Fiber Optics

A New Approach to Monitor and Control Process Temperature

The coupling of optical fibers to infrared detectors and signal processing electronics represents the latest progress in the field of non-contact temperature measurement and control.

Only recently have fiber optics become the object of widespread interest thanks mainly to their ability to carry optical information signals over long distances and around unavoidable obstructions.

For years infrared detectors have been used in conjunction with conventional optical elements (lenses, mirrors, prisms). Fiber optics were excluded from consideration since they are made of either glass or plastics, both of which are opaque throughout most of the infrared spectral region. Thus, according to fundamental laws of physics, their marriage to infrared detectors could never work.

Months of painstaking development proved the reality and practicality of transmitting IR with fiber optics. And thus it happened that coupling fiber optics with infrared detectors resulted in several new families of instrumentation and control systems endowed with superior performance characteristics.

Since most if not all of you are currently familiar with the theory of infrared radiation and the variety of methods for monitoring IR this discussion will deal mainly with the application of fiber optics in conjunction with IR detectors, i.e. their construction, advantages, disadvantages and applications.

A typical optical fiber is usually constructed of a silicon (glass) material, however, plastic and quartz are also available but normally for data transmission. Today most of all optical fibers manufactured consist of a light-conducting glass core surrounded by a thin layer of glass cladding with a lower refractive index. This cladding serves to protect the core finish.

All fibers used in infrared instrumentation are made of glasses especially chosen for their ability to transmit the radiation comprised in the chosen spectral region.

All rays entering the front surface that acquire an inclination smaller than the critical angle are totally reflected inside the fiber core, and keep propagating in this fashion until they reach the opposite end or are totally absorbed, whichever comes first. For a fiber having a critical angle of X° means that all rays incident onto the fiber's front surface at the same angle or less with its axis are trapped inside the fiber by total internal reflection.

On the other hand, all incident rays entering the fiber with an inclination larger than the same angle will leave the first contact with its internal surface. This behavior is commonly called “spilling” (See Figure 1).

The value of the critical angle is a function of the ratio between the refractive indexes of the glass of which the core is made and of the medium surrounding it. By controlling the ratio we can increase or decrease the acceptance angle of fiber optics, thus obtaining special performance characteristics.

For most IR monitoring applications, optical fibers are assembled into fiber bundles consisting of many hundreds of individual fibers contained within a flexible or rigid sheathing of either metallic or nonmetallic material. Each end of the bundle is held in place using a high temperature epoxy. The end surface is then highly polished to assure a clearly defined angle of acceptance and diminish reflectance losses due to irregular surfaces. Using such a large number of narrow fibers in a bundle allows us to gather and transmit more signal to the detector while retaining mechanical flexibility. Typically, the outside diameter of a single fiber is 25μ.

Generally speaking, in the majority of applications where optical fibers are used with infrared radiometers, the lengths are 1 or 2 meters long. On occasion fibers will be made up to approximately 10 meters in length. The determining factors in using fiber bundles to transmit IR, are MMT (minimum measurable temperature), target distance and spot size. The higher the temperature the longer the fiber, conversely low temperatures require a shorter fiber due to the glass attenuation.

Unfocused fibers (those without a viewing lens) have a field of view or angle of acceptance of 60°. This is the target area viewed by the detector which is slightly larger than the distance between the front end of the fiber and the target surface. This can be easily verified by backlighting the target with visible light which will project onto the target surface. Unfocused fibers are used when the target area is large and it is desirable to measure its average temperature.

Focused fibers (those with a viewing lens assembly attached to the front end) are used to measure targets as small as .01 cm from as far away as 4.5 meters or further. The determining factor as with fiber length is the amount of energy being collected. By backlighting we can be assured the lens is properly focused and aligned on the target. In some applications, where vibration or other type movement may alter the lens's alignment, a bifurcated fiber is preferable. One branch of the fiber is connected to a high intensity light source and activated by a momentary-on switch which will verify to the operator the correct alignment of the fiber. The other branch will allow the infrared detector to “see” the target at exactly the same spot that was illuminated.

