

# MAINTENANCE TECHNIQUES FOR TURBOMACHINERY

by

William E. Nelson

Manager, Maintenance Services

Amoco Oil Company

Texas City, Texas



*W. E. Nelson is Manager of Maintenance Services at the Amoco Oil Company refinery in Texas City, Texas. He has been with Amoco for nineteen years in various engineering, purchasing, and maintenance assignments. "Ed" received a B.S. degree in Mechanical Engineering from Texas A&M University in 1951 and is a Registered Professional Engineer in Texas.*

## INTRODUCTION

Manufacture and maintenance of turbomachinery are completely different. The first involves shaping and assembling of various parts to required tolerances while the second involves restoration of these tolerances through a series of intelligent compromises. This is the crux of maintenance techniques—keeping the compromises intelligent. The process industry has pushed for “bigger and better” turbomachinery until operational problems have become tremendous. We are literally “snowed under” by these problems. The failure to provide adequate feedback of relevant operational troubles into the design phase is the greatest problem facing the turbomachinery industry today.

This lack of communication results in much turbomachinery designed with too little regard for the operating and maintenance complexity created. Many of our maintenance techniques are, in a word, inadequate to cope with the troubles we encounter. The mechanics in our various installations are not, in general, technically competent enough on the complexities of our equipment to adequately maintain it under unit operational pressures. The growth of contract maintenance firms has not been sufficient to fill this void. The ability of the original equipment manufacturer (OEM) to provide technical service has also frequently been inadequate. Hopefully, this symposium may light a candle in this darkness. Perhaps some of the procedures used at Amoco to combine the best of our capabilities, those of the OEM, and those of specialty service organizations to meet our problem will be of interest to others facing similar situations.

## BACKGROUND

The Amoco refinery at Texas City is fourth largest in the nation in crude capacity. Because of the severity of some of our reforming processes, generation of 60 megawatts of power, and large ammonia production, it ranks higher in complexity of equipment. Much of our equipment is less than ten years old. It is sophisticated, large, and complex. Since modern design trends toward single train equipment, we have some of the largest equipment made. The rapid growth of this refinery has

created tremendous pressures on our maintenance personnel and experience has become extremely scarce. At the present time over two-thirds of the machinist hourly personnel have under six years experience in the machinery field.

Having problems, we have been forced to find solutions. These solutions can be divided into four basic categories:

1. Training of personnel
2. Tools and equipment
3. Replacement parts
4. Reliability improvement projects

## TRAINING OF PERSONNEL

We believe that training must be the central theme to the solutions of our problems. The days of the mechanic armed with a ball-peen hammer, a screwdriver, and a crescent wrench are gone. More and more complicated maintenance tools must be placed in the hands of the mechanic and he must be trained to utilize them.

People must be trained, motivated, and directed so that they gain experience and develop, not into mechanics, but into highly capable technicians. Good training is expensive but it does yield great returns. Machinery has grown more complex, requiring more knowledge in many areas. The old traditional craft lines must yield before complicated equipment maintenance needs. A joint effort by craftsmen is necessary to accomplish this.

### *Basic Machinist Training*

To meet our problems we have embarked upon ambitious training programs. Since 1967, over 100 new machinists have completed an intensified training program involving 800 classroom hours of instruction in machinery principles and concepts. Most of this training has been developed and conducted by in-plant personnel. It has been expressly tailored to our equipment and is highly detailed. Training must be carefully planned and administered to fit the requirements of each situation. At present we have a full time training staff of two people in our maintenance division. The responsibilities of the group range across all crafts. These machinery related subjects have been covered recently:

1. Reverse Indicator Alignment Seminars (see Figure No. 1)
2. Gas Turbine Overhaul
3. Mechanical Seal Maintenance—a video-tape was developed in our corporate training group.

### *Practical Training*

After the machinist receives his fundamental training, his on-the-job experiences should continue his training and test his skills. For this reason we attempt to do

as much repair work with our own people as possible. We do not have the lathe operators or machine operators in our machine shop. Each man is rotated among various jobs to accelerate his learning and development and is as familiar with a large compressor as he is with a small pump. Over half of our shop personnel can operate a balancing machine expertly. The remainder have worked on the machine and are familiar with its operation. The spreading around of the hardest jobs develops more competent people. If we restrict a man to one type of work, he will probably become expert in that area but his curiosity, which we feel is a prime motivator, will eventually fade.

