New Techniques for Aligning and Maintaining Large Ring Gears

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Abstract

This paper presents two new techniques for aligning and maintaining large ring gears. One technique uses the "Operating-Temperaures" in the mesh of a ring gear set to evaluate the relative distribution of load across the face of the gearing. The other uses "Stop-Action" photography to record the surface condition and lubricant film on the pinion teeth. These techniques are recommended for use in conjunction with conventional maintenance procedures. Combined they optimize the gear set performance at the time of initial installation and then for the life of the gearing if they are used during subsequent maintenance procedures.

INTRODUCTION

The "Operating-Temperatures" alignment and the "Stop-Action" photography techniques have been under development at Falk for the last 5 to 6 years. Both have been rigorously tested on well over 100 different ring gear sets from various industrial applications. The gearing ranged up to 35 feet in diameter, 31 inches of face, and had pitches as course as $3/4$ DP. The techniques and the instrumentation required to use them are described in this paper. Also presented is some recent work which utilizes these procedures and interprets the results.

ALIGNMENT

Conventional Alignment Methods

There are basically three conventional methods which are used for aligning ring gear sets. These are presented here to provide a reference for comparison with the "Operating-Temperatures" method. The first uses feeler gages to measure the clearance at each end of the face, between the load flanks of the gear teeth when they are clean and contacting. With the second method, prussian blue, lamp black, or an equivalent is applied to several cleaned pinion teeth. That area of the pinion is then manually rotated into mesh with the gear and the teeth are bumped together transferring a contact pattern to the gear and the teeth are bumped together transferring a contact pattern to the gear where it can be inspected. The third method involves cleaning and dyeing the load flanks of several pinion and/or gear teeth with layout dye. The gearing is then operated under load for several hours, stopped and manually rotated to a convenient location to enable inspection of the dyed teeth. Areas on the teeth where dye is removed indicate the presence of contact.

These conventional techniques have certain disadvantages. The feeler gage and bump check methods indicate only static contact conditions. Since under load, the pinion, the gear, and associated equipment can deflect, twist and/or move through the internal clearance of the bearings, operating alignment may differ from static. The layout dye method offers a means of adjusting operating alignment to produce full face contact. Therefore, it can indicate when the entire face width of a tooth is carrying some load. However, it does not indicate whether the load intensity at one side of the face is greater than the load intensity on the opposite side.

Operating Temperatures Method

The "Operating-Temperatures" technique is a procedure, whereby, a uniform load intensity can be obtained across the entire face. This procedure is recommended for optimizing alignment after good initial alignment has been established using conventional methods. The basic premise behind the use of "Operating-Temperatures" is that misaligned gear sets experience non-uniform load intensity across the face of the gearing (Fig. 1). This variance in load intensity results

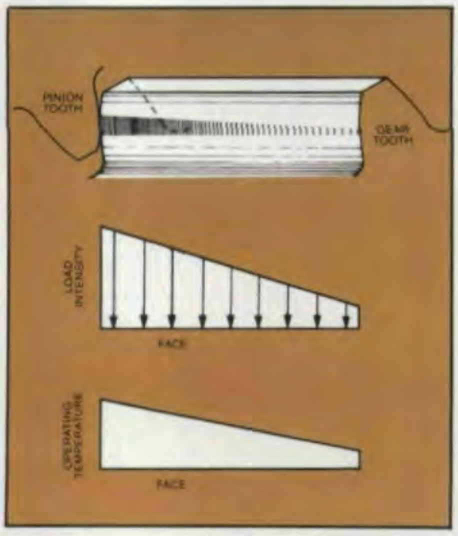

Fig. 1

in higher operating temperatures at the points of higher load. Therefore, misalignment will cause the operating temperature on one side of the face to be higher than on the other. As a result, equal temperatures at both ends of the face indicate a uniform load distribution and optimum alignment. Unequal temperatures indicate that the gear set may be misaligned with greater load intensity on the side of the face with the higher operating temperature.

