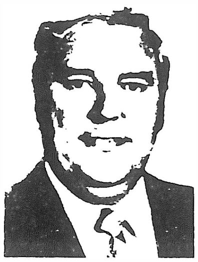
OPTICAL ALIGNMENT OF TURBOMACHINERY

by

A. J. Campbell

Manager, Field Engineering
Dresser Clark Div., Dresser Industries
Houston, Texas



Born and educated in Scotland, A. J. Campbell graduated in May 1952 as a Marine Engineer from the Stow College of Marine Engineering, Glasgow, Scotland.

He has 21 years of experience on marine and land based compressors and turbines. He has been with Dresser Industries from 1959 and is presently the manager of their Field Engineering Department based in Houston. During the last four years he has been involved deeply with optical alignment techniques for reciprocating and centrifugal compressors, plastic extruders, and gear cases.

INTRODUCTION

Optical alignment is a technique which has proven its usefulness in original installation, repair and maintenance of turbomachinery.

Optical alignment, sometimes referred to as optical tooling utilizes precision optical instruments, such as alignment telescopes, jig transits (Fig. 1), precision sight levels, etc., rather than mechanical tools to determine straightness, flatness and squareness.

The heart of the technique is an instrument with built-in optical micrometers for measuring displacement from a precise and referenced line of sight. The micrometers are divided into increments of 0.001″, and the accuracy obtained when taking readings on an optical scale (Fig. 2) is approximately ±0.001″ at 1 feet to ±0.002″ at 50 feet. Because of inherent advantages over other techniques, optical alignment has gained widespread acceptance in the aircraft industry, paper mills, shipyards, and of course, the industries associated with the use of reciprocating and turbomachinery.

The alignment of high speed rotating equipment is one of the most troublesome problems in industry today. It has been observed that many of the vibration problems encountered on rotating equipment, was a direct result of misalignment. The nature of this equipment which includes a power source (electric motor, steam turbine

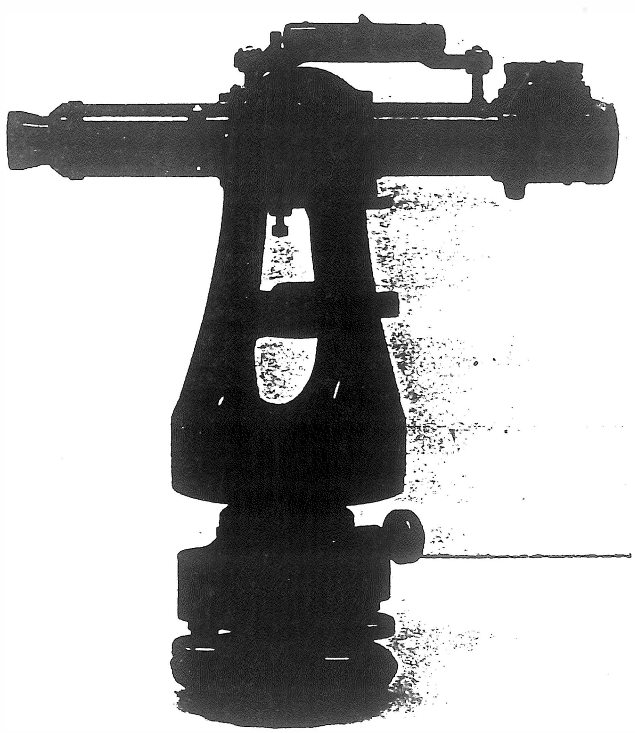


Figure 1. Typical Jig Transit used for alignment checking of turbomachinery.