We encourage the participation of the machinist in the solution of difficult problems. This policy often causes the machinist to seek out information on his own. References to API specifications are not uncommon on our shop floor. To encourage this type of participation we have a library adjacent to the shop floor with filed drawings, written histories of the equipment, catalogs, and other literature pertinent to the machine maintenance field. The "librarian" and "editor" of the weekly summary of repair histories is an hourly-paid machinist. This job is rotated periodically to develop interest. He also alters equipment drawings and service manuals as revisions and changes are made.

#### *Update Training*

In order to pass on knowledge and to update the mechanic, unusual experiences or special techniques are written up and distributed to all machinists frequently. The ground rules of this "newspaper" limit it to two type-written pages and use of reduced size sketches and/or drawings is encouraged. This information is Xeroxed on the front and back of a single piece of paper and is distributed to all machinists who retain them in a loose-leaf binder for future reference. In addition, the machinists are given copies of all machinist-oriented issues of a similar training newsletter issued by our Engineering and Technical Division. We feel that knowledge breeds more knowledge.

#### *Manufacturer Training*

Our personnel are sent to manufacturer-conducted training sessions. As an example, a number of our people, including first-line foremen, have attended the very excellent maintenance school conducted by the manufacturer of the six gas turbines we operate. This is a very

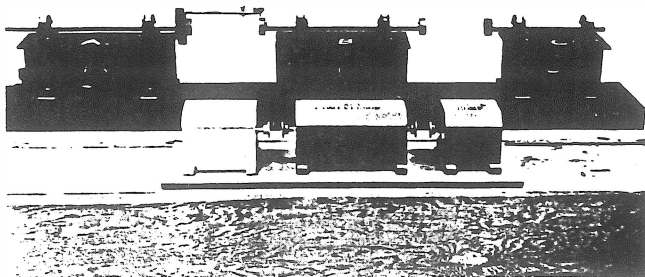


Figure 1. Models used to teach reverse indicator alignment.

effective effort on the part of the OEM to provide maintenance instruction on machinery to the customer. We would like to see more along these lines.

#### *Servicemen as Trainers*

We look upon manufacturers' servicemen as trainers. Their primary reason for being in our plant is to train our people. Because of these views, our standards for this type of work are very high. We attempt to get lasting value from their services. Unfortunately, the equipment manufacturer frequently suffers from the same problems that we have—a shortage of capable people. For this reason we attempt to train our own people as much as possible. We have one foreman who is our in-plant serviceman. He supervises no hourly personnel, but acts as a consultant to maintenance jobs. A three-man technical group devoted to turbomachinery was established in 1971 to further our internal capabilities.

#### *Instructional Books*

Manufacturers' instruction books are often inadequate. We have resorted to writing maintenance manuals for the mechanic on such subjects as mechanical seals, vertical pumps, hot-tapping machines, and more recently, gas turbines. The gas turbine overhaul manual consists of (1) step-by-step overhaul procedures developed largely from the manufacturers training school mentioned previously, (2) almost a hundred photographs illustrating the step-by-step procedures using one of our gas turbines, and (3) an arrow diagram showing the sequences of the procedures. This was bound into a book form and used as the basis for a four-hour training session to our supervisors and mechanics that combined the best of the experiences of all our people.

Detailed drawings are developed to aid in maintenance. Our first large scale effort involved a contact seal assembly which was developed after we held up the operation of our giant catalytic cracking unit because the "typical" dimensionless drawing supplied by the OEM was not adequate to correctly assemble the compressor seals. Many other assembly drawings have been developed since that first effort.

#### TOOLS AND SHOP EQUIPMENT

Many maintenance tools should be made available to the mechanic. We attempt to do as much specialized machine work as economically feasible. Figure Number 2 shows a cooling water pump being machined to replace a suction flange that was broken. Doing jobs like this keeps us technically competent enough to tackle other jobs. The catalytic cracking unit air blower turbine nozzle blocks shown in Figure Number 3 were fabricated in our shops in eight shifts because a new one could not be delivered in under three months. The "homemade" nozzles have been in service for several months with no loss of efficiency.