Operating temperatures can be measured with either an infrared radiation thermometer, while the gearing is operating, or with a surface contact pyrometer immediately after stopping. (For

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Fig. 2 – Contact Pyrometer

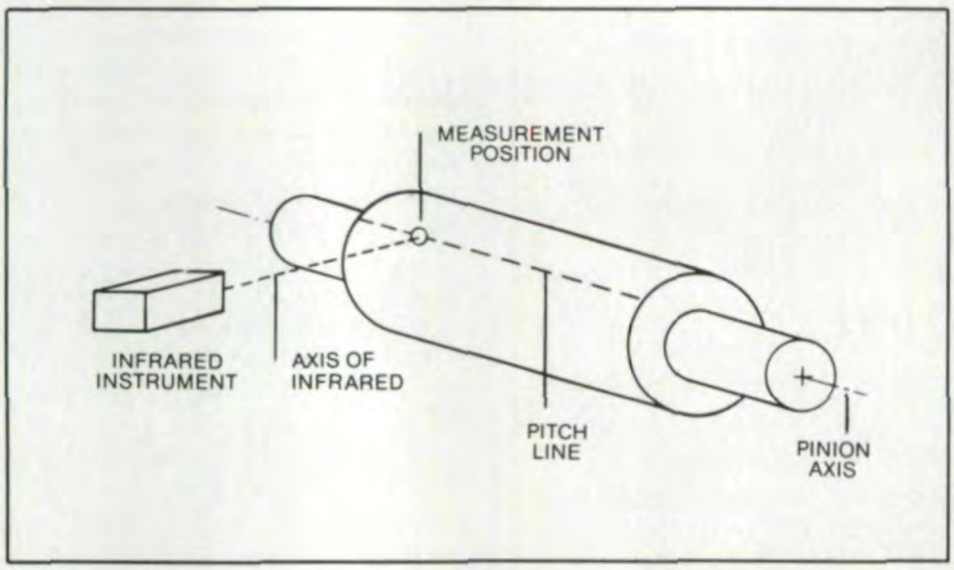


Fig. 3

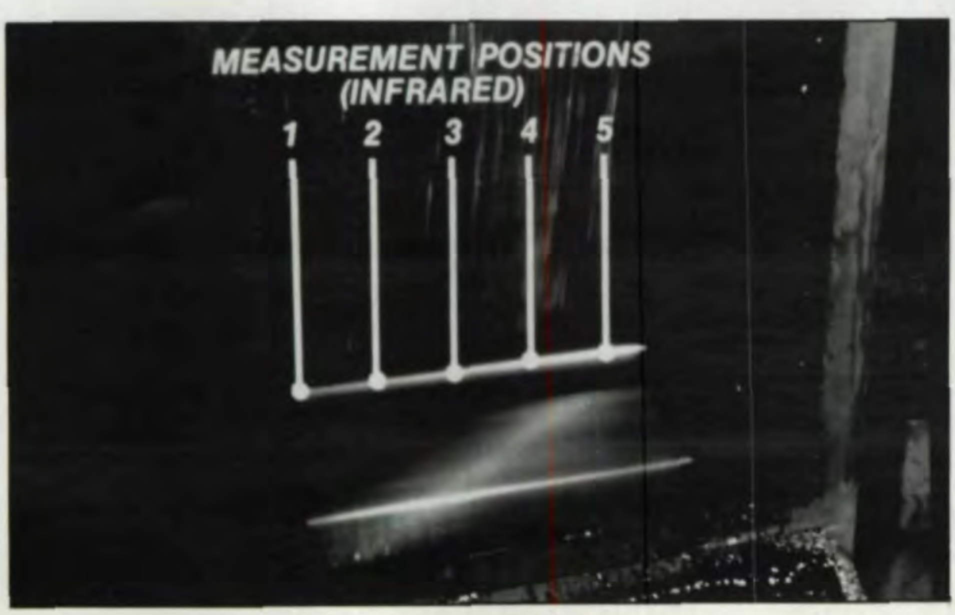


Fig. 4 – Measurement Positions

typical instrument specifications, see Appendix A).

When using the surface contact pyrometer procedure, the probe is placed on the load flank at the pitch line of at least one tooth (Fig. 2). The measurements are taken directly through the lubricant film and immediately after stopping the gearing, since temperatures begin to change within minutes.

The infrared measurements are taken while the gearing is operating by pointing the infrared radiation measuring instrument perpendicular to the axis of the pinion and then aiming at the measurement position on the load flank along the pitch line (Fig. 3).

Examples of Evaluating Operating Temperatures

Five measurement positions were selected along the face of the mill pinion in Fig. 4. One measurement was taken at each end of the face . . . one at the center . . . and two additional midway between these points. It is very important that infrared measurements be taken along a straight horizontal line (as illustrated) in order to obtain the pitch line position. Deviations from this horizontal will produce erroneous data.

Temperature measurements can also be taken on the gear, however, the magnitudes of the temperatures and the temperature differentials across the gear face have been found to be smaller than those of the pinion and less sensitive to changes in alignment. Therefore, the pinion temperatures are considered more suitable for use in "Operating-Temperatures" alignment evaluations.

