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Control of induction heating with infrared pyrometry

When process temperatures must be held constant over time, balance of power input and heat loss is a must. One proven way to control these factors is IR non-contact sensors.

by STANLEY ZINN

In almost all applications of induction heating systems, the basic techniques for assuring repeatable part temperature depend upon control of power and/or time. The relationship of these factors to part temperature derives from the fundamental formula for determining the amount of heat needed to raise a fixed mass a specific change in temperature:

P=M x S.H. x ATΔ

P = Power of Btu's

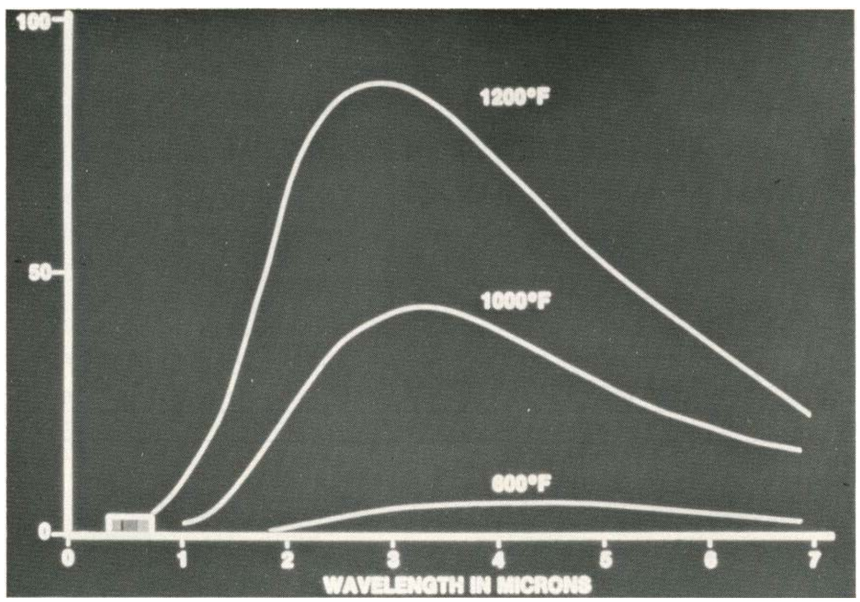
M = Weight in lbs.

S. H. = Specific heat A

TΔ = Change in temperature

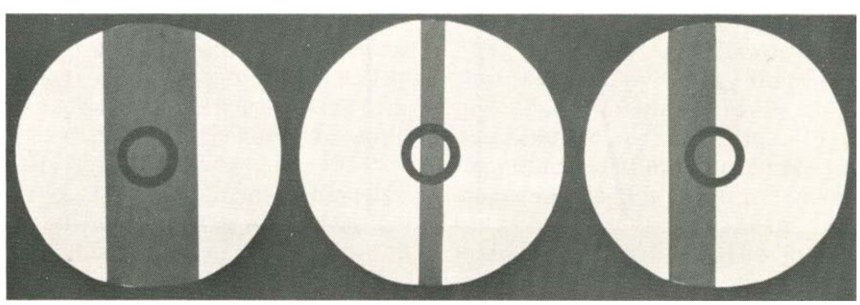
The Btu figure thus derived reflects the heat required to raise the work piece to the desired temperature. In terms of time, the mass (M) can be expressed in pounds-per-minute of material to be heated. Since there arc 57 Btu's per minute per kilowatt of induction power delivered to the part, we can therefore convert the formula in order to read the amount of power (kw) needed to raise the mass to a specific temperature: P x T, = M x S.H. x A TΔ Power, in Btu/min., is divided by 57 to provide kw/min. Time, in minutes, is expressed as TΔ. Since the mass and specific heat are fixed by the material of the part and its physical characteristics, time and/or

Fig. 1



Shown here is a series of emissivity curves. As they intersect a single wavelength, a change in temperature reflects a change in signal.

Fig. 2



The sensor averages the signal in the target circle. The circle at left is fully resolved on the target, thus assuring that true temperature will be measured

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power can be varied to control the temperature. For most induction heating applications, where temperature is not critical, this technique is quite practical.

However, where temperature becomes a significant factor in final part quality, there are a number of factors —conduction, radiation, voltage fluctuation to the power supply, to name a few — that can adversely affect the production of a repeatable temperature based solely on control of time and power. Further, where process temperatures must be held for any time duration (soaking, etc.), some means must be found to balance power input versus heat loss to maintain set point temperature.

While in some instances thermocouples can be utilized as sensors, their limitations, particularly as encountered in an induction field, preclude their use in many applications. For this reason, a non-contact temperature sensing device that can optically "look at" the heated area, and accurately determine temperature, is ideally suited to the control of induction heating systems. The infrared optical pyrometer meets these criteria.

