Process optimization for controlling and regulating the power of high-temperature heating elements

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The JUMO IPC power converter is an intelligent and innovative solution for controlling and regulating electrically operated thermal process systems. This simple solution for plant builders and operators saves space, reduces operating resources, and cuts operating costs. Several unique features of the patented operating process ensure that acquisition costs are paid for in a very short time. This report describes extended operation of high-temperature heating elements based on new technology and the resulting advantages.

Especially in the manufacturing of saw blades, the quality of the product is monitored on the customer's test bench daily and must meet the requirements of practical use. So it is all the more urgent to optimize and refine the materials and manufacturing procedures in this process continuously.

JUMO GmbH & Co. KG and Amada Austria have launched a cooperative venture for this purpose, to combine the latest technology and experience in a product that not only meets these requirements, but exceeds them and sets new standards in cost effectiveness and efficiency. Because of its extensive expertise and many years of experience in manufacturing quality saw blades, Amada is responsible for planning, concept, and execution.

Description of the project

The temperature in an oven equipped with a total of 164 Kanthal SIC heating elements is regulated by fourteen JUMO IPC power controllers. The emphasis in the concept of the system is to achieve a very high level of cost effectiveness, efficiency, and user friendliness. A key consideration is the IPC with its specific properties, without which most of these requirements could not be met at all. When controlling and regulating a SIC low-voltage heating element of this type, a number of points must be considered and require suitable measures:

- Technical layout
- The problem of resistance characteristics
- Operating processes
- Electrical power load
- Availability of heating elements

Technological requirements

To use and operate high-temperature ovens, which is frequently required in many types of applications, special heating elements such as SIC (silicon carbide), molybdenum disilicide (for example Kantal Super), carbon or infrared heat radiators. These elements, which are designed for temperatures of up to 2000°C, are frequently operated at a relatively low voltage of about 5...60 V (low-voltage elements) and at a high current.

In contrast to the working principle of thyristor power controllers, which require a transformer to reduce the voltage, the IPC works with a throttle in series to the heating elements.

The nominal current of the throttle is based on the maximum possible power consumption of the IPC. A filter is added to reduce conducted interference to a minimum in compliance with applicable EMC standards (Fig. 1).

IPC operating process

JUMO IPC is a power converter for controlling heat loads which until now have required a transformer, regulating transformer, or the combination a thyristor power controller with a transformer. Because of its operating principle, it is referred to as an electronic transformer with pulsating direct voltage at the output. It combines the advantages or a conventional regulating transformer.

Fig. 1: Layout of switch cabinet (IPC, throttle, filter)
such as regulating amplitude and sinusoidal power load, with the advantages of a thyristor power switch, for example current limiting, load monitoring, lower-level regulation, etc.

In contrast to the conventional phase angle or pulse group modes of thyristor power controllers, the IPC power converter has only one operating mode, amplitude regulation (Fig. 2).

In this case the power is controlled by changing the sinusoidal current amplitude. The height of this amplitude depends on the power derived from the mains power supply (Fig. 3).

Because the input current for the IPC is nearly sinusoidal and in phase with the input voltage, only the required effective power is taken continuously from the mains power supply (Fig. 3).

**Aging compensation**

The specific properties of the SIC heating elements that are used allow for a very high temperature range. For all elements of this type, the electrical resistance increases as the duration of operation is extended. This is referred to as long-term aging. To further complicate matters, the resistance of the elements changes depending on the temperature (Fig. 4).

The nominal resistance values of the SIC heating element are based on measurements that were performed at a temperature of 1070°C and fall within a tolerance limit of +10% to –20%.

To calculate the maximum power consumption for which the IPC is designed, in addition to the tolerance of the resistance value, the resistance minimum from the characteristic resistance curve (at a surface temperature of about 500...600°C) must also be considered. As shown in the diagram, these are also –20% of the nominal resistance at 1070°C.

