BENCHMARK GAUGES FOR HOT ALIGNMENT OF TURBOMACHINERY

by

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Benchmark gauges offer a simple and effective means of securing hot alignment data for turbomachinery trains by accurately measuring the movement of the machines relative to the foundation itself. With this system, benchmarks are permanently affixed to the foundation and to the bearing housings as shown in Figure 1. All four benchmarks lie in a plane normal to the shaft centerlines. Similar reference points are located at each bearing housing in the train.

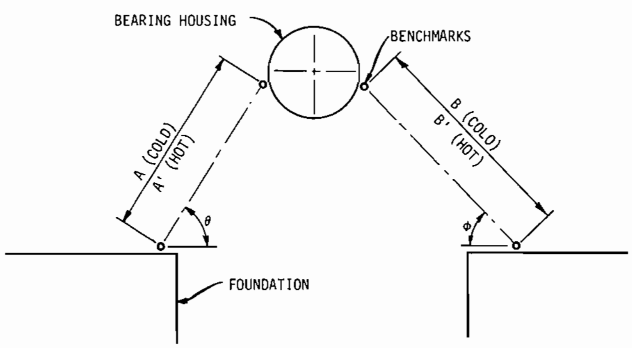

Figure 1. Typical Placement of Benchmarks on Foundation and Bearing Housing.

To use this technique, cold alignment of the couplings is done in the normal manner, preferably using reverse indicator techniques for maximum accuracy [1]. When acceptable cold alignment is obtained, reference dimensions A and B and angles θ and φ are taken at each benchmark location. These data are recorded along with the final dial indicator alignment readings taken at the couplings themselves. Coupling dial indicator readings and benchmark gauge readings are made simultaneously, thereby establishing a unique relationship between the two. When the equipment is brought on line, dimensions A′ and B′ are taken and recorded for each location. The data thus obtained is sufficient to determine the vertical and horizontal movements of each bearing housing relative to the foundation. From this information, the actual misalignment of the coupling in the running condition can be determined.

Reduction of the data to determine running alignment of the equipment couplings is most readily done by using programs developed for hand-held, programmable calculators such as the Texas Instrument TI-59 or the Hewlett-Packard HP-41C. Figure 2 shows a typical worksheet for a program which uses "cold" and "hot" benchmark gauge readings to calculate vertical and horizontal movements of the bearing housings in the equipment train. This information, along with the final "cold" coupling alignment readings, is used to calculate actual angles of misalignment of the coupling in the running condition, as shown in Figure 3. With this information, a judgment can be made as to the acceptability of the coupling alignment for that particular machine. If alignment corrections are required, a third program in the series, Figure 4, will calculate shim changes and horizontal movements needed to obtain precise coupling alignment.

A graphical solution can also be used to obtain vertical and horizontal movements of the bearing housings from benchmark gauge data, as shown in Figure 5. Using common grid paper (4×4 per inch grid is usually a convenient size), lay out reference vectors A and B at angles θ and φ, having these vectors cross at one of the grid intersections. The intersection of these vectors represents the centerline of the machine shaft in the cold position. Now refer to cold and hot measurements previously made (A, B, A′, and B′), and determine the movement of the bearing housing along vectors A and B by taking the differences between cold and hot measurements (ΔA and ΔB) for each location. Lay out these movements along vectors A and B using any convenient scale, say ¼ inch equals 0.001 inch, to establish points a and b. Now draw lines through points a and b perpendicular to vectors A and B. These lines represent arcs of radiuses A′ and B′ drawn from the foundation benchmarks. The intersection of these lines defines the position of the machine shaft centerline in the hot position relative to the cold position. To determine the movement in the vertical and horizontal directions, it is necessary only to scale off the dimensions referred to as ΔH and ΔV, using the same scale as used in plotting ΔA and ΔB. A similar plot for the data secured at each bearing housing affords sufficient information for plotting the hot alignment of the entire turbomachinery train.

A typical benchmark for this technique is shown in Figure 6. The benchmark is made of stainless steel, and the spherical segment is integral with the mounting base. These benchmarks are normally secured to the bearing housing by a threaded stud. Benchmarks on the foundation are usually secured by an anchor inserted into a hole drilled directly into the concrete. A variety of benchmark styles are available to suit the specific needs of the application.