A basic understanding of how an infrared pyrometer works can greatly help to simplify its use.

All bodies radiate infrared energy in a wide spectrum of wavelengths: flowers, the human body, and heated metal all radiate infrared energy, though indifferent amounts. To establish a relative value, we compare the radiation from these objects to the value produced by a theoretical ideal radiation source, the "black body". Each body therefore radiates an amount of energy at a particular temperature and a specific wavelength relative to what would be emitted by the black body at that same temperature and wavelength. Assuming the Black Body radiation to be a unit of one (1), we can establish a ratio:

$$\varepsilon = \frac{\text{Radiation emitted by target}}{\text{Radiation emitted by Black Body}}$$

(All measurements at same temperature and wavelength)

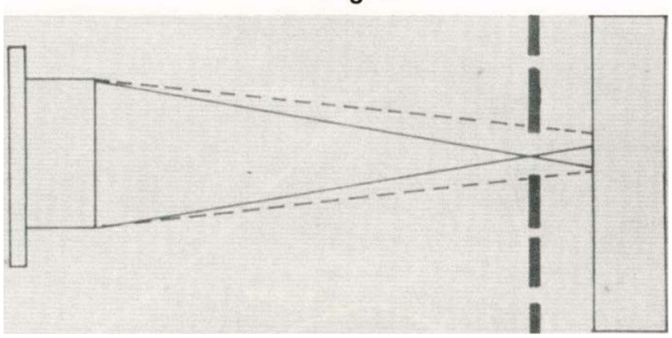
The ratio derived, ε , is called the emissivity of the measured material. We can thus see that with any infrared pyrometer calibrated for a black body emissivity of 1, a direct indication of true part temperature can be achieved by setting the gain control to compensate for the corresponding emissivity ratio.

Looking at the graph, **(Fig. 1),** which depicts a series of emissivity curves, we can see as they intersect a single wavelength that a change in temperature reflects a change in signal. Thus, via the electronic circuitry of the instrument, we can amplify the signal to produce an output giving a direct indication of part temperature, and also provide a relative temperature signal usable for system control.

How does the infrared pyrometer do this? Most units use a sensing head that is similar to a single-lens reflex camera. You sight through the optics at the target. A reticle in the optical system presents an aiming circle which is superimposed on the view of the part being measured. The sensor, via a special mirror, is looking at the same target. The size of the aiming circle is matched to the size of the sensor. The sensor then averages all the energy coming from within the circle and produces a signal relative to the average temperature. In other words, "What you see is what you get."

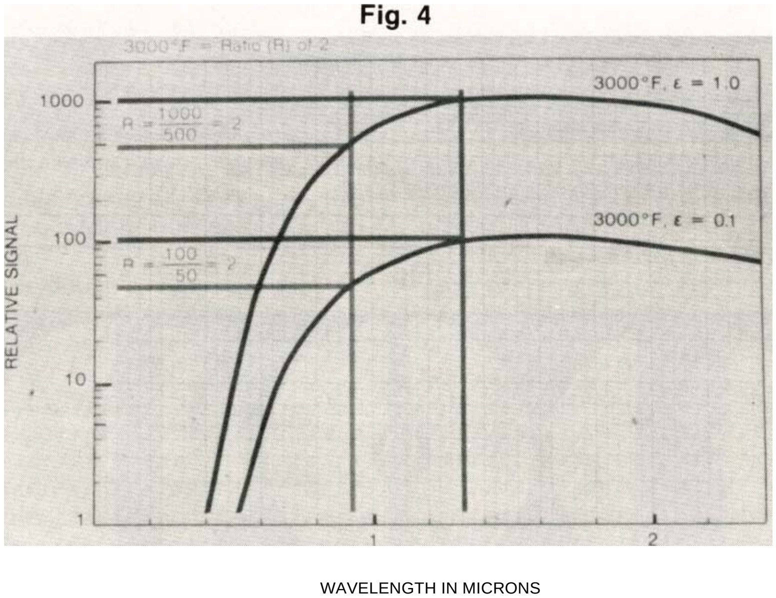
How big is the aiming circle? The size of the circle on the target relates once again to the optics of the sys-

Fig. 3



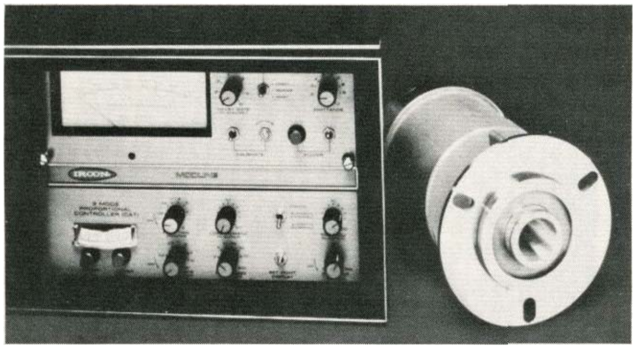
The heavy black lines represent the inductor coil, and the large rectangle shows the part. The so/id lines show the correct way of focusing.