In-plant balancing capability is one of the most valuable tools in a petro-chemicals plant. Our 4,000-pound rotor capacity balancing machine has had a very significant effect in development of know-how. Until about six years ago, we relied entirely upon outside balancing facilities and only balanced the more critical equipment. After purchasing balancing equipment, we began to practice on equipment that we once felt did not require dynamic balancing. Vast improvement of pump seal life

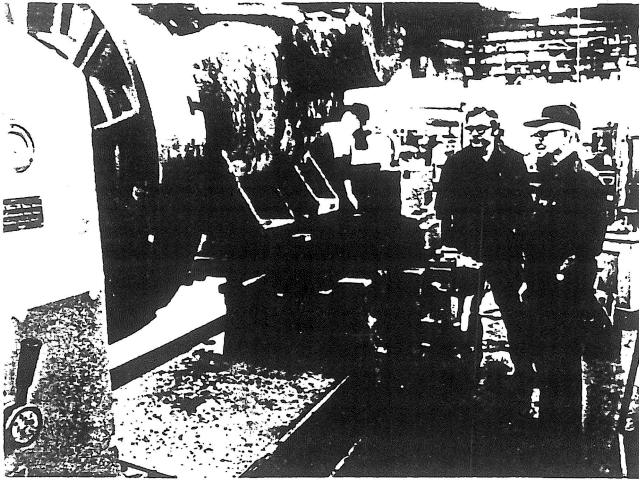


Figure 2. Versatile tools develop skills.

as well as bearing life on some of the smaller equipment was achieved. The static balance of pump impellers is woefully inadequate for long runs and reliable service. In brief, the balancing machine paid for itself in balancing pumps, motors, and small turbines that we once thought did not need dynamic balancing. The dynamic balancing of impellers of vertical pumps is especially advantageous in reducing maintenance. The long slender shafts are highly susceptible to any vibration induced by imbalance. Many problems are solved by balancing. The man familiar with the plant equipment tends to balance closer if the machine's operational history has proven to have a balance sensitive rotor, another advantage. This sparks the development of that much sought-after know-how.

Techniques to check balance gear-type couplings for the large high-speed compressor and turbine drives as a unit were developed. This led to the solving of many vibration problems. High speed couplings are routinely check-balanced now.

### SPARE PARTS

Spare parts problems are an inherent phase of the machinery maintenance business. Cost of replacement parts, long delivery times, and quality are problems everyone has faced. Amoco, at Texas City, undertook to combat this problem by forming a spare parts group to consolidate the spare parts activities for its expanding refinery on a company-wide basis. We believe in stocking spare parts; our present inventory is over 16,000 items, including 75 complete rotors. Dollar value runs into many millions. The field of spare parts is changing very rapidly and is much more complex than in the past. Many pieces of equipment on process units are made up of unitized components from several different vendors. The traditional attitude has been to look to the packaging vendor as a source of supply. Many vendors are refusing to handle requests for replacement parts on equipment not directly manufactured by them. More and more specialty companies are entering the equipment parts business. Some are supplying parts directly to OEM companies for resale as their "own" brand. Others are supplying parts directly to the end user. The primary function of our spare parts group is to develop

multiple sources of supply for as many parts as possible. Gaskets, turbine carbon packing, and mechanical seal parts are purchased from local sources almost entirely. Shafts, sleeves, and cast parts such as impellers are becoming increasingly available from local sources.

We have found some OEM's are altering their spare parts system to improve service due to this local competition, definitely a bright spot in the picture.

### MACHINERY RELIABILITY IMPROVEMENT

High maintenance costs and low operating reliability go hand in hand. Usually the low reliability is a greater economic factor than the high maintenance costs. Almost one-third of the unscheduled (and costly) shutdowns in our refinery are caused by machinery failures. Machine "revamps" and alterations have been necessary to improve reliability. A brief discussion of some of the benefits of our training, spare parts program, and our major asset—people.

#### Governor Redesigns

Due to a long history of failures and poor performance with our four process gas turbine governor control systems, we undertook to redesign these systems using state-of-the-art electronics and "plug-in" concepts for ease of maintenance. The first system, dubbed "Turbotronic," was installed in 1969. Since that time two other gas turbines have been converted. All of these installations have been highly successful in that maintenance has been minimal and is usually accomplished on-stream. Also, turbine performance, speed control, and flexibility are greatly improved. The original design has been supplemented to include a self-contained alarm system, a semi-automatic sequential start system, and a complete trip and protection system as well as the electronic controls. Our cost of this system is considerably less than the cost of a similar device offered by the OEM on new machines. The controls for the fourth and final conversion are due for installation in late 1973. The original installation will be dismantled and an updated version installed at the same time. Total horsepower involved is almost 80,000.