Fig. 5 illustrates the pinion temperature distribution of a gear set having optimum alignment. The temperature gradient, which is the temperature at Position 1 minus the temperature at Position 5, is zero indicating that the load intensity is the same on both ends of the pinion. Position 1 is taken toward the mill end of the pinion face.

Fig. 6 illustrates the temperature distribution of a gear set having poor alignment. The temperature gradient of the pinion is $+40°F$ indicating that misalignment is producing higher load intensity on the mill side of the pinion. A negative gradient would indicate higher load toward the opposite side of the pinion face.

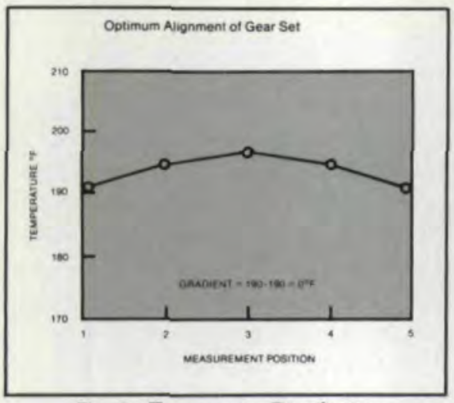


Fig. 5 – Temperature Distribution

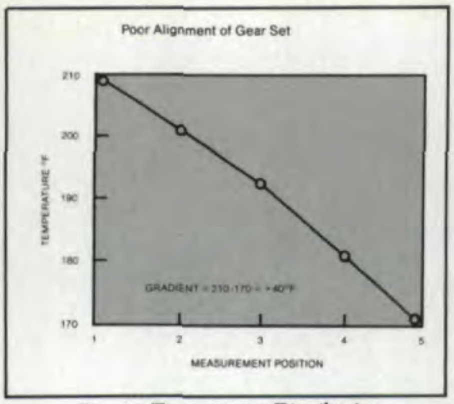


Fig. 6 – Temperature Distribution

Alignment Techniques

In addition to establishing a more uniform load distribution, the "Operating-Temperatures" technique offers two conveniences. First, when using the pyrometer, it is not necessary to connect an inching drive and rotate the gearing to view the contact patterns. Second, infrared techniques are able to sense the temperatures without stopping the mill.

The major limitation to using temperatures is that the surface condition of the teeth might influence the temperature and cause a false indication of alignment. Therefore, the presence of severe surface distress, recent scoring, wear pads, high points on the teeth, or other profile disturbances, should be considered when interpreting the temperatures.

Instrumentation

Both the surface contact pyrometer and the infrared instrument have advantages and limitations. The pyrometer has the advantage of accurate temperature measurement and simplicity of use. It has the disadvantage that the gearing must be stopped and, since temperatures begin to shift rapidly after stopping, only one or possibly two teeth can be measured.

Infrared has the advantage that the temperatures are measured during actual operating conditions. The temperatures recorded are, therefore, not changing with time as for the pyrometer. Also, the infrared averages these operating temperatures over many teeth at a given measurement position and, therefore, represents an overall alignment rather than the alignment of one or two particular teeth.

The primary limitation of the infrared is that it must be calibrated for the infrared energy emittance or emissivity of the pinion. This emissivity is essentially the relationship between the actual temperature of the pinion teeth and the amount of infrared energy tht is emitted for that temperature. It can be influenced by the type of lubricant, the lubricant film, and the tooth loads. Its value is determined by obtaining pyrometer measurements and then adjusting the infrared instrument to produce the same values. Experience has indicated that for various types of gear applications and lubricants the emissivity values may differ. However, the typical values appear to be in the order of 0.7 to 0.8. Since only relative and not absolute temperatures across the pinion face are desired to evaluate alignment, a value of 0.7 or 0.8 may be used and the measured temperatures considered nominal.

During the last five to six years, Falk has studied the gearing of over 100 different ring gear sets. The study was based primarily on mill gearing and has not been tested as thoroughly on kilns, because it is believed that the heat from the kiln along with the slow speed of the gearing might be misleading to infrared measurements. For mill gearing, detailed formulas have been developed to predict the alignment corrections required based on the measured temperature gradients. A study covering this is presented in Reference 1. However, for most mills, with only one pinion rotating out of mesh and located approximately 20° to 30° below the mill horizontal, equation 1 gives the approximate size of shim required to correct the alignment. This shim would be removed from or added under the appropriate pinion bearing to reduce the temperature and load intensity on the end of the face where it is the highest.

