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Advanced Combustion System Makes California Plant Possible

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Betts Spring, an OEM producer of coiled springs for automotive and other uses, was established in 1868 in the San Francisco Bay area of California. They have been in business longer than most companies because they are successfully dealing with (among other things) cost increases – both production costs and the cost of living for associates. To provide a better quality of life for their employees and to control costs for the company, the management team made the decision to move their spring production operation to a new location.

As one of the five oldest family-owned companies in California, Betts also has a deep commitment to its home. Given California's reputation for emissions standards, however, the desire to relocate within the state faced serious challenges. According to Terry Holcomb, vice president of production, "California's central valley has the most stringent emissions standards in the world." Nevertheless, Fresno, in the heart of the central valley, was chosen as the site for the production line since it met all other criteria for the company. This meant that they needed to find a system that allowed them to drastically lower NOx, CO, CO_2 and SOx emissions.

Working with the state of California and with TNI Spring Technologies of Newnan, Ga., a combustion system was chosen based on a WS, Inc. (Elyria, Ohio) REKUMAT 200M burner using FLOX® flame, and the Chameleon control system from Thermal Products & Solutions (Kent, Ohio). The burners and combustion-control system were integrated into a walking-beam furnace designed and built by TNI.

"Using the burners and the pulse-fire application included with the Chameleon control system, we took energy usage from 12MM BTU/hour to 1.65MM BTU/hour," Holcomb said. "It was the technology that allowed us to pass muster on the (emissions) permitting."

In fact, the permit level for the walking-beam furnace is for usage of 2.87MM BTU/hr. With gas consumption at nearly 50% of the permit level, emissions inspection was passed easily.

Even better than achieving permit requirements, the new system allows more product to be put through the furnace. "Production on our worst day has increased 100% over the old system. Some days we produce at a rate 300% higher," said Holcomb.

Fig. 1. The TNI walking-beam furnace showing the bar loading system.

Fig. 2. TNI's hearth and walking-beam design provides very low heat loss through the hearth.

Fig. 3. WS REKUMAT burners firing in "flame" mode with 90% POC extraction. The walking-beam rails are shown in the foreground.

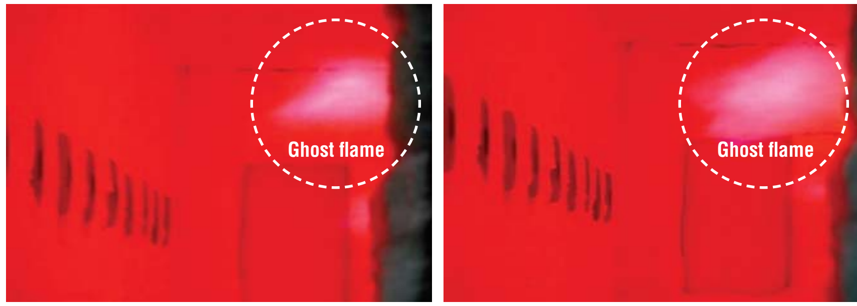

Fig. 4. Burners firing in FLOX® mode. Note the "ghost" flames that occur where the flame becomes briefly visible in deep violet colors. FLOX combines low emissions with recuperative technology to meet emissions and efficiency requirements.

Product quality is also extremely important. With the new system, not only has scrap been reduced by at least 10%, metallurgical studies of the end product show that both the consistency and quality of their coiled springs has improved.

With complete automation of the production line, operation of the system has become much easier. "The material-handling system and overall level of automation has allowed us to substantially reduce operating costs on the coil production line," Holcomb said.

The furnace design is essentially a 22 foot by 10 foot box furnace with an open slot running the length of the furnace to allow either automated or manual loading of spring-steel bar stock. Stock is moved through the furnace using a walking beam and exits though a small opening on the side of the furnace via a roller conveyor. The shell of the furnace is lined with refractory fiber, and it is fueled with natural gas.

While using high-quality components makes the overall system easy to operate and trouble free, to achieve the results as described above, three critical components of the system must work in concert: the material-handling system, the combustion system and the control system.