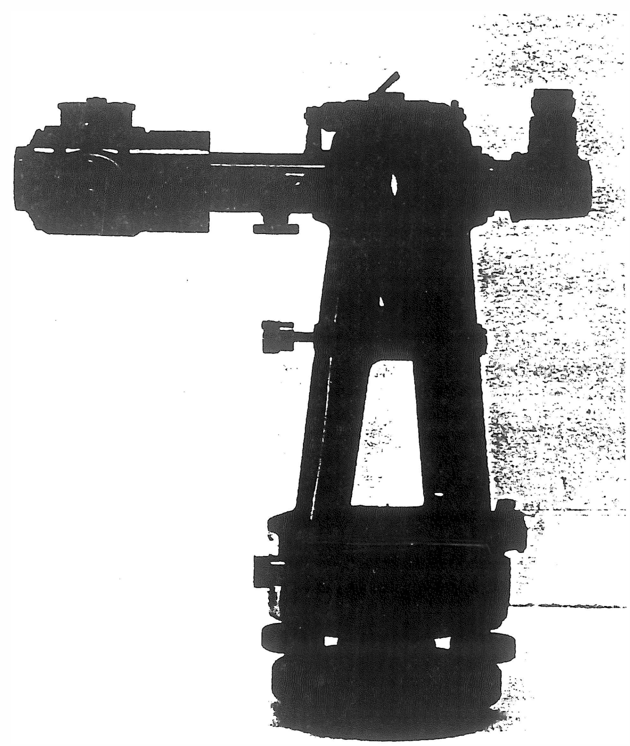


Figure 1a. Typical Jig Transit Square with hollow axle and right angle eyepiece and fitted with combination micrometer to allow readings in two (2) planes without rotating micrometer head.

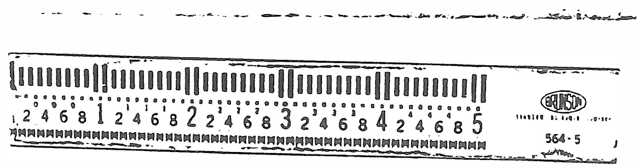


Figure 2. Typical Optical Scale showing four (4) different divisions which can be used depending on the distance from the Jig Transit to the Optical Scale. Example: Small divisions are for short distances, large divisions for long distances.

or gas turbine), a compressor/compressors or large pump and possibly a gear operating at high rotational speed, requires accurate shaft to shaft alignment when at rated load and design temperatures.

MECHANICAL ALIGNMENT PROCEDURE

The determination of this alignment is normally accomplished when the unit is shutdown and cold and is accurately determined by using the "reverse indicator graphical plotting" method. However, the thermal growth of the unit, pipe strain, foundation settlement, etc. can only be guessed at, based on manufacturers suggested figures. The mechanical "hot alignment" has traditionally been taken as quickly as possible after a unit is shutdown. Units of today aften are equipped with continuously lubricated couplings which require a minimum of one (1) to two (2) hours to disassemble. During this coupling removal, considerable cooling occurs making the accuracy of the "hot" readings highly questionable.

OPTICAL ALIGNMENT PROCEDURE

Contrast the preceding method with the optical technique. After the initial cold mechanical alignment has been made and the train is essentially ready for start-up, optical alignment reference points are established at each end and each side of each unit in the train and as close to the couplings as possible. On most units, this is usually the bearing housing. A jig transit is then set up, leveled, a line of sight established and a complete set of readings taken and recorded for each reference point in the train in the vertical plane. Somewhat similar, a line of sight is established between two (2) reference points in a horizontal plane and a set of readings recorded for each point in that horizontal plane. Both sides of a train are checked in this manner. Once the train is started and operating at design conditions and allowed to stabilize, another complete set of optical