Figure 7 shows a benchmark gauge set designed for turbomachinery alignment work. The gauge uses a long range dial indicator mounted in a spring-loaded telescoping column. Spherical seats at either end of the column match the spherical portion of the benchmarks, and the gauge is self-supporting when inserted between pairs of benchmarks. The range of the tool is varied by adding extensions in much the same manner that bore gauges or inside micrometers are adjusted for various

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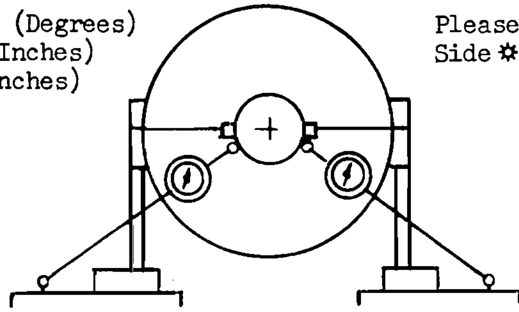
Program 3

[Please Read Instructions]

HP-41C

INPUT:
Inclinometer Readings (Degrees)
Cold Reference Data (Inches)
Hot Reference Data (Inches)

Please Identify:
Side ☼ Is NORTH



Location						OUTPUT (Mils) Vertical + ↑ Horizontal + →
Turbine Outboard End	40	00	Angle	47	03	13 A V
	32.310	01	Cold	31.180	04	-3 B H cm
	32.316	02	Hot	31.192	05	
Turbine Coupling End	36	00	Angle	40	03	14 A V
	41.605	01	Cold	39.721	04	4 B H cm
	41.616	02	Hot	39.727	05	
Compressor Coupling End	48	00	Angle	43	03	6 A V
	32.565	01	Cold	31.635	04	1 B H cm
	32.570	02	Hot	31.638	05	
Compressor Outboard End	45	00	Angle	46	03	-7 A V
	28.722	01	Cold	29.321	04	-1 B H cm
	28.716	02	Hot	29.317	05	

- TO LOAD MAGNETIC CARDS:
  [XEQ] [ALPHA] SIZE [ALPHA] [0] [7] [0]
  [ ] [GTO] [·] [·]
  INSERT CARDS INTO READER
- TO RUN PROGRAMS ALREADY IN MEMORY:
  ENTER DATA INTO STORAGE REGISTERS
  [XEQ] [ALPHA] THREE [ALPHA]
- TO MAKE ROOM BY CLEARING ALL MEMORY:
  TURN CALCULATOR OFF, DEPRESS AND
  HOLD [←] WHILE TURNING CALCULATOR ON

Machine No. C-2520
Cold Alignment Data: Date 5/8/78 Time 1030 AM
Hot Alignment Data: Date 5/12/78 Time 310 PM
Comments
Machine On Line 6 Hours
3/4 Load
Discharge Temp. 280 °F

Figure 2. Calculator Worksheet for Determining Machine Movements.