Equation 1

$$\text{Shim} = \frac{\text{Gradient}}{10{,}000} \quad \frac{\text{Bearing Span}}{\text{Face}} \quad \frac{\text{Design Load}}{\text{Operating Load}}$$

Example:

Consider a 3000 horsepower mill with a single pinion having a 39°F temperature gradient. The bearing span is twice the face width and the mill is operating at 2600 horsepower. The computed shim value would be:

$$\frac{39}{10{,}000} \quad 2 \quad \frac{3{,}000}{2{,}600} \quad = .009''.$$

Therefore, a .009" shim would be added or removed from under the appropriate bearing to reduce the load intensity on the high temperature end of the pinion.

Once an alignment correction is made, the mill should be allowed to operate for at least twenty hours in order to reach its steady state operating temperatures. The alignment should then be rechecked to determine whether further adjustments are necessary. Generally, when a gradient of 15°F or less is obtained, a satifactory alignment has been reached.

Stop Action Photos

The illustration above describes the surface condition and lubricant film on the pinion teeth of a ring gear set. It is a "Stop-Action" photo taken while the gearing was operating and provides a permanent detailed description of the tooth surface condition and the lubricant film existing on the pinion at the time the photo was taken. Surface distress such as scuffing, pitting and wear can readily be detected. By observation of the lubricant film, misalignment and lubricant contamination can at times be found. When "Stop-Action" photographs are used in conjunction with "Operating-Temperatures," misleading temperature rises and its cause can be identified. An example would be high temperatures due to localized scuffing when a lube spray nozzle fails.

The advantage of the "Stop-Action" photo is that it can be obtained with minimal effort, simple camera equipment, and most importantly, without stopping the gearing and interrupting production. It contains information useful to maintenance and engineering personnel for evaluating the performance history of the gearing and for detecting the need for corrective actions. It is also a means for recording and communicating tooth conditions and lubricant films to mill builders and gear manufacturers for review and appraisal.

The ability of "Stop-Action" photos to capture the tooth surface condition and lubricant film is further illustrated in the Fig. 7 series. Fig. 7A is a "Stop-Action" photo taken of a mill pinion during operation just seconds before the gearing was stopped. Fig. 7B was taken a few seconds after the gearing had stopped. Some lubricant had dropped on the pinion from the gear above. Fig. 7C presents the cleaned teeth of the pinion. These photos indicate that the "Stop-Action" photo gives a good representation of the appearance of the lubricant film and tooth surface conditions as they would appear had the gearing been stopped for a visual inspection.

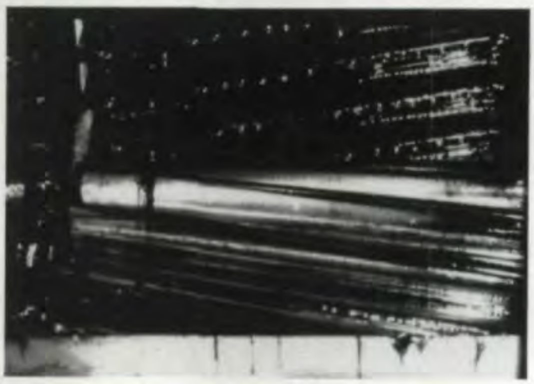
Fig. 8 illustrates the history documenting capability of "Stop-Action" photos. This series records the tooth surfaces of a particular pinion over a one year period. Initially the gearing was found to be scuffed and some pitting had occurred (Fig. 8A). Two months later (Fig. 8B), the condition was found to be improving. This improvement continued through the remainder of the year (Fig. 8C and 8D). Had the pitting become worse, corrective action could have been planned and nonscheduled downtime avoided. The significance of this series is that the photographs provide a far better history than memory, notes or sketches from which to make maintenance decisions.

Photographic Technique

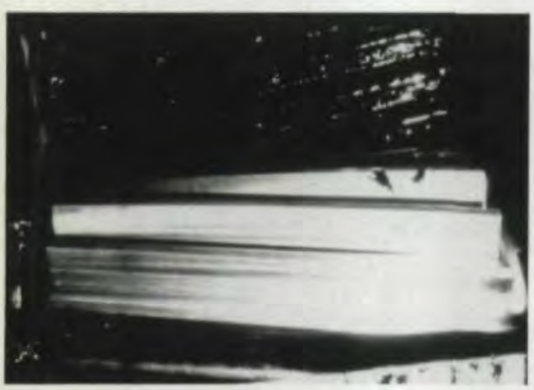
The photographic equipment required to obtain "Stop-Action" photos is readily available, relatively inexpensive and simple to use. The camera is a 35 mm single lens reflex type having a 50 mm focal length lens. Stopping the motion of

Fig. 7 – Operating Teeth vs. Static

7A Operating



7B Static



7C Cleaned Teeth

the pinion is accomplished with an automatic electronic flash having a guide number of about 100 (ASA100) or higher, and also a remote sensor which can be mounted on the camera hot shoe. Color slide film (ASA160 or ASA200) has worked well and is recommended. Print type film is nor recommended since the colors of the prints can be influenced during processing.