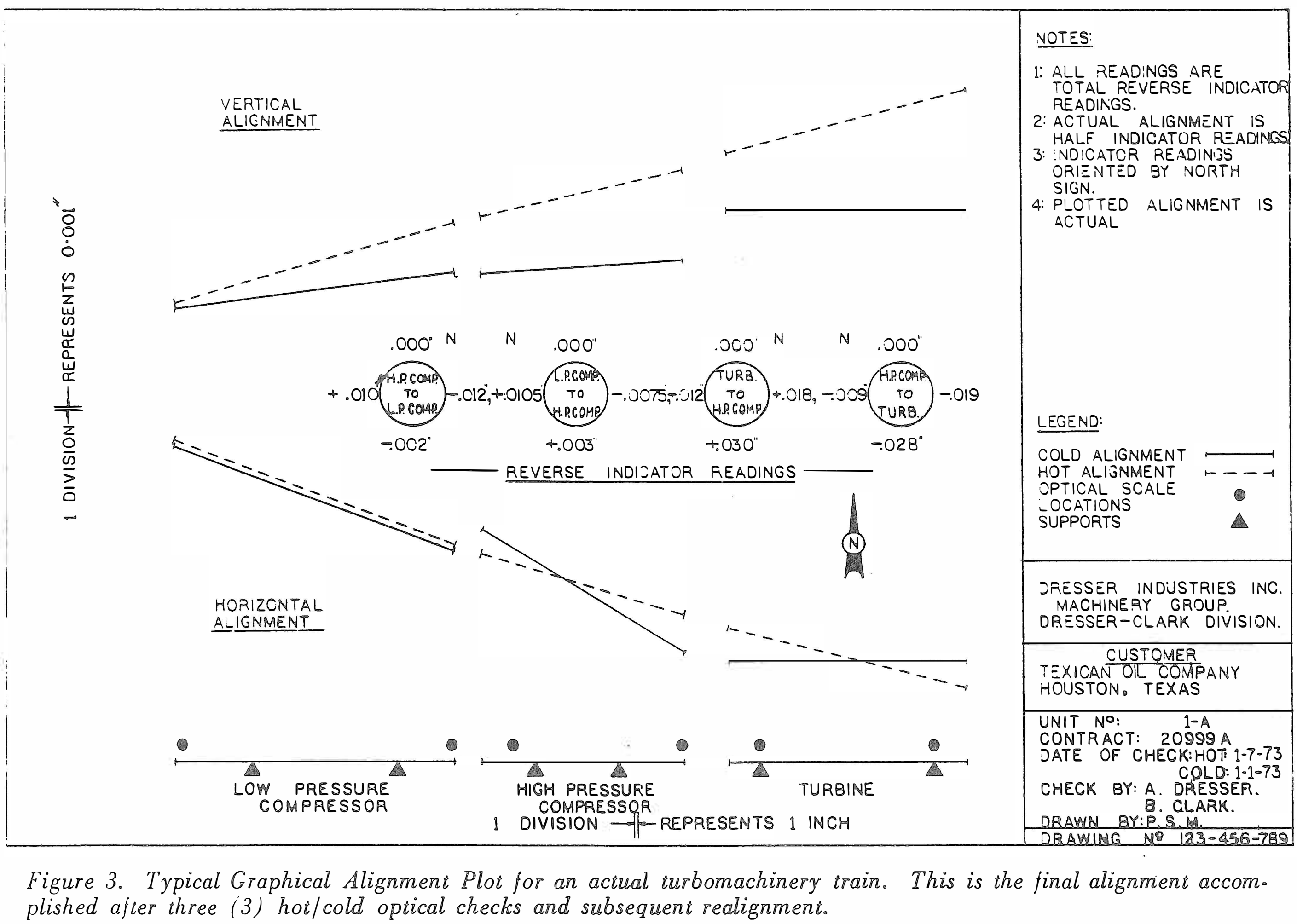


Figure 3. Typical Graphical Alignment Plot for an actual turbomachinery train. This is the final alignment accomplished after three (3) hot/cold optical checks and subsequent realignment.

readings are recorded without having to shut the unit down. Compring the "hot" readings to the cold alignment and cold optical readings, the exact relative growth of each point can be obtained. The resulting growth can then be plotted on the alignment graphical plot (Fig. 3) and it can then be observed if realignment is necessary. If realignment is required, the correction amounts can readily be calculated from the graphical plot. Naturally if the "hot" alignment is within the tolerances specified for that particular length of coupling, then the unit will be left operational.