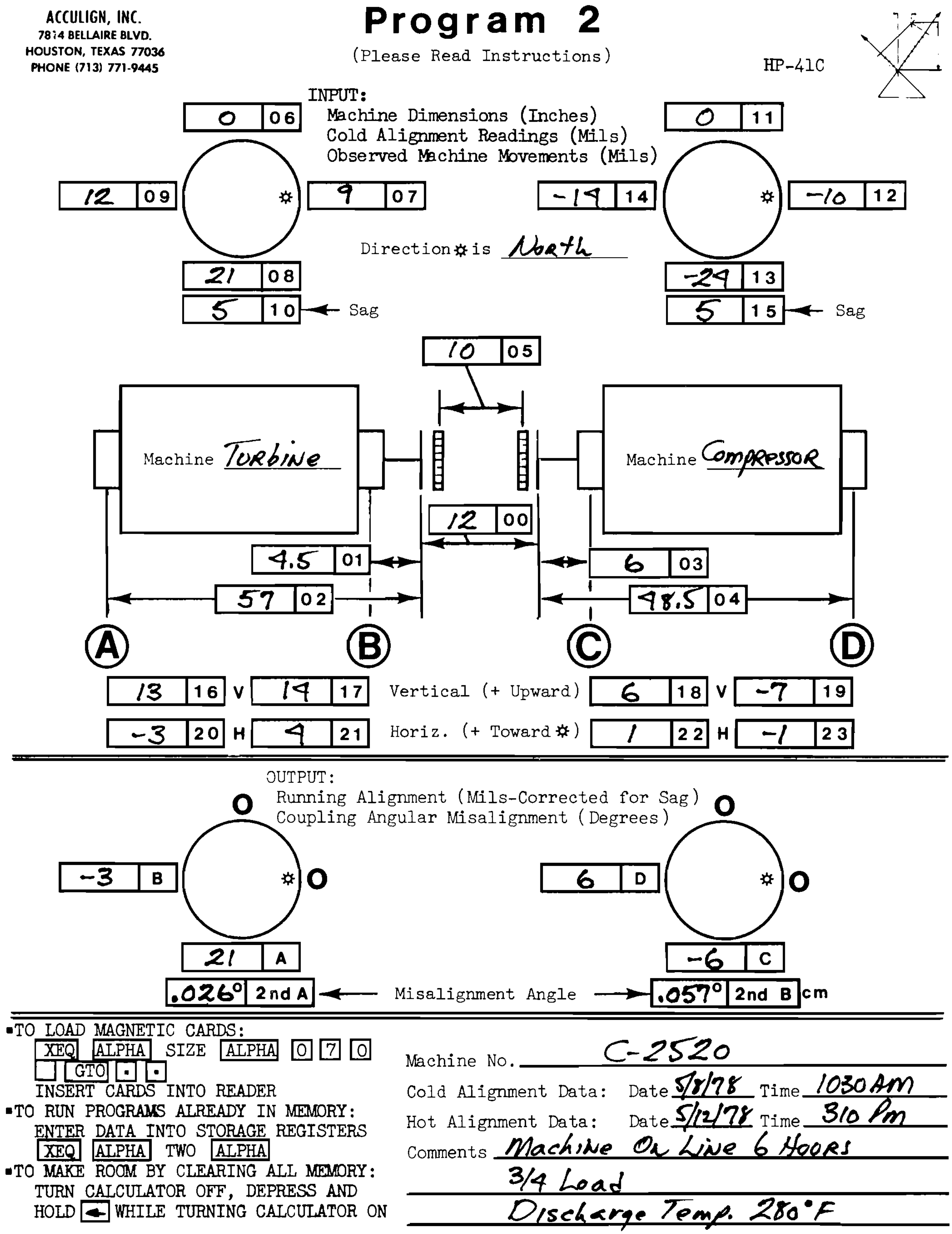


Figure 3. Worksheet Showing Running Misalignment.

