Sales at Sales@IpsenUSA.com or 1-800-727-7625, or visit www.IpsenUSA.com.