ALTERNATIVE OPTICAL PROCEDURE

The preceding is the method normally used when the train in question is a new installation. On what is termed an "old train," a reverse method is generally adopted: first comes the "hot" optical check, then the cold optical check, followed by the mechanical reverse indicator readings, the graphical plot, and any realignment, if required. It is a good point to have the mechanical reverse indicator readings taken as close to the time of the "cold" optical check as possible.

PROBLEMS ENCOUNTERED IN ALIGNMENT

Since the introduction of optical "hot" alignment checks, many interesting things have occurred, some of which were almost unbelievable until double checked.

1. The biggest culprit causing misalignment of turbomachinery is pipe strain being transmitted to equipment. One of the unbelievables was 0.220″. Although more common in a horizontal plane, pipe strain will also affect equipment in a vertical plane. Pipe strain is generally caused by the final run of piping arriving at the compressor flange and being anything from a few thousandths of an inch to several inches away from said flange. It is the few inches that naturally cause the problems as in many cases, the pipe fitters simply correct this by putting a "some-a-long" to it and drawing it up to the compressor flange, and generally with the comment, "how can this little piece of pipe move that big piece of iron." Another item which causes compressors to go out of alignment is improper tension or size of pipe hangers. A change of tension has, on record, changed the horizontal alignment by 0.060″ and vibration level from 0.4 mils to 3.8 mils. Please try to insure good installation of piping, especially on new units.

2. Another culprit is gear cases—not so much the old type cast cases, although cast cases are still being manufactured today, but the new and generally larger fabricated cases. Many of the problems have no logical explanation, such as a case that will rise 0.060″, 0.070″, 0.080″ when the calculated thermal rise is only 0.015″. It would require operating temperatures in the 600°F. to 700°F. range to get the large rise figures on this particular case. In many situations, the gear case does not rise evenly, but with a twist. Twist will occur on a case that is grouted into concrete, as well as a case that is mounted on a skid. Hot optical checks have been conducted on gear cases during shop tests which allows for optical data to be taken in a constant temperature and unaffected by the elements of weather. The large rise and twisting still occurred under said conditions. Figure 4 shows a typical optical scale location on a gear case.

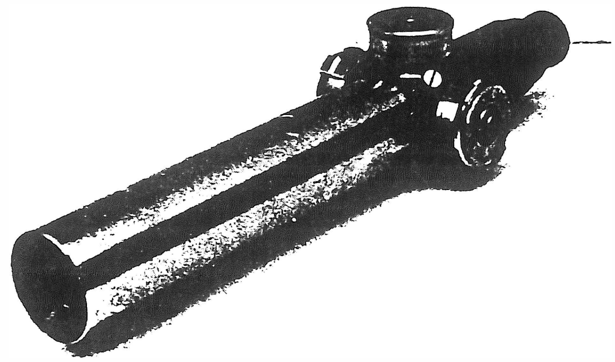


Figure 4. Micro-Alignment Telescope: Used mainly for checking bearing and labyrinth bores.

Note the difficulty of actually getting the optical scale location on the bearing housing.

3. Manufacturers generally supply an approximate figure of thermal growth to allow the contractor, customer or their service people to install their equipment in the proper alignment. Having checked many different types of compressors by different manufacturers, a study was made of a particular size of compressor case under similar operating conditions and what the rise would be. Out of a total of ten (10) cases, a minimum rise of 0.006″ to a maximum of 0.032″ was observed. Horizontally, I do not believe anyone could predict that, and again the prime reason for such a statement is pipe strain. Due to said unforeseen, unusual, etc. happenings,