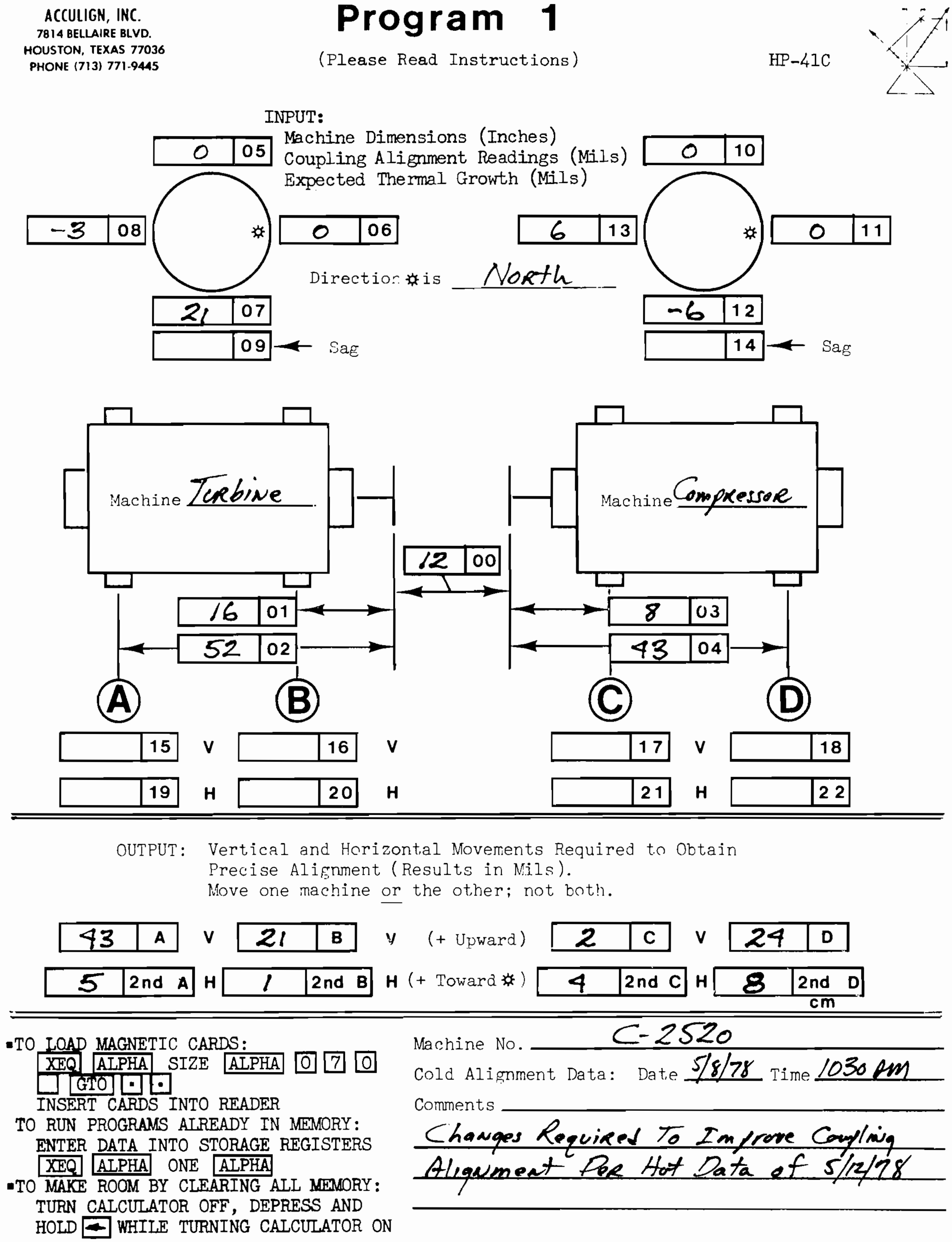


Figure 4. Machine Movements Required to Improve Alignment.

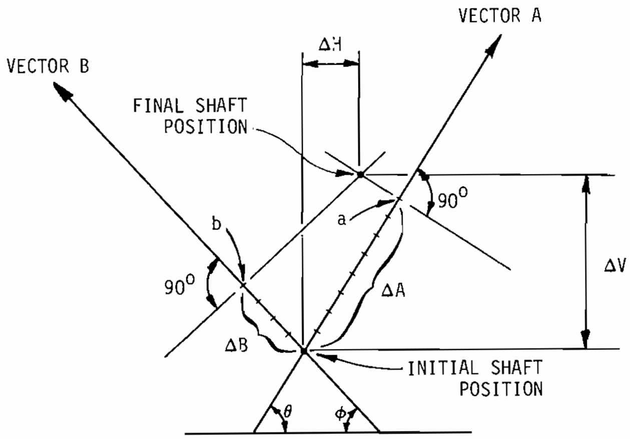


Figure 5. Graphical Determination of Shaft in Hot Position Relative to Cold Position.

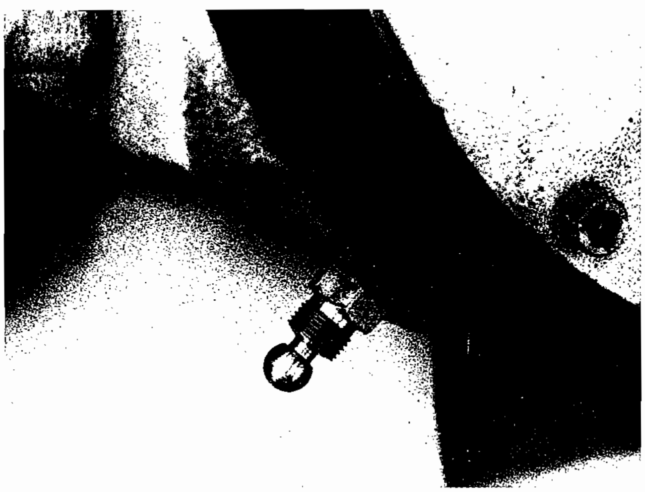


Figure 6. Stainless Steel Benchmark Mounted on Bearing Housing.