Walking-Beam Furnace Burners

The combustion-system requirements for the walking-beam furnace were dictated by the Betts Spring specifications, the design philosophy of the furnace builder and the emissions and fuel-efficiency mandates set forth by the California EPA.

To achieve the net input requirement of 2,115,000 BTU/hour, a total of 12 REKUMAT® M200B burners are installed in the rear wall of the furnace. They are mounted 36 inches above the walking beam and fire toward the front of the furnace, against the direction of product travel. The burners' high-velocity flame causes intense mixing of the products of combustion (POC) within the furnace chamber, resulting in excellent temperature uniformity and improved convective heat transfer (Fig. 3).

The burners are self-recuperative, meaning that the POC exit the furnace through the burners, eliminating the flue opening. An eductor, driven by a combustion-air bypass, creates suction at the burner exhaust port and draws out the POC. The exhaust is collected downstream into a main header and connected to a standard flue. Approximately 90% of the POC are drawn through the burner with the remainder exhausted through the bar-stock entry slot. The rate of draw through the burners is adjusted to maintain a slightly positive furnace pressure and prevent tramp air infiltration.

Before POC exit each burner, they pass over the outside of the burner's integrated heat exchanger, preheating the combustion air that is entering the burner on the inside of the recuperator (Fig. A).

At zone temperatures of 1750°F, combustion air is preheated to approximately 1100°F and results in combustion efficiency of 73%, a gross input per burner of 241,400 BTU/hour and a net input per burner of 176,200 BTU/hour. A cold-air burner without preheated combustion air would require roughly 352,400 BTU/hour – approximately 32% more. For reference, the total connected load needed to achieve the gross input specification is 2,897,000 BTU/hour.

However, preheated combustion air raises the flame temperature and therefore increases thermal NOx formation. In the past, higher air preheat temperatures meant a trade-off between efficiency and NOx emissions. Now, by using FLOX® (FLamless OXidation) combustion it is possible to significantly

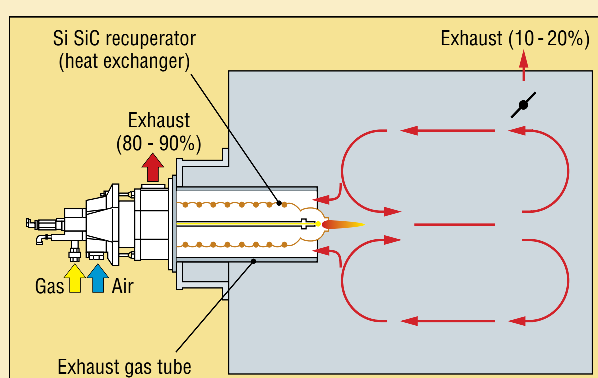

Fig. A. Self-recuperative principle as implemented in the REKUMAT burner

Walking-Beam Design

A special serrated-style walking beam moves material through the furnace. Composed of 46 discrete locations that look like teeth on a saw (Fig. 1), the walking beam rests about 4 inches above the hearth. The hearth of the furnace is lined with precast refractory blocks. The 4-inch gap between the hearth and the walking-beam rails is a critical feature that allows optimal heat circulation around the product and contributes to uniform heating and efficiency (Fig. 2).

Motive force for the walking beam comes from a small 5-HP, variable-frequency drive, hydraulic plant and two hydraulic cylinders. Sensors beneath the furnace detect the position of the two large support beams. The system can handle bars from 0.5- to 2.25-inch diameters that are from 6-20 feet in length. Transit time through the furnace is 8.5 minutes, with soak time dependent on the diameter of bar stock being fed into the furnace.

Once heated by the walking-beam furnace, the bar stock feeds into a specialized spring coiling machine (also manufactured by TNI Spring Technologies). The coiler features advanced controls that automate the changeover process (except for the mandril) and set the spring pitch and lead-end pig-tailing function. The coiler is designed to match the high throughput of the furnace.