The minimum resistance value is calculated as follows:

$$R_{\text{min}} = 1 \, \text{Ohm} \cdot (R_{\text{nom}}) \cdot 0.8 \cdot \text{(Tolerance)} \cdot 0.8 \cdot (R_{\text{min}}) = 0.64 \, \text{Ohms}$$

Because of this long-term aging, a higher voltage is required as resistance increases to maintain a constant temperature in the oven:

$$P = U \cdot I = U^2 / R = I^2 \cdot R$$

The resistance characteristic may change by a factor of 4.

Because of this, the load current of the IPC power converter is designed for the power consumption of the SIC heater when it is new, which is when the greatest current flows. Over the time of the aging process, as the resistance increases, the current falls to about half the nominal current.

At the same time the voltage must be raised to achieve the required power.
A voltage reserve is factored in for the IPC, ranging from a factor of 1.5 to 2 times the nominal voltage of the heating elements. The automatic aging compensation of the IPC ensures maintenance-free operation.

**Power consumption**

Since the input for the IPC is nearly sinusoidal and in phase with the input voltage, only the current effective power is taken from the power supply.

This means the IPC is responsible for the current/voltage transformation and always takes the required power from the power supply, whether the condition of the heating elements is new or old. Consequently, the power supply connection no longer needs to be overdimensioned with thyristors in pulse group or phase angle mode as in conventional operating methods.

Because of the continuous, uniform power consumption of the IPC and symmetrical distribution of the load, power supply optimization, also called synchrocycle control, which is necessary in conventional operating methods, can also be eliminated.

**Comparison of phase angle**

As described above, the power supply voltage of the IPC and current are in phase. Together with the expertise of the oven manufacturer, this ensures the requirement for the newly designed system can be met. Power consumption on the power supply side is reduced in comparison to phase angle control by the amount of the reactive component.

The magnitude of the “control reactive power” depends on the control angle alpha, which can vary depending on the required temperature and thus the required power (Fig. 5).

Therefore if the system is brought down to a reduced power level because full power is never required, for example because of:

- greatly reduced operation over the weekend
- on holidays
- or simply because reduced power is sufficient,

the result in phase angle mode with the conventional method is a modified effective reactive power ratio due to the greater control angle.

Using the IPC power converter, which reduces the energy need by the reactive power component, achieves an enormous cost advantage.

The reactive power compensation system can also be completely eliminated. Thus use of the newest technology saves energy costs, repaying the cost of investment in a very short time (Fig. 6).

**Comparison of pulse group mode**

If a SIC heating element is operated using the conventional method with a thyristor power controller (TPC) in pulse group mode, complete sine paths of the power supply voltage are switched through or blocked. For example, a TPC operating at 60% output switches three full waves of power supply voltage to the consumer while two full waves are blocked. This results in 60% of maximum power for the consumer.

Since the maximum available voltage is always switched through, a more cost-intensive transformer is required to reduce the voltage to the nominal voltage.

To keep the SIC heating element, which ages over the course of operation, continuously at the desired output level ($P = U^2/R$), a transformer with several voltage taps must also be used.

If the voltage made available by the transformer is no longer sufficient, the transformer must be switched manually to the next higher voltage tap.

This results in a voltage jump, which places a load on the heating element. In addition, the heating elements respond sensitively to an abrupt change in voltage or power: The service life of heating elements subjected to this event is reduced. The integrated voltage reserve and amplitude regulation ensures this process is automatically assumed by the IPC or is not even necessary any more.

**Conclusion**

Eliminating reactive control power (reactive current, reactive power) and a reactive power compensation system significantly reduces operating costs. Less intense operation achieves a longer service life for the expensive heating elements, while low-voltage heating element can be operated directly on the power supply network without an adjusting transformer. The voltage reserve ensures automatic aging compensation for SIC elements. Since no transformer with voltage changeover is needed, significant savings in space, weight and cost can be achieved. Amplitude regulation ensures compliance with existing and planned EU standards regarding harmonics and fluctuations (EN 61 000 Part 3.2 and Part 3.3).

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**Fig. 5:** Current amplitude of a new vs. old SIC element

**Fig. 6:** Effect of the phase angle on reactive power

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