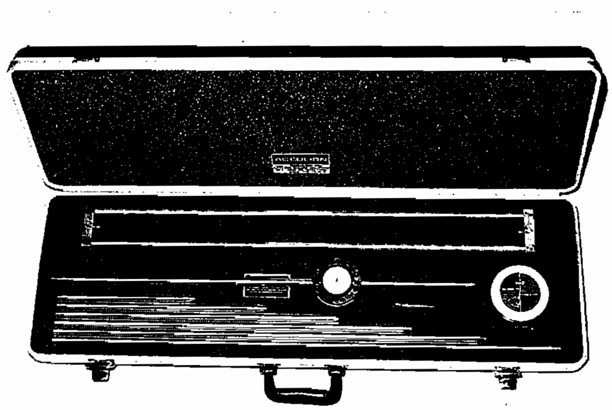


Figure 7. Benchmark Gauge Set for Turbomachinery Work.

ranges. The gauge set shown covers a range of 25-60 inches (625-1500mm in the metric version). Other sizes are also available.

To minimize measurements errors resulting from thermal changes in the benchmark gauge itself, the extensions are made of Invar, as is the 30 inch (750mm) standard which is used to "zero" the telescoping column at the time measurements are taken. Invar is an alloy having a very low coefficient of thermal expansion, the specific properties being discussed in more detail in the Appendix. Zeroing the benchmark gauge with the Invar standard is an important step in assuring the accuracy of data obtained with benchmark gauges (see Figure 8). An inclinometer is used to determine the angle at which the benchmark gauge readings are taken (Figure 9).

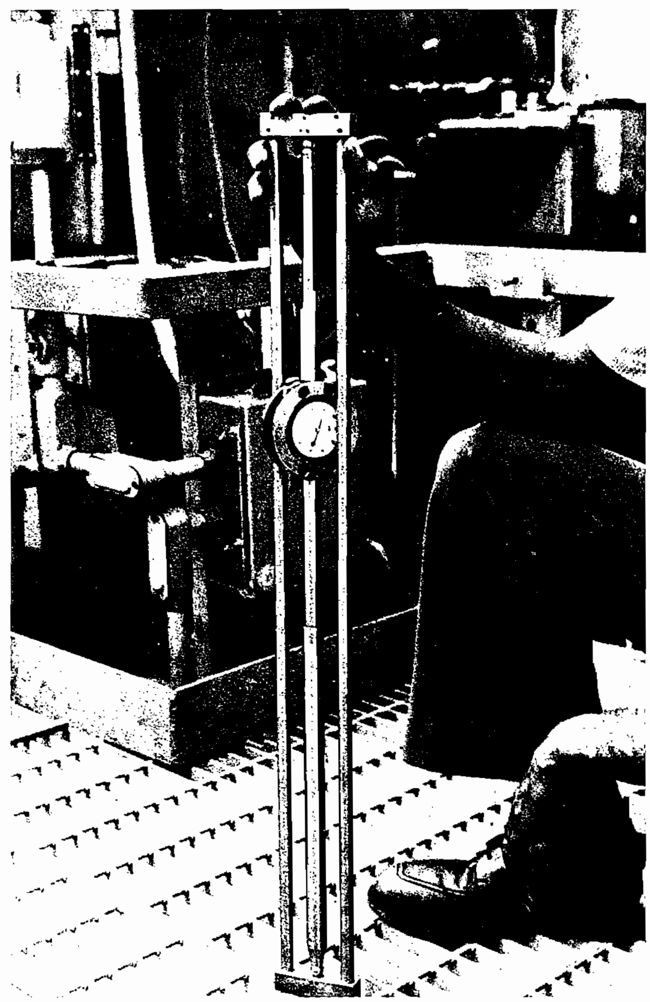


Figure 8. Zeroing the Benchmark Gauge in the Invar Standard.

A stepwise procedure for using benchmark gauges to obtain hot alignment data is as follows:

1. Affix the benchmarks to the machine and to the foundation in a manner similar to that shown in Figure 1. Try to locate the benchmarks such that the included angle between A and B is in the range of 60° to 120° (90° is ideal).
2. Align the machinery train in the normal manner [1,2].