Fig. 4



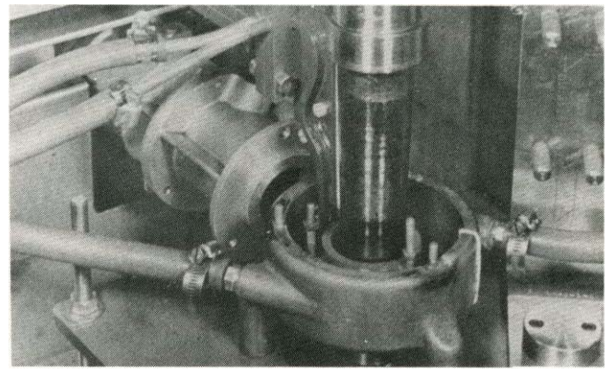
In the two-color pyrometer, the instrument measures radiation from the target at two different wavelengths simultaneously

Fig. 5



The relative signal from the sensor (right) is returned to the instrument (left) where it is amplified and linearized. An analog or digital indicator is provided for readout of part temperature

Fig. 6



The temperature of a boating surface is observed by the pyrometer which looks through the quench ring and coil turns

Control

tem. Generally, each instrument has a "focal factor," derived by the manufacturer, which is indicative of spot size. The distance from the front of the sensor to the target is divided by this focal factor to give the actual spot size of the circle on the target.

Generally, the higher the temperature range of the instrument, the larger will be the focal factor and, thus, the smaller the circle or spot size. This is due to the fact that at the shorter wavelengths used for high temperature measurement, high temperatures produce large radiation signals. Thus, a smaller target area can be used for measurement while producing sufficient signal strength for the sensor.

Remember, the sensor is averaging the signal in the target circle. If part of the signal is target and part is background, the sensor will average the two signals and an incorrect reading will occur. In Fig. 2, the circle at left is fully resolved on the target and true temperature will be measured. In the other two views, where the background material is observed in addition to the target, the system will average the overall temperature in the target circle and an incorrect temperature indication will occur.

In those induction heating systems where the turns of the coil may obstruct the line of sight and preclude fully resolving the target, a number of techniques can be utilized. In Fig. 3, focusing on the hot part beyond the coil turns would be impossible. The temperature of the cold coil turns would be averaged with the hot part. (This would be similar to **Fig. 2**). Instead, a piece of paper with a penciled mark is held against the coil turns. The sensor is focused at the mark to provide the smallest spot size at a point between the coil turns. The spot size will increase as the lines diverge on the other side of the coil turns, and the sensor will measure the part temperature on this slightly larger spot. The instrument optics, however, must be capable of providing a spot size at the focusing point that is smaller than the spacing between coil turns.

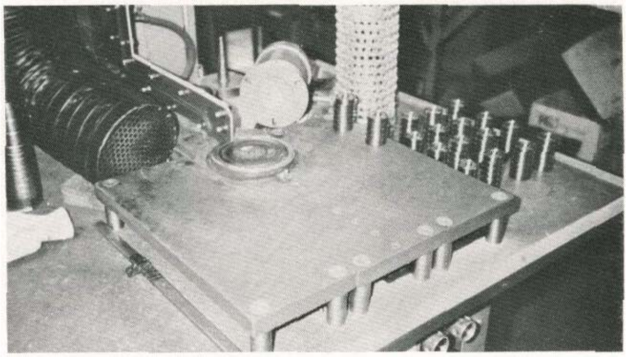
Another approach would be to utilize a two-color-ratio pyrometer as compared to the single wavelength system. In the two-color pyrometer **(Fig. 4),** the instrument measures radiation from the target at two different wavelengths simultaneously. For each emissivity curve (relative to a specific temperature), a ratio can be established between these two readings that is equivalent to the slope of the curve. This ratio is essentially independent of emissivity (£) as shown by the two curves. The instrument, as long as it has sufficient signal, recognizes that ratio as a particular temperature. It does not matter if the signal is large or small; the ratio will remain constant and the unit will indicate the relative temperature.

In some instruments, up to 95 percent of the signal can be obscured by cold target area (only 5 percent of the circle filled by hot target) and sufficient hot target signal will still be received so that the instrument reads properly. Obviously then, we can look through the turns of the cold coil and read the temperature of the hot object. This same technique can be used through a viewing window, though clouding by dust or dirt might reduce the apparent radiation from the target.