Fig. 9 illustrates the positioning of the camera and flash. The camera should be centered and focused on the load flank of the pinion teeth until the camera viewer is filled by the pinion teeth. The flash should be set to automatic operation for an aperture of approximately f5.6. The camera lens should be set to the same aperture. The remote sensor should be positioned on the camera hot shoe and the flash oriented at approximately 30° to the helix in order to minimize reflected glare from the tooth surface.

Once the proper camera and flash position is attained, the shutter button is depressed. This opens the camera lens. The flash will then fire in approximately 1/5,000 to 1/30,000 of a second stopping the action of the gearing like a stroboscope and exposing the film. The camera shutter then closes and the "Stop-Action" picture is obtained.

Both "Operating-Temperatures" alignment and "Stop-Action" photography provide useful infor.ıation regarding the operation of large ring gearing. Presented here are some ways that these two techniques have been used, both individually and in combination, to gain more insight into ring gear alignment and lubricant films. Presented first, is a discussion of transient shifts in the alignment of a mill gear set from start-up to steady-state conditions. This is followed by an investigation into the influences of lubricant type, viscosity and operating temperature on the appearance of the lubricant as captured in "Stop-Action" photos.

Alignment Transient Shifts

As previously indicated, static alignment and operating alignment may be different. One possible source of this difference, (discovered through the use of infrared) is that the alignment of a mill gear set can shift over a period of time as the mill progresses from a stopped condition to its steady-state operating conditions. This transient type shift was encountered in hot air type dry process mills.

An example of the temperature gradients of such a mill is given in Fig. 10. Here the gradient of the mill pinion shifted from −21°F to +18°F over a period of approximately twenty hours. This represents a 30°F shift in gradient which, for that particular mill, corresponded to a .009" change in alignment over the pinion bearing span. It is suspected that this shift was the result of thermal growth of the mill as it came up to normal operating temperatures.

A wet process taconite grinding mill is also included in Fig. 10 for comparison. For that mill, the steady state operating gradient was reached within approximately one-half hour with no evidence of any alignment shift.

At any rate, to be certain steady-state operating temperatures have been reached, it is recommended that the mill be operated for approximately twenty hours prior to taking "Operating-Temperatures".

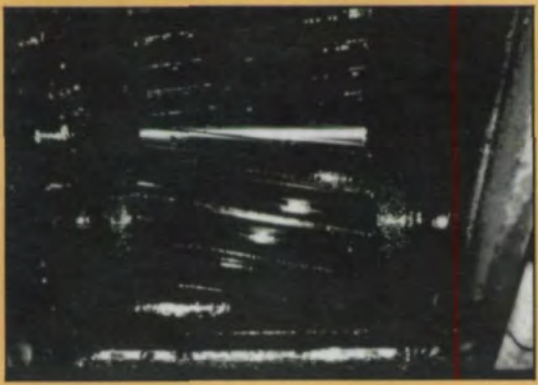
Lubricant Films

"Stop-Action" photography, besides recording pinion tooth surface conditions, describes the operating lubricant films on the pinion tooth. Falk experience indicates that these films can vary significantly depending upon the type of mill and the operating conditions. These visual differences in lube film prompted exploratory tests regarding the possible influences of lubricant type, viscosity and operating temperature on the appearance of the film.

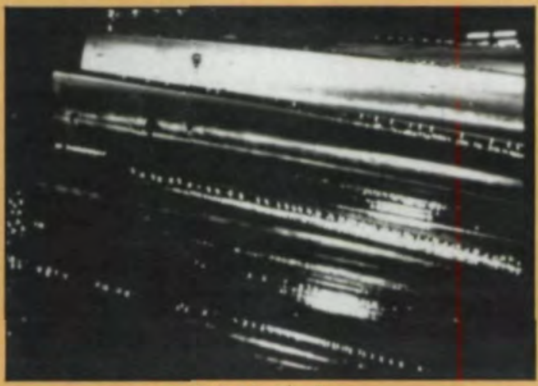
Lubricant Type

The lubricants. investigated were asphatic base, residual type compounds typically used for ring gearing. Their viscosities ranged from 4,750 SSU to 17,200 SSU at 210°F undiluted. They were produced by various manufacturers. None of the lubricants had a large percentage of solid lubricant additives.