With these successful installations, we turned to steam turbines. A compressor drive on our most vital

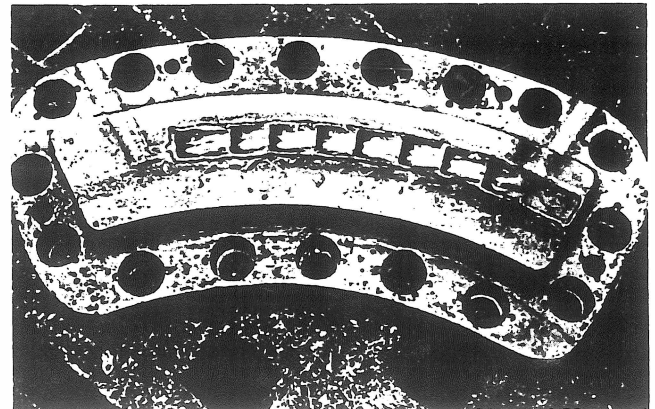


Figure 3. Shop-made nozzle block in semi-finished condition.

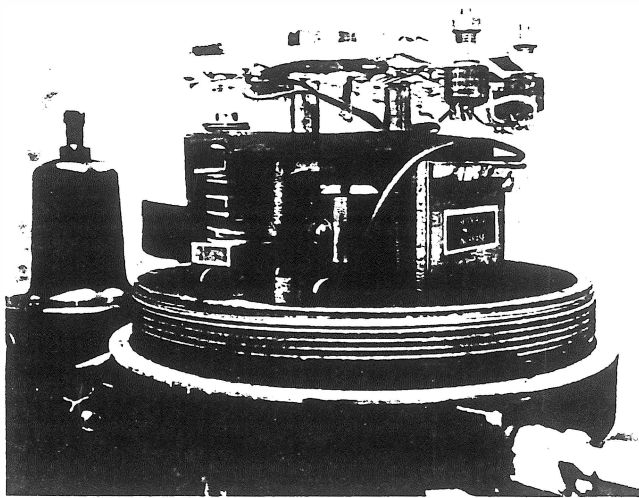


Figure 4. Electronic governor for small single valve turbines.

process unit had been plagued by governor drive reduction gear problems. The turbine speed (approximately 9,000 rpm) was reduced for governor drive via a three-shaft gear train. Vibration induced by the poor design limited the maximum run to about three months. The Woodward governor and the gearing were removed and our own electronic governor installed. This governor was built, installed, and test run in four days. Since the installation in May 1971, vibration has been minimal and governor performance has been excellent.

To date eight more multi-stage steam turbines driving process compressors with a total horsepower of 58,000 have been converted. These electronic governor installations again are less expensive and more effective (in our opinion) than any commercially available product. A miniature ("Minitronic") system for single-stage, lower horsepower, mechanical-drive turbines that were in critical service but had unreliable governors has been developed. Nine of this design (Figure Number 4) have been installed. Cost of this design is less than that of a quality self-contained governor.

Application of these systems to an existing machine is not difficult. A pneumatic actuator is coupled to the pilot or directly to the governor valve.

Design and construction of these twenty-three conversions has been done with plant personnel. Patent applications are pending on various portions of all these designs.

#### Bearing Conversion

Bearing failures rank high as causes of rotating equipment failures but bearing design has lagged behind as rotational speeds have risen. Parameters for bearing design are well defined by Herbage<sup>1</sup> and Abramovitz<sup>2</sup>. It has been demonstrated that the reliability of rotating equipment can be increased through the use of bearing design improvement. Design modifications fall into three major types:

1. The changing of tapered land thrust bearings to tilting pad thrust bearings with leveling links: Experience—ours and others (3 & 4)—indicates that for equal

areas, improvements in load-carrying capability can be achieved. Sudden load surges and liquid slugs will occur. Thrust bearings which do not have the ability to absorb such loads will fail; therefore, we feel we should have the maximum possible thrust capacity.

2. Changing radial bearings from cylindrical and/or pressure pad babbitted sleeve type to tilting pad journals: This improves rotor stability, eliminates chances of oil whirl, and improves survival of journal bearings under rotor imbalance and during critical speed dwells. Present state-of-the-art indicates that the tilting pad journal is generally the best in journal design because of self-stabilizing characteristics.

3. A material change of tilting pad journals and thrust bearings: These type bearings are generally supplied with steel-backed babbitted pads. Changing to copper alloy-backed, thin-babbitted pads conducts heat away from the babbitted surface at a faster rate than the steel-backed shoes, improving load-carrying capacity. Literature (3 & 4) and experience indicates that a 50 to 100% load-carrying improvement can be obtained.