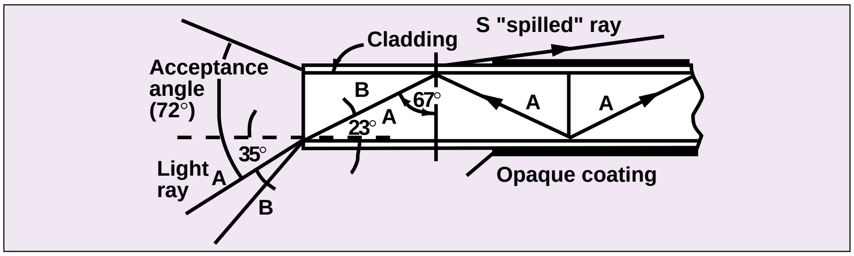

Figure 1

Fiber Optics Cont'd

FIBER ASSEMBLY VARIETIES

The wide selection of fibers and lens configurations available allows for a satisfying and endless number of applications.

Following are some of the many components that make up a fiber optic system and allow for such versatility.

Sheathing

– Single, bifurcated or trifurcated fiber optic systems
– Flexible stainless steel (standard)
– Heavy duty S.S. wire braid
– Heavy duty braided fiber Imperial Eastman
– Teflon (for use in high RF fields)
– Protective tubing

Lenses

– 1.27 cm, 1.90 cm, 2.54 cm x 8.59 cm to 27.7 cm max.
– Natural - black anodized aluminum
– Angular lens configurations available

Replaceable Tips

– Glass or quartz, 7.62 cm, 15.24 cm & 22.86 cm long
– Ceramic or stainless steel jacket

Optical Rods

– Glass, 15.24 cm, 30.48 cm & 60.96 cm long
– Ceramic or stainless steel jacket

Specials

– Right angle prisms, high speed scanners, angled bundle configurations

APPLICATIONS

Since virtually every manufactured product – from automobiles to the safety pin – requires the application of heat treatment in some form, the use for non-contact temperature monitoring and control is virtually limitless.

INDUCTION HEATING

Because of the strong RF inductive energy field needed to heat the metal parts being treated, conventional measuring devices are of little value since they will be heated directly by the induction coil.

Figures 2 and 3 show typical applications of fiber optic systems used to monitor and control induction treatment of metal objects either stationary in, or moving through induction furnaces.

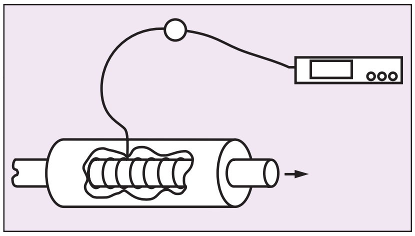

Figure 2: Monitoring steel rod continues induction heating.

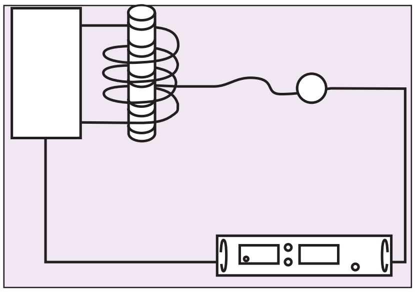

Figure 3: Controlling induction treating of automotive crankshafts.

and Thermal Monitoring System.

Using fiber optics vs. the conventional direct line of sight infrared detection systems allows placing the viewing end of the fiber optic in close proximity of the target. The tip of the fiber in many cases may be positioned between the induction coils to view the processed material. To eliminate the adverse effects of the RF field a ceramic replaceable tip is utilized. In those instances where the design of the system won't allow room for the fibers, a lens system will then be provided to view and monitor targets from a distance.

The fiber and electronics normally are not affected by induction energy fields, however, in unusual circumstances when the electrical noise environment is excessively high, a synchronous demodulation system is specified. The sync. demod, converts the 400 Hz AC signal from the detector head to DC. This conversion differs from conventional AC to DC converters in that it selects only the signal component at 400 Hz and discriminates against noise components of other frequencies.