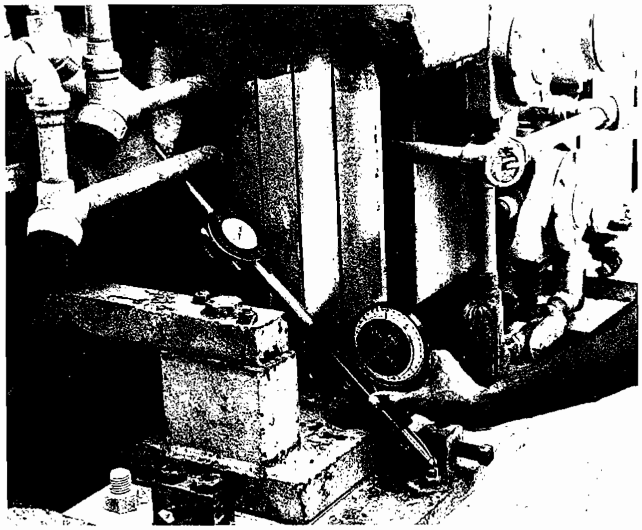


Figure 9. Using the Inclinometer to Find the Gauge Angle.

Figure 11. Gauge Placement at the Coupling End of a Centrifugal Compressor.

3. When satisfactory cold coupling alignment is achieved record coupling alignment readings and benchmark gauge data simultaneously. Simultaneous readings are important to assure the proper relationship between coupling alignment and benchmark gauge readings. Also, it is very important to use the Invar standard to zero the benchmark gauge at the jobsite. The Invar standard will change very little with ambient temperature changes; the benchmark gauge itself may change considerably. Figure 10 through 13 show typical benchmark gauge applications.
4. Determine the angles at which measurements are being made by using the inclinometer as shown in Figure 9. Record the data.
5. When the machine is brought on line, repeat the benchmark gauge readings at each location and record the data.

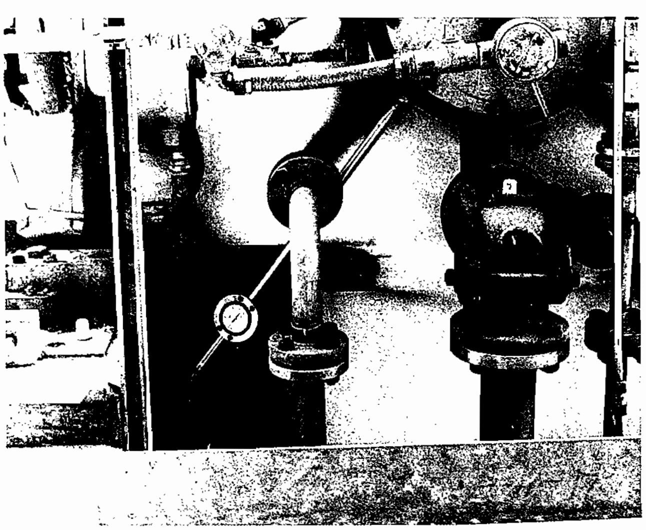


Figure 10. Benchmark Gauge at the Outboard End of a Centrifugal Compressor.

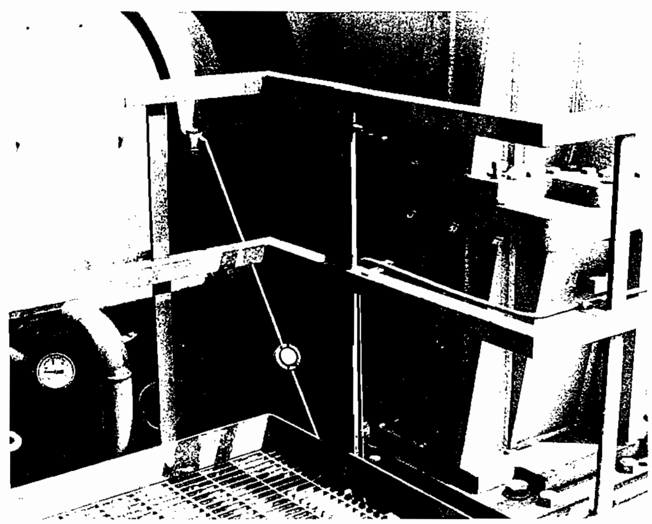


Figure 12. Coupling End of a Large Steam Turbine.