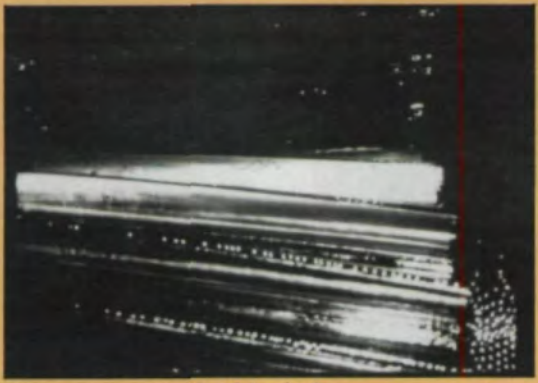
Fig. 8 – Gear Performance History



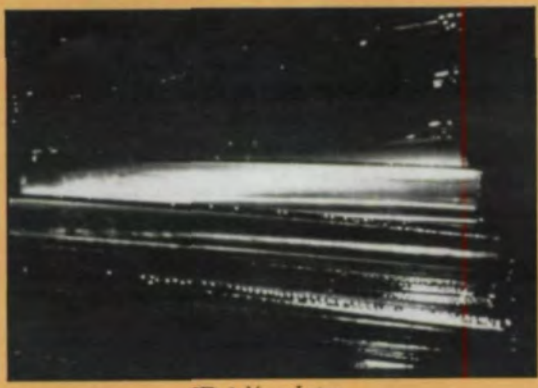
8A Initial Photo



8B 2 Months Later



8C 8 Months Later



8D 1 Year Later

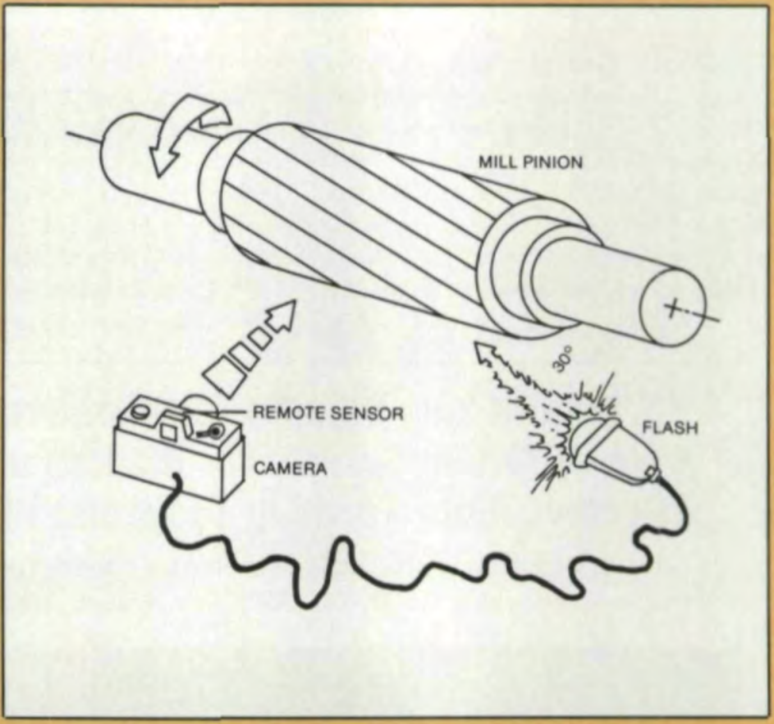


Fig. 9 – Camera and Flash Positions

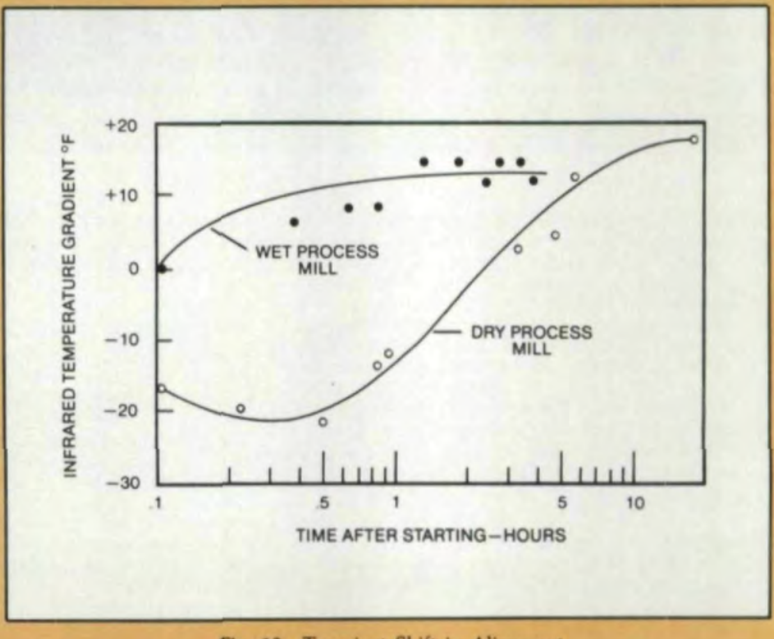


Fig. 10 – Transient Shift in Alignment

Since differences in the lubricant films on photos appeared as changes in darkness and color, it was important to determine whether the color of the lubricant varied with film thickness or differed between lubricants of different manufacturers. A laboratory test was performed. It involved placing a piece of ½" plate glass over a ground steel bar, which had been coated with lubricant and had a .002" step in the bar (Fig. 11). This step produced a space between the bar and the plate glass that increased from 0" to .002" over the 3" length of the step and which was filled with lubricant. The relation between lubricant film thickness and its color could then be observed through the glass and photographed.

Inspections of the glass and the plate indicated that both were flat to within less than .0001" over the area of contact. Before applying the lubricant to the steel plate, the glass, the lubricant and the plate were heated to approximately 190°F to drive any diluent from the lubricant and achieve a uniform temperature. The photography lighting was identical for each lubricant photo. It was also very similar to the lighting used for photographing operating mill pinions.

The results of this testing show that the color distribution with film thickness is very similar for each lubricant. Additional tests in which the lubricants were allowed to cool to room temperature (70°F) indicated that the color of the lubricant did not change with temperature.

These exploratory tests suggest that residual type lubricants are basically the same color and that lubricant film color might be used to estimate or compare lube film thicknesses.

Lubricant Viscosity