Burners and Combustion System

In order to meet emissions requirements and still provide efficiency, the WS REKUMAT burner was chosen by TNI. The burners are self-recuperative, designed to light at high-fire (a necessary feature if pulse-firing on/off) and include a patented firing technology (see sidebar for burner details).

The burners are fed from a fuel train designed and built by TPS. The fuel train uses Kromschröder safety shut-off valves (SSOVs), regulators and pressure switches. The system includes proof-of-closure switches on the main valves as well as a valve proving system to detect leaks at either of the SSOVs, a redundancy that allows the safety devices to be constantly verified by the control program.

Control System

The walking-beam furnace uses the Chameleon control system from Thermal Products & Solutions. The Chameleon is a highly distributed, programmable logic controller-based (PLC-based) control system that uses both industrial networks and hard-wired logic to control and monitor the combustion system and the material-handling system of the furnace.

The mixture of both hard-wired logic

reduce peak flame temperatures and thus reduce thermal NOx formation. FLOX is activated at 1550°F (well above the self-ignition temperature of natural gas) and works by redirecting the flow of fuel gas internally and injecting it directly into the furnace. The fuel mixes with combustion air and large amounts of inert POC outside the burner nozzle, reacts in a controlled fashion and lowers the flame temperature, thus lowering NOx. FLOX combustion is nearly invisible and eliminates the typical roaring of a flame (Fig. 4).

Using FLOX it is possible to meet the emission requirements of the California EPA without sacrificing fuel efficiency. NOx emissions were required to be less than 50ppm at 1750°F for the Betts permit. Measurements during production conditions show NOx emissions less than 30ppm when corrected to 3% O_2.

Each burner is equipped with individual solenoid valves for gas and combustion air as well as a CBFF burner control box. Upon receiving a fire command via the Profibus network, the gas and air valves are opened, a spark is generated by the ignition transformer and a flame is created. The UV sensor, mounted on each burner, will initiate a fault lockout in case of unwanted flame loss.

Gas and air-flow volumes are adjusted via the throttling mechanism on the solenoid valves. The proper flow is determined by measuring delta-p settings on the gas and air orifice plates and adjusting flow until the nominal values are obtained.

The burners are pulse fired. The amount of energy introduced to the furnace is determined by the amount of time each burner fires. At high-heat demands (furnace cold), all of the burners fire continuously. As the temperature setpoint is approached, burners begin to turn off for calculated periods of time. The burner off times increase as the furnace temperature approaches the setpoint.

Pulse firing eliminates the need for inaccurate and difficult-to-adjust proportioning devices. The burner is set to fire at its optimum point – typically to achieve excess oxygen content of 2-4%. Regardless of heat demand, the burner will always maintain its optimum setting.