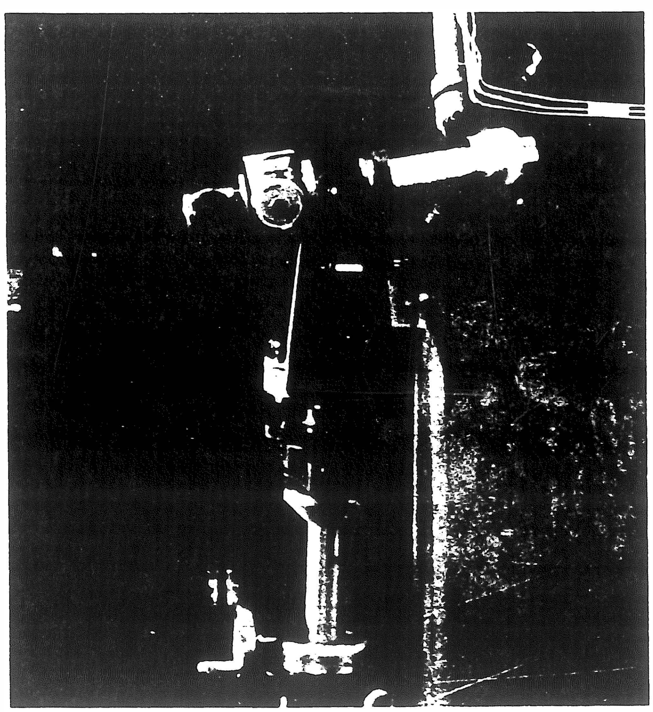


Figure 5. Micro-Alignment Telescope adapted for use similar to a Jig Transit.

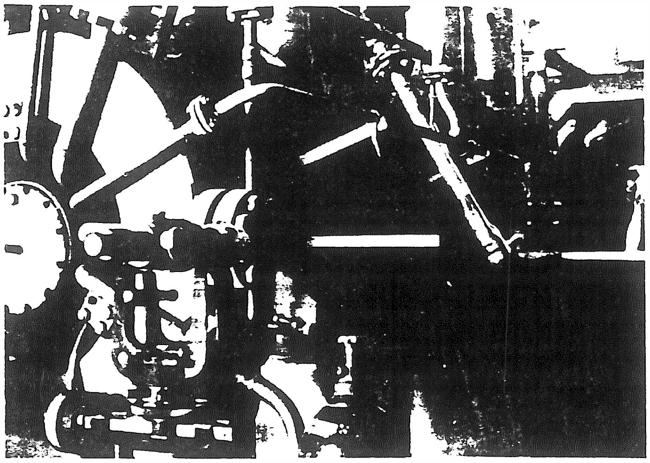


Figure 5a. Micro-Alignment Telescope being used to take readings of horizontal movement of a barrel type compressor.

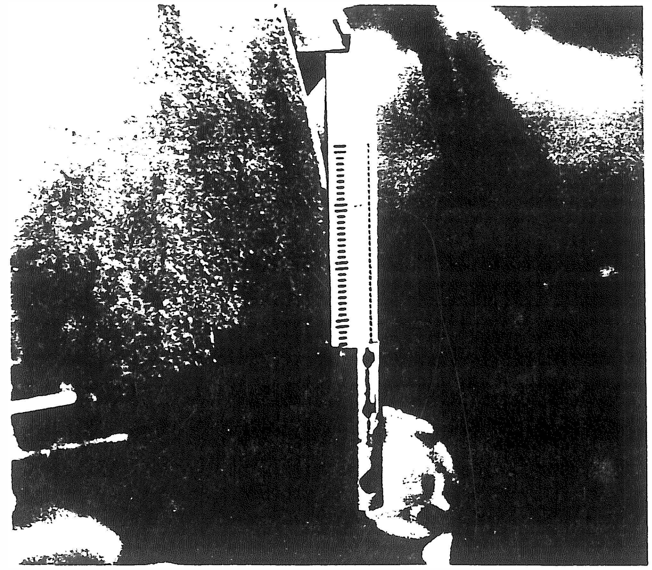


Figure 6a. Optical Scale set for vertical reading on barrel type compressor case.

it has been extremely difficult for manufacturers to establish units of misalignment, but they have provided a figure which can be correlated to a coupling length. In many cases, the manufacturer is faced with the problem of having to supply a short coupling simply due to the minimal space provided by the customer for the installation of units. Many companies have fortunately come to realize that short couplings are a cause of their alignment/vibration problems and one company has made it a point that in new installations, the coupling spacer shall not be less than 18 inches long. It is to be hoped that many more companies will follow along the same lines.