The glass plate test also indicated that changing viscosity within the 4,750-17,200 SSU range did not significantly influence the relationship between color and film thickness of the lubricants tested. This observation was used in the evaluation of a field test where these same lubricants had been individually applied to the same mill pinion. Adequate time had been allowed for each lubricant to establish its own film. The resultant films were very similar. The pinion operating temperatures, which were monitored with infrared and surface contact temperature instruments, remained essentially constant (184°F to 190°F) for all lubricants tested. The indication of this test was that the change in non-diluated viscosity within the 4,750 to 17,200 SSU range, which is typical for residual compounds, did not significantly influence the lubricant film appearance.

Operating Temperature

From the previous testing, the variance in lubricant film, between different pinions, does not appear to be significantly related to the specified viscosity or manufacturer of the lubricant for the viscosities and lubricant types tested. The third parameter investigated, temperature, was found to have significant influence. This was observed in a field test where the lubricant film was monitored from the time the mill started, at ambient temperature (80°F), until it reached its

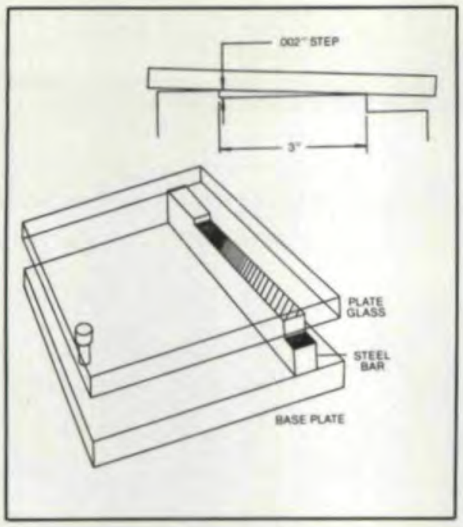


Fig. 11 – Lube Film Test Setup

Fig. 12 – Lubricant Film Color Change After Start-Up (Start 70°F Final 179°F)

12A ½ Hr. After Start

12B 2 Hr. After Start

normal operating temperature of 179°F. Fig. 12 describes the change in film at various times after startup and shows that the lubricant film becomes lighter in color as the temperature increases. From the glass plate test, this would indicate that the film thickness is also decreasing.

The relationship between lubricant film and operating temperature is further illustrated in Fig. 13. Here, four mill pinions from different applications, using different lubricants, are shown along with their corresponding operating temperatures. Again, the color of the lubricant film becomes lighter, indicating a thinner film as the operating temperature increases. This agrees with the results in Fig. 12. In general, similar results were found on other gearing where both photos and temperatures were obtained.