CONTINUOUS CASTING

These operations utilize fiber optic

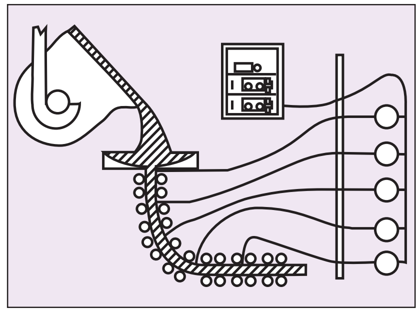

Figure 4: Five-channel multiplexing, signal-processing and display system.

assemblies up to thirty feet in length that are installed between the rollers themselves to within one or two inches of the slab surface. A remotely located automatic multiplexing chassis monitors several points on a time shared basis, achieving significant savings in terms of cost and space. Due to the shielded path of constant transmissivity provided by the optical fibers and the short wave length 0.8 to 1 silicon detector, the system “watches” the target through smoke, fumes, vapors and water. (See Figure 4.)

Quite often in this type of application the fibers are exposed to substantially elevated temperatures and mechanical abuse necessitating the need for air purging and special heavy duty protective sheathing. The purge tube is designed to allow the air flow to exit the front end of the fibers at a right angle thus preventing the build up of contaminants.

METAL FORGING, HOT STAMPING, PIPE BENDING

Forging of metal parts includes both rough shape as well as precision forging, which requires less material removal and waste. Pipe bending and shaping is also included in this application. These operations are carried out by heating the parts to be worked upon to the optimum temperature with any of the several means available (ovens, flame, induction field, etc.) If the part temperature is below the optimum, cracks and internal tensions will develop, while if it is above the optimum, drooping will take place. The precise temperature control afforded by the use of infrared fiber optic controllers will:

– Avoid the formation of defective parts (from cracks or drooping), thus eliminating rejects and waste due to these defects;
– Save thermal energy by ensuring that no heat is wasted by heating the parts

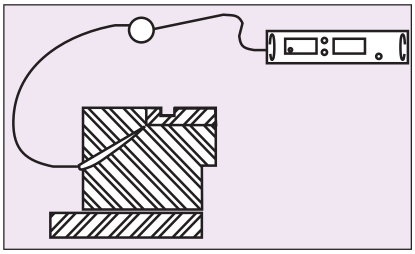

Figure 5

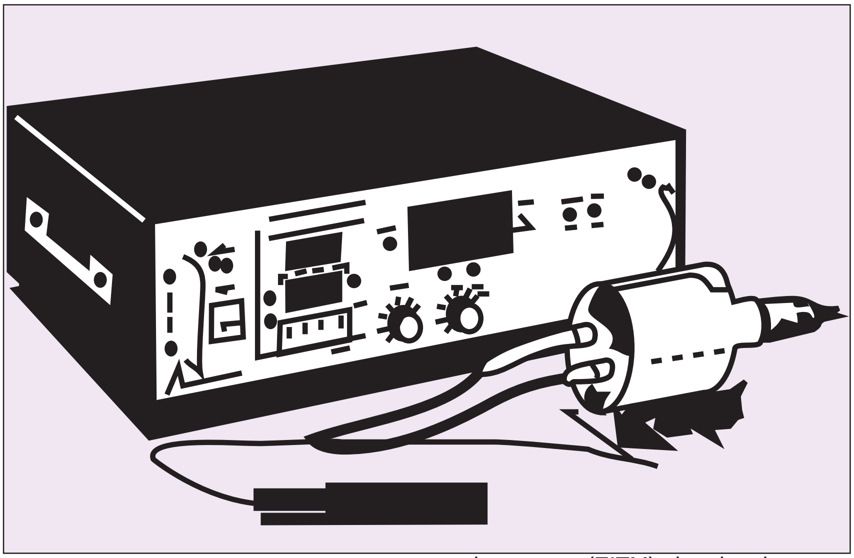

Figure 6

beyond the optimum level;

– Speed up production by allowing a faster rate of heating the parts without danger of temperature overshoot.