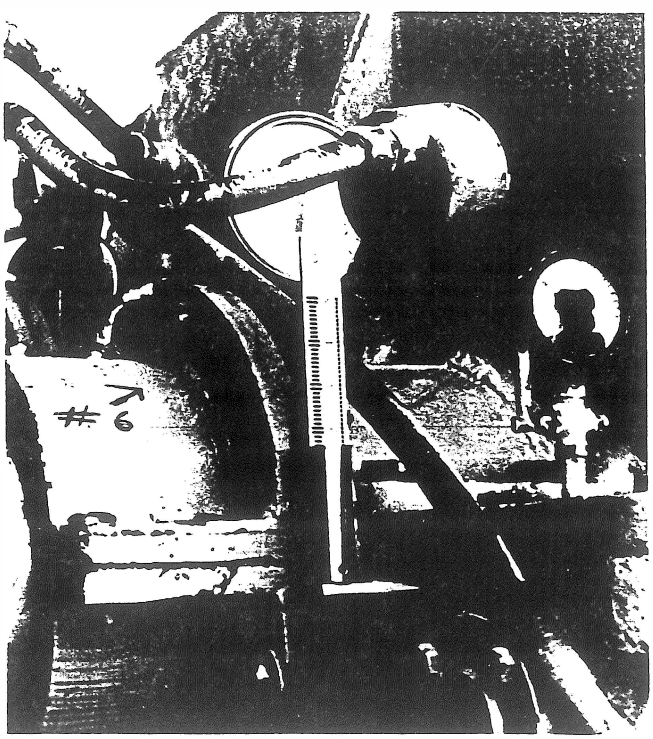


Figure 6. Optical Scale set for vertical reading and showing difficulty of getting a point on a bearing housing of a gear case.

Many different methods are used when aligning turbomachinery today and one of the biggest problems is the initial cold alignment. Many mechanics still insist on using a face reading on a coupling hub or shaft end and a rim reading with no thought whatsoever to taking out the shaft thrust or the diameter over which the face reading is taken. As long as the face reading is within one thousandth or two, they will tell you that it is close enough.

The initial cold mechanical alignment is extremely important when optically checking turbomachinery and this point must be continually stressed. One particular customer could not get dependable *reverse* indicator readings and decided that their compressor/turbine train be cold aligned optically. Timewise, this took a little longer, but the results were exceptionally good being due primarily to the fact that three (3) cold/hot optical checks had previously been conducted on this particular train. This customer has now advised that whenever possible, all new units will be cold aligned using optics.

NON-OPTICAL METHODS OF CHECKING ALIGNMENT

Other methods being used today to check cold/hot alignment is the proximity probe mounted on water cooled stands (Reference 1), and the probe and bar method (Reference 2) mounted at the couplings. You will hear "pro and con" about the two (2) methods, but there is no question as to their accuracy on monitoring the movement of units.

Another instrument being used is the laser. The laser can only be used under certain alignment conditions, as the equipment required to check a turbomachine train while in operation has not yet been fully developed to where it would replace the alignment telescope or jig transit. The laser is an excellent instrument for checking a unit that has the rotor removed and a bearing/labyrinth type alignment check is required. From information received from laser users, the instrument does not travel too well and therefore should try to be contained at one (1) location only.

CONCLUSION

Many methods of cold and hot alignment have been covered and many pages could be written of case histories involving optical alignment of turbomachinery, however, it is to be hoped that what has been covered in this paper has given an insight to the workings of optical alignment.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of the personnel of the Optical Alignment Department, Dresser Clark, Houston, Texas.