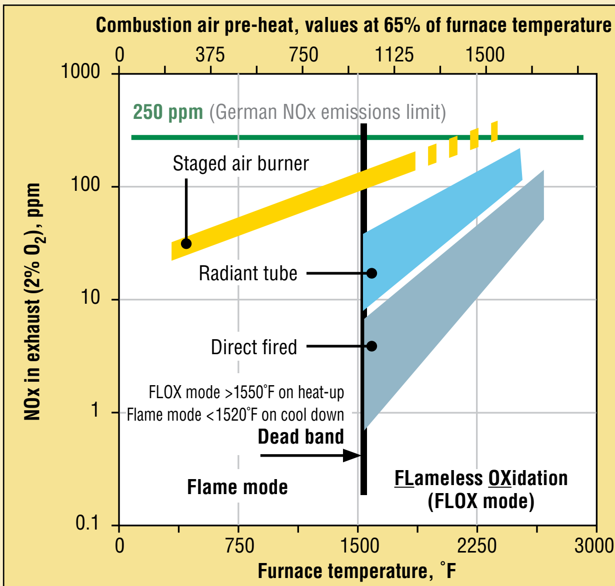

Fig. B. NOx emissions with FLOX® technology

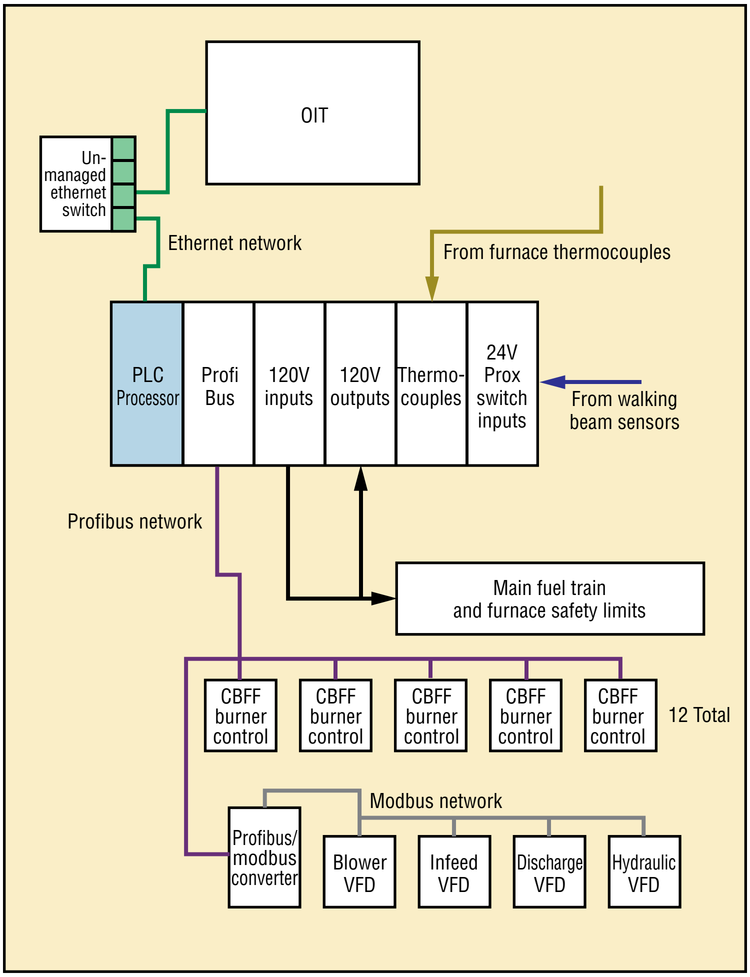

Fig. 5. The Chameleon control system uses a mixture of industrial networks and hard-wired connections in a highly distributed combustion control system.

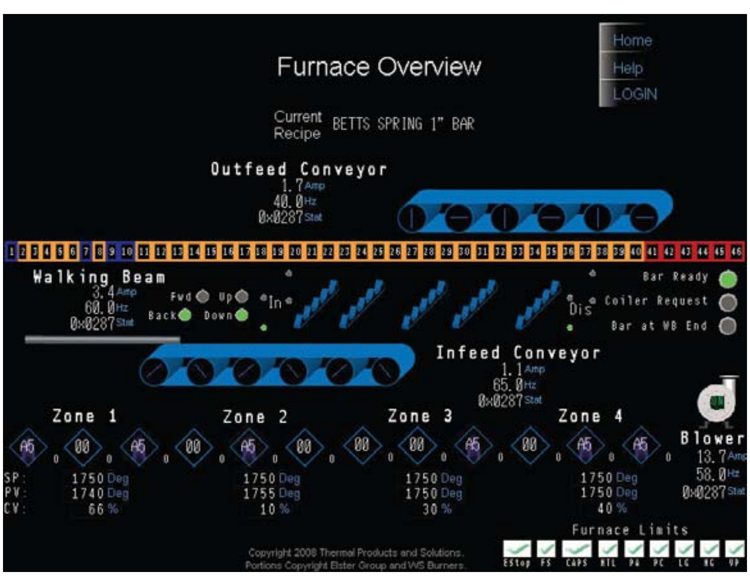

Fig. 6. The Chameleon furnace overview screen presents a complete status picture to operators of the walking-beam furnace.

and industrial automation networks creates a control system that has built-in redundancy for critical safety limits of the furnace and provides an extremely flexible, adaptable control. All safety limits are hard-wired into individual discrete relays with parallel connections to PLC inputs. While a PLC output enables the limit string, the PLC cannot override any of the safety limits.