METAL DIE CASTING

The die temperature is of critical importance in die casting of metals. Thermal cycling of aluminum products, with reference to die temperature has been successfully implemented with the help of optical fibers. Figure 5 shows schematically and in detail how the front end of the fiber is inserted through the mold frame and held in a corner of the runner plate, in contact with the aluminum flowing through it.

The major advantages offered by this solution are:

– Substantial savings of thermal energy, by eliminating overheating and drastically reducing production rejects.
– Increased production due to the speedup of the casting cycle. The operation is automatically controlled by the temperature of the casting material and not solely by time, resulting in faster operation.
– Improvement in the quality of the casting due to the control of the process as a function of temperature, results in simpler operation and automatic compensation for a cold die start-up or interrupted cycles.

Direct indication of the die and furnace pot temperature of the metal. Low level and blocked water lines are easily indicated several shots before the casting can display conditions visibly.

CONTROL OF METAL-WORKING LASER

Lasers, generally high-power CO_2 lasers, are used for welding, surface treating and finishing metals of various types. The conventional approach is to periodically sample the beam to keep its power at the desired level. This approach, however, cannot automatically take into account the emissivity variations of the target surface. These variations, in turn, affect the amount of laser power absorbed by the target, and consequently the target's temperature, which is of paramount importance for good operating performance.

This difficulty is overcome by the use of an emissivity-independent infrared fiber optics system (EITM) aimed at the spot of laser beam impact. (See Figure 6.) The infrared system is made blind to the laser wavelength, and in this way it measures precisely the target temperature at the same spot and, via a feedback loop, it controls the laser power to ensure that the operation is carried out at the optimum temperature.

Among the advantages offered by the fiber optics infrared approach are the following:

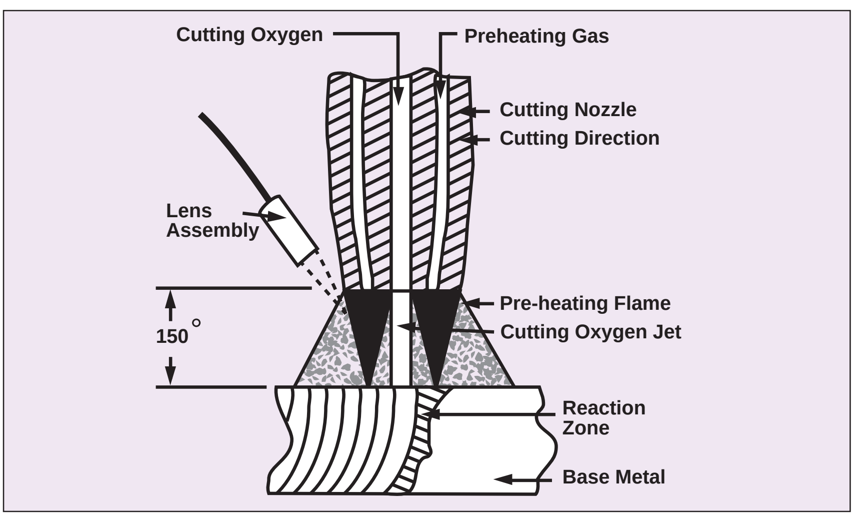

Figure 7

– Non-contact temperature measurement in real time.
– Fiber optics allow easy access to view the laser heating area because of their relatively small size.
– EITM compensates for variations in emissivity as the part is being heated.
– EITM response can be matched to the response speed of the laser.

Additional applications of interest:

FLAME CUTTING

Automated flame cutting involves either pattern tracing or computer control to repetitively cut steel plates into a variety of shapes. (See Figure 7.)

During start-up, a natural gas or propane flame heats the metal plate until a “puddle” of molten metal is detected by the operator; on multiple heat cutters the time may vary between torches. The puddle having been formed, oxygen is injected into the gas stream and blows the molten metal through the plate at which time the cutting cycle begins.

If the oxygen is injected prematurely a defective cut is made leaving an objectionable rough and wide pitlike depression in the plate.