6. Determine the alignment of the couplings in the train either by using the calculator programs discussed above, or by conventional plotting of the observed movement of the components of the train.
7. Make appropriate alignment changes, if required, as indicated by the data.

Over the past ten years, this alignment technique has gained the acceptance of many users in the oil and petrochemical industries by offering the following advantages:

- The technique is simple, easily understood, and requires no special technical skills.
- Vertical and horizontal movements of the machines are obtained with equal ease.
- The benchmarks are permanent and easily maintainable for long-term monitoring. Once the benchmarks are mounted, setup time for hot checks, or re-checks, is minimal.

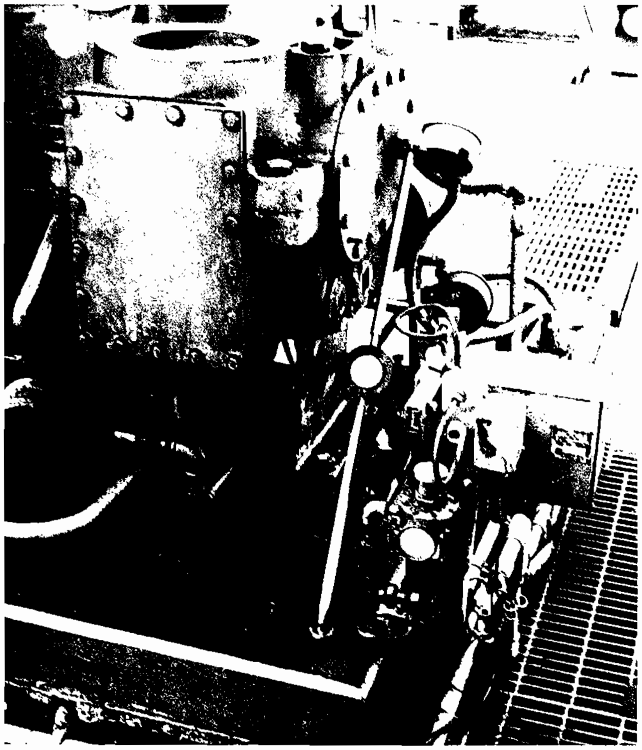


Figure 13. Outboard End of a Steam Turbine.

- Data-taking is a one-man operation.
- The tools are simple, reliable, and require minimum calibration.
- Since benchmarks are easily mounted by field personnel, the system is equally applicable to existing equipment and to new installations. Factory or shop modifications to equipment is not required.
- The method is adaptable to cramped quarters. There is sufficient flexibility in the choice of benchmark locations that interference with piping, instrumentation, or other equipment seldom presents major obstacles.
- The availability of programs for programmable calculators makes data reduction quick and accurate.
- It is a cost-effective method of obtaining reliable data.

ACKNOWLEDGMENT

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LITERATURE CITED

1. Essinger, J., "A Closer Look at Turbomachinery Alignment," *Hydrocarbon Processing*, September 1973, 52, No. 9, p. 185.
2. Jackson, C., "How to Align Barrel-Type Centrifugal Compressors," *Hydrocarbon Processing*, September 1971, 50, No. 9, p. 189.

APPENDIX

Invar is a 36% nickel alloy having a very low coefficient of thermal expansion in the temperature range of roughly −60°C to 120°C (−76°F to 248°F). Outside this range, the coefficient of thermal expansion increases, and is roughly the same as carbon steel at temperatures above about 200°C (392°F). The specific value of the coefficient of thermal expansion is greatly influenced by heat treatment and cold work of the material. Data published by The American Society for Metals (1948 Metals Handbook) lists values as high as 3.11×10^{-6} per °C for forged Invar, to as low as 0.14×10^{-6} per °C for quenched and cold drawn material. Tests by Acculign, Inc., on several heats of cold drawn material used for benchmark gauges shows an average coefficient of about 0.67×10^{-6} per °C, or about 1/17 that of carbon steel. These tests were conducted in the temperature range of −18°C to 45°C (0°F to 113°F).