Over 150,000 horsepower has been converted since late 1969. Two dozen more machines have been recommended for conversion. We do not believe we should wait for a failure before deciding to change because of the process penalties resulting from a bearing failure. The conversions have been done using the services of some of the best bearing specialists in the country. Amoco participates in the fundamental design by supplying basic dimensions and some machine peculiarities. One equipment manufacturer has begun to offer bearing upgrading "kits" for the machines already in service. Again a bright spot in the overall picture.

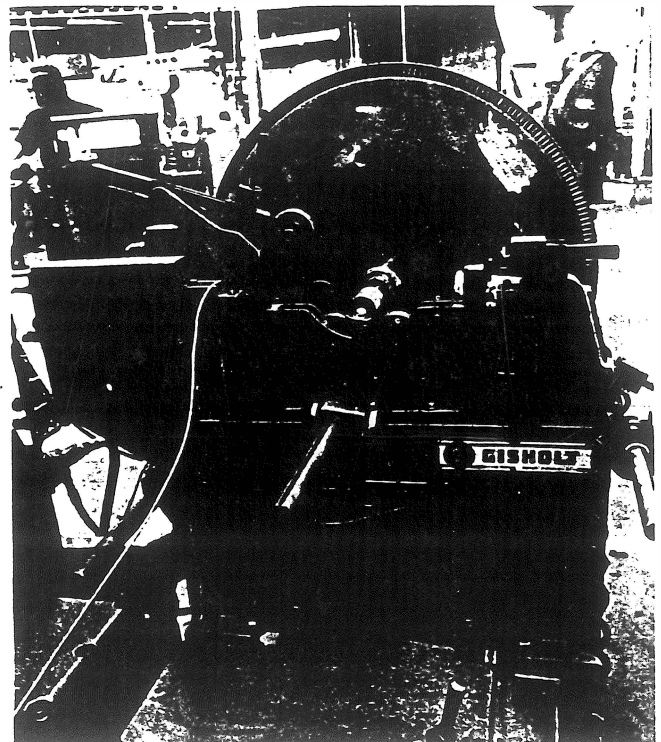


Figure 5. Turbine wheel being balanced on a mandrel before restacking rotor.

### *Rotor Redesigns*

We have found that many steam turbines of stacked rotor design are built by the manufacturer with substantial imbalance couples. It has proved advantageous in many instances to unstack a rotor, individually balance each wheel, and then progressively balance the rotor as it is reassembled, the way most experts agree it should be done. Many machines, once highly sensitive to vibration, have been made more reliable by this technique. In addition, the shrink of the wheels on the shaft provided by the manufacturer often proves to be inadequate for the steam operating temperatures. This allows the wheels to move on the shaft. Shafts have been redesigned to provide locking rings for each wheel.

The wheel in Figure Number 5 is part of a 2,000-hp., 5,000-rpm, eleven-wheel steam turbine that has been remanufactured to more exacting standards than original. Six machines of one make have been remanufactured to date. Continual improvement and updating of our machinery is necessary to maintain long runs. We can no longer "fix like we did that last time" but must continually strive for newer, better ways to make repairs. The machinist is often called upon more frequently to make revisions than he is to "fix" a machine.

### CONCLUSION

There are no simple solutions to the maintenance difficulties we face. The principal ingredients of successful turbomachinery maintenance are training, equipment,

parts, and people (both hourly and technical). These factors must be coupled with a determined management if we are to move ahead and find solutions to these problems. Our experience has been that each of the four areas contributes to our solutions. All are necessary.

Today's process industry cannot be dependent upon any one source for solutions to its troubles. Original equipment manufacturers, contract service shops, contract maintenance companies, and specialty companies can only supplement the basic skills that must be developed within our own organizations.

### REFERENCES

1. Abramovitz, Stanley, "Fluid Film Bearing Design Consideration." Presented at Turbomachinery Symposium, Texas A&M, 1972.
2. Herbage, Bernard, "High Speed Journal and Thrust Bearing Design." Presented at Turbomachinery Symposium, Texas A&M, 1972.
3. Sohre, J. A., "Reliability-Evaluation for Trouble-Shooting of High-Speed Turbomachinery." Presented at the 1970 ASME Petroleum Mechanical Engineering Conference, Denver, Colorado.
4. Sohre, J. A., "Operating Problems with High-Speed Turbomachinery, Causes, and Correction." Presented at the 23rd Annual Petroleum Mechanical Engineering Conference, September 23, 1968, Dallas, Texas. Revised version, November 15, 1968.