By positioning a fiber optic bundle with lens assembly to look through the “clean” flame at the plate surface, the temperature is monitored and controlled to maintain the necessary temperature. By multiplexing and using hi-lo logic with relays tied in series, the oxygen is not turned on until all setpoints and associated relays are closed, insuring high quality cuts.

FLAME HARDENING OF STEEL WHEELS

Hardening the surfaces of steel wheels used on heavy construction equipment such as drive & idler wheels for bulldozers, backhoes, and other track type equipment is presently being accomplished by flame hardening.

A flame head is positioned on either side of the wheel (Figure 8). As the wheel is rotated the flame impinges on the surface elevating the temperature to approximately 976°C. Within close proximity to the flame the surface is rapidly quenched with cooling water (Figure 9).

Because of the variations in the wheels, both in roundness and lateral distortions, if the flame head were fixed the hardening process would not be uniform throughout the critical areas.

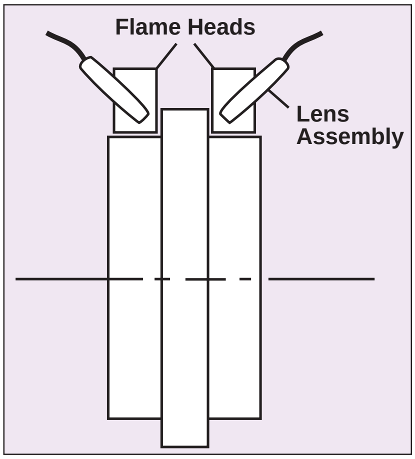

Figure 8

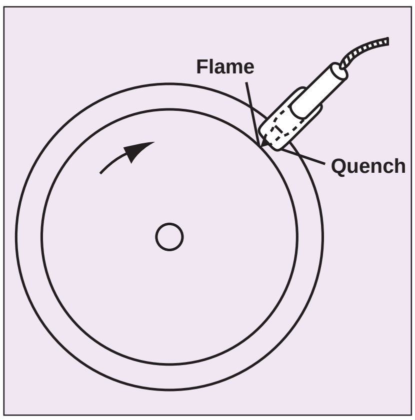

Figure 9

By optically looking through the “clean” natural gas flame at the optimum point on the wheel, Figure 10, the variations in the temperature determined by the Thermal Monitor provide a proportional signal which is fed to a pneumatic transducer which pneumo/mechanically moves the head to the correct position.

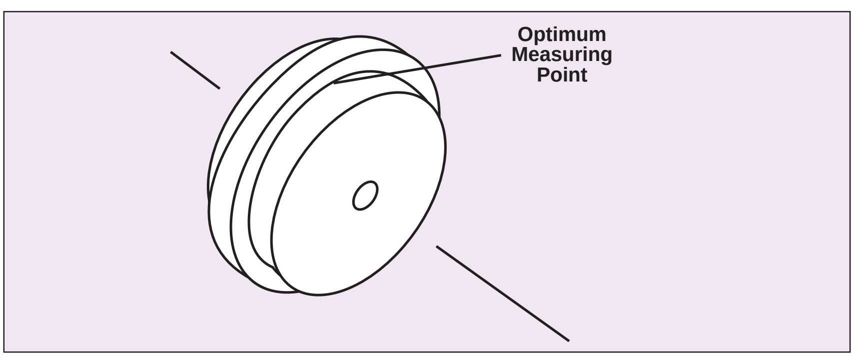

Figure 10

Substantial savings are realized by eliminating a previous costly process of destructive testing.

COKE GUIDE PYROMETER

By monitoring both level and temperature, the Coke Guide Pyrometer assures the optimum efficiency in the manufacture of coke. The multiplexing of several detectors on a vertical plane allows the operator to measure both height and temperature of the coke in the processing oven.

When desired parameters are met, a controller signal activates the pusher to dump the processed coke into an awaiting transfer car, thus assuring a quality product and energy conservation.

The above are but a few of the many and varied uses of fiber optics. The range and applications for these systems is only limited by one's imagination. The technology is expanding exponentially. Fiber optics are no longer viewed with doubts and misgivings. Like IC's, chips, bubble memories, RAM's, ROM's and PROM's, they are here to stay, they are the future.

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