The relative signal from the sensor is returned to the instrument where it is electrically amplified and linearized **(Fig. 5**). An analog or digital indicator is provided for direct readout of part temperature. An additional output signal or signals can then be provided relative to the measured temperature. This signal can be used to operate an on/off or proportional temperature controller much as a thermocouple-fed instrument might do. In addition, the signal can also be fed to a microprocessor or computer for integration in the overall control process.

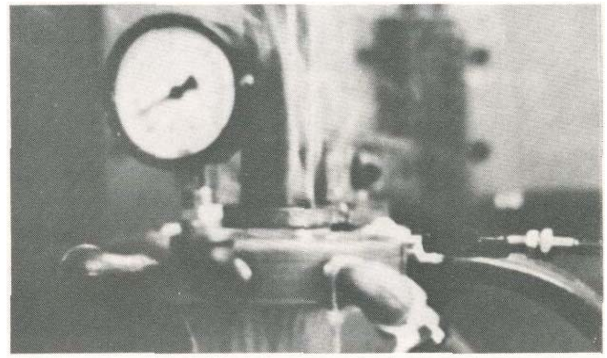
In its simplest application, the infrared optical pyrometer finds a major application in controlling part temperature for hardening. In the manufacture of main shafts for helicoper drives (**Fig. 6**), the temperature of the bearing area being hardened is critical. The infrared pyrometer looks through both the quench ring and coil turns to observe the temperature at the bearing surface being hardened. When

Fig. 7



In the assembly of aircraft bearings, heat in the outer race is monitored so that metallurgical structure is unaffected

Fig. 8



An infrared instrument utilizing a fibre optic pickup is inserted between the work coil and a spray quench.

proper temperature has been reached, the induction heater is turned off by the infrared controller, simultaneously initiating the spray quench. A second output from the infrared controller records part temperature on a chart for traceability.

A variation on this technique has been used to identify the point at which all cams and bearing areas on camshafts are at proper temperature prior to quenching. On automated induction camshaft hardeners, the shaft is generally placed between centers and removed from the feed conveyor. The centers transport the shaft into the induction system so that each area to be hardened is positioned within its own induction coil. Since all coils are in parallel, all areas are then healed simultaneously. When they arc at hardening temperature (about 100°F above critical to allow for temperature loss prior to quenching), the parts arc brought back to the conveyor by the same movable centers. They are then lowered into the quench on the conveyor.

It is possible, however, that due to coil misalignment, loose connections, etc., one or more of the areas to be heated may not be at proper temperature prior to quenching. Considering that as many as 16 zones might have to be monitored for proper temperature in this application, a single pyrometer was mounted at a position between the work coil and the quench conveyor. As the transport centers move the heated piece from the coils to the quench, each heated area passes the aiming point of the pyrometer. The controller is set to accept only those readings above the acceptable critical temperature. Each heated area, therefore, as it passes the sensor, produces a pulse output if it is at proper temperature. The pulses are counted, and if there are fewer pulses than the required number of heated zones, the system is shut down for correction.

This is, in effect, a quality control system.

In many instances, infrared pyrometers combine the functions of induction heating control and QC qualification, in the assembly of aircraft bearings (**Fig.** 7), the standard technique for final assembly involves heating the outer race sufficiently so that it expands and the last ball falls in place. The race has been hardened prior to this operation, and it is critical that the temperature not exceed certain limits or the metallurgical structure might be affected. Further, since the bearing is rather heavy, a heat soak must be used to prevent the outer bearing surface from overheating before the inside diameter of the race expands sufficiently for assembly.

In this application, the infrared pyrometer looks at the outside diameter of the outer race between the turns of the work coil. As the part nears temperature, the controller reduces induction power to prevent overheating of the surface, while allowing the part to soak at proper temperature for the race to expand. Traceability is again assured by providing a chart record of the operations. A similar system is utilized in tempering the threaded ends of outboard motor crankshafts.

Since the measurement signal from the infrared pyrometer is both continuous and non-contact, it can also be used for induction applications where the part is in constant motion. **Fig. 8** shows an infrared instrument utilizing a fibre optic pickup inserted between the work coil and the spray quench on an induction scanner. Ideally, the shaft temperature should be about 50°F above critical prior to quenching.

Here the location of the fibre optic permits it to monitor the part temperature as it exits from the coil. This signal is fed from the instrument to a controller that modulates the induction generator power output to maintain a constant part temperature prior to quenching. This control could operate via the control board of a static inverter, the regulator of an M-G or the input to an SCR controller on an RF generator. Depending on the requirement, it might also control scan speed if the generator power were held constant.

Properly applied, whether on a high production line or as a special tool in a job shop heat treat operation, the infrared optical pyrometer is a versatile addition to the induction heat station. It gives assurance of actual part temperatures and serves as a means of assuring precise, quality, heat-processed parts.