The combustion blower, hydraulic pump, in-feed and discharge conveyors are all powered with motors controlled by programmable variable-frequency drives (VFDs), which are in turn controlled by the PLC through the profi-bus network (Fig. 5). Using networked VFDs, energy-saving strategies are implemented for all motors so that each motor spins only as fast as necessary. For example, the discharge conveyor rotates at a slow rate (to prevent warping of the rollers) until a piece of bar stock is loaded onto it, at which point it runs at a high speed to quickly move the stock from the furnace. All motor speeds are user configurable so that the system can be adjusted over time to achieve the best performance.

While the networking and configurability of the system make it easy to set up and run, the key contribution of the control system to the quality of Betts' springs is the pulse-fire temperature-control algorithm that manages firing of the WS REKUMAT burners.

The pulse algorithm essentially uses the output of a PID control block from the PLC to proportionally pulse the burners in each zone. The start times for the burners in a zone are staggered (either automatically by the PLC program or using configuration parameters) so that the firing of the burners appears almost random within the furnace. The benefits of pulse firing as implemented on this system include:

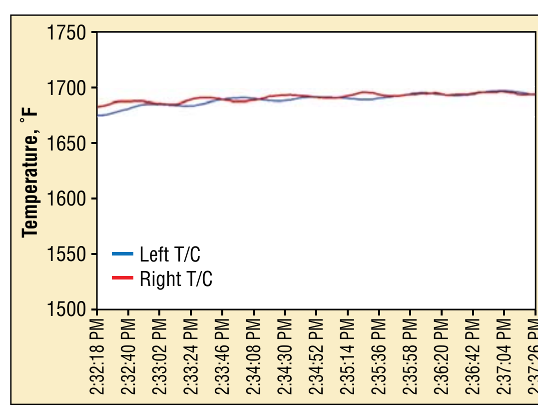

Fig. 7. Last five minutes of furnace uniformity survey showing uniformity between load thermocouples. The load couples are placed 12 feet apart. In addition to the 1°F difference shown on this side-to-side test, additional testing showed a maximum 3°F front-to-back temperature difference when the bar stock was heated at the entrance of the furnace.

- Greater convection within the furnace (enhances heat transfer to the load and speeds heating)
- Greater mixing within the furnace (increases uniformity)
- Firing each burner at its high-fire optimum fuel/gas ratio (burners are fired on/off)
- Since burners are fired on/off, they can be set to fire with an absolute minimum of excess air (saves fuel)
- Burners always fire at their highest velocity (since they fire on/off)

Reducing Chances for Operator Error

To accommodate different spring bar stock, the Chameleon system provides "recipes" that allow Betts to set the desired temperature, the required dwell time in the furnace for the spring bar stock and various VFD settings for efficient material handling. Recipes are determined and configured by the engineering staff. Selection of the recipe is done before material is loaded in the furnace by the operator (Fig. 6).

Material is loaded in bulk onto a bar-loading system, which moves individual bars onto the walking beam until each of the 46 locations on the beam are filled. The control program tracks and times each bar through the furnace and indicates to the operator when the bar closest to the discharge conveyor is ready for coiling. This timing is critical since underheating bars prevents them from being coiled properly and overheating bars both weakens the steel and produces an excess of scale.

With the Chameleon program managing the material handling as well as complete combustion control, it takes only two operators to manage the entire coiling line (compared to four operators in the past).

Conclusion

The success of the Betts' spring system is best demonstrated by the increased quality, reduced scrap and improved metallurgical properties of the springs produced through the walking-beam furnace. The combination of the walking-beam and hearth design, the advanced, low-emission combustion system and the overall control system not only produce great springs, it made installation of a new industrial heat-processing system in California's central valley possible. **IH**

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