CONCLUSION

This paper has presented two new techniques for aligning and maintaining large ring gears. The techniques are particularly beneficial because they can be utilized while the gearing is operating and, therefore, do not interfere with production. The unique advantage of the "Operating-Temperatures" technique is that it indicates relative load intensity across the face of the gearing and not just contact. The "Stop-Action" photo captures the tooth surface condition and lubricant film on the teeth of an operating gear set. This is accomplished with readily available, simple to use and relatively inexpensive photography equipment. The photos provide a far better history than memory, notes or sketches from which to make maintenance decisions.

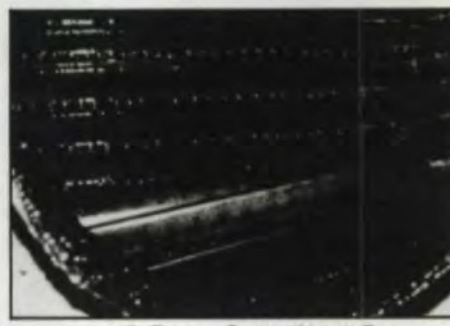
Both these techniques are recommended for use by engineering and maintenance personnel for evaluating gearing condition and performance. They are also recommended for consideration when taking necessary corrective action during the life of the gearing.

Reference

1. ANTOSIEWICZ, M., "The Use of Mill Gear Operating Temperatures for Alignment Evaluation," IEEE Cement Industry 21st Technical Conference, Tarpon Springs, Florida May 1979.

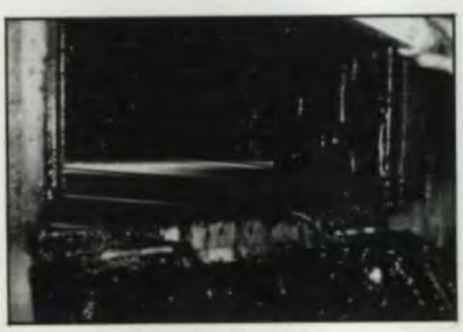
Fig. 13 – Lubricant Film vs. Lubricant and Temperature

13A Whitmore Med. 147°F.



13B Texaco Crater 5X 165°F.

13C Mobiltac C 180°F



12C 6 Hr. After Start

12D 24 Hr. After Start

13D Mobiltac C 195°F

(Appendix continued on page 48)

HOB LENGTH EFFECTS . . .
(continued from page 19)

$$F'(Y) = 4 \times KA \times Y^3 + 3 \times KB \times Y^2 + 2 \times KC \times Y + KD$$

For first approximation Y can be set equal to PD/2

$$\text{so } Y = PD/2$$

This method allows fast and precise calculation with a small number of iterations.

Having Y, one can obtain X and Xo, by substitution.

Consulting Fig. 7, since QP=Xo, distance OP=Xo × tan(q) and roughing zone: Lr=OP - Lg/2

3. ENGAGEMENT ZONE

As mentioned above, the engagement zone is the sum of roughing and generating zones.

$$Le = Lg + Lr$$

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E-3 ON READER REPLY CARD

TECHNIQUES FOR ALIGNING & MAINTAINING . . .
(continued from page 43)

APPENDIX A
INSTRUMENTATION SPECIFICATIONS

Surface Contact Pyrometer

A digital type pyrometer having an accuracy of ±3°F and a response time of approximately five seconds or less was used. The contact probe was surrounded by ceramic type substance to shield it from the influence of ambient temperatures.

INFRARED

Instrumentation

There are basically two styles of infrared instruments. One focuses the infrared through a lens and the other reflects it from a mirror. The lens type can be aimed more precisely making it superior from an accuracy viewpoint. Unfortunately, lens type instruments are the least portable.

The specifications of each of these types of infrared instruments can vary widely. The following key specifications are recommended for this application:

Temperature	50°F to 300°F
Spectral Response	8-14 microns
Field of View	2° or less
Spot Size (max.)	1½" at 40" distance
Emissivity Range	.6-1.0 (min. range)

A digital readout or a meter readout with a meter hold feature (not peak) is recommended. Some mirror type instruments are available with laser optics to aid in aiming the instrument. This option makes them equivalent to the lens type.

Setup

Fig. A-1 illustrates the setup of the lens type infrared radiation thermometer. A fluorescent light is an aid for aiming the detector at selected measurement points. It has been determined that the heat emitted from this light does not influence the measurements. It is very important that the light be held horizontally to obtain a horizontal reflection from the pitch line of the mesh. The tripod is recommended.

Fig. A-2 illustrates the setup for a mirror type instrument. In this case, the fluorescent light and tripod are also recommended for instruments without laser sighting optics.

Fig. A-1—Test Set-Up
Lens Type Infrared Radiation Thermometer

Fig. A-2—Test Set-Up
Mirror Type Infrared Instrument

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