MAGNETISM IN TURBOMACHINERY

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SCOPE OF MAGNETISM

An understanding of simple forms of magnetism is illustrated in Figure 1. In Figure 1A, the source of magnetism is shown to consist of a magnetically hard component containing a magnetic residual source coupled with soft magnetic parts which carry the field to an air gap. In turbomachinery this gap would be an oil film in a bearing or seal. The magnetism source could also be from an electric current passing around a soft steel part as shown in Figure 1B. In order to obtain a field similar to that caused by the residual source of Figure 1A, the current "I" must be a direct current. This current can originate from some external source or it can occur because of internal currents of an electromagnetic or electrostatic nature. If this current is alternating in nature, then the field in the air gap is alternating. An alternating field can also be produced if the air gap should change due to mechanical motions or vibration by affecting an otherwise direct field. This condition may exist in the situation as shown in Figure 1C.

Magnetic fields and currents exist almost everywhere in various amounts; however, a combination of factors has made them particularly damaging to turbomachinery. Specifically, there have been frosting, spark track damage, and even welding on shaft journals and collars. Coupling and gear teeth have become pitted and welded. The critical factors found in turbomachinery attendent with this damage are: 1) high operating speed; 2) large steel cross sections in casings, piping, etc; 3) a source of magnetism, either electromagnetic or residual; 4) extremely close running gaps; and 5) in the case of sudden or disastrous events, an upsetting incident. This latter can consist of compressor surge, high vibration, temporary loss of lubrication or shock, to mention a few.

Methods to reduce damaging currents have been under investigation in recent years. Many of these are well-known in the industry and others are being developed for the special situation of turbocompressors. Simply stated they consist of either removing damaging magnetic fields or impeding the conductivity of the current path in the affected component.

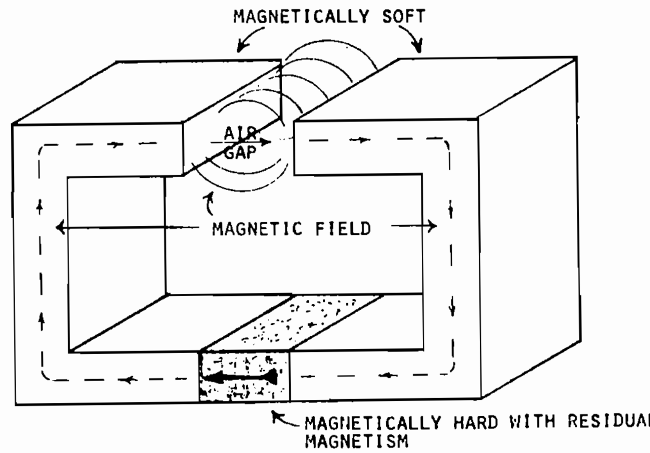

FIGURE 1 A

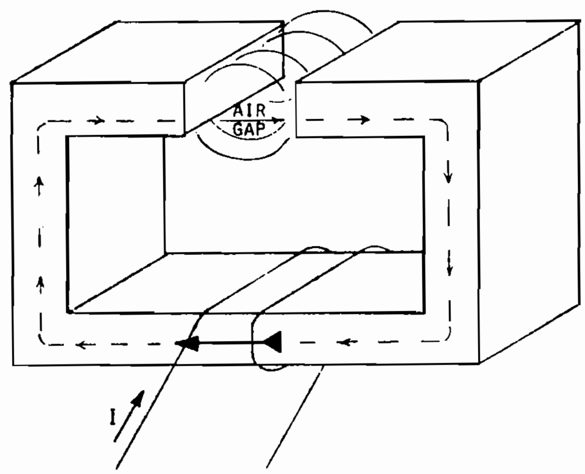

FIGURE 1 B

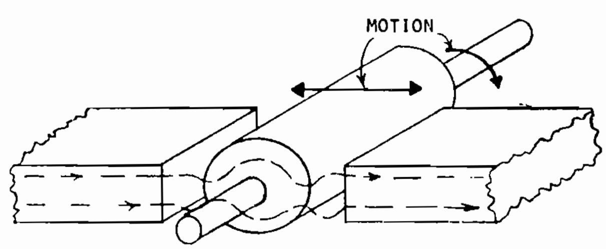

FIGURE 1 C

Figure 1. Simple Magnetic Circuits.

One straightforward measure is to demagnetize components and structures to remove residual magnetism which may produce damaging fields. This will be discussed later with respect to effective cycling demagnetization.

Another method is to reduce the magnetic field by insertion of non-magnetic components in critical magnetic flow paths.

A third method to reduce residual magnetism is to raise the temperature of the components to above the Curie temperature and hold it there until all the magnetic dipoles have been normalized to a non-magnetic state. This is not usually possible with precision machinery.

With respect to damaging currents, these have been reduced or eliminated as a factor in electrical machinery by placing insulation at the bearing housing or pedestal, and maintaining it in an insulated state to block current conduction through the bearing. For various reasons, such as system dynamics, the high temperature of operation and other factors, it cannot be applied as easily to turbomachinery. Methods are being employed at this time; however, their effectiveness has yet to be determined. Insulation, which may be effective in reducing currents, may not reduce through magnetic flux to the shaft unless unusually thick insulation is used. This through flux may generate localized currents in the bearing-journal interface.

A property of magnetic fields in turbomachinery, not fully understood but continuing under investigation, is the restoration of magnetic fields in previously demagnetized components. In some instances a component has had its apparent external field reduced. Then after some period of time, possibly associated with mechanical or thermal cycling, the field tends to be restored to its previous value, or some portion thereof. It is believed that this occurs through one of two mechanisms. The first is that apparent demagnetization occurred not to the true source, but resulted from inducing magnetism in a soft magnetic field zone which opposed that in the original hard zone, giving the surface the appearance of reduced magnetism. Shortly thereafter the magnetism on the soft zone disappeared and the original hard magnetism projected through.

Another possible cause lies in the fact that magnetism, which is depicted as a form of oriented electron spin and rotation, may be reduced temporarily by altering the electron spins and rotation. Presumably there is an overpowering internal atomic force to restore these to their original conditions. Thus, after some period of time or after "seasoning" effects have occurred, there is a tendency toward original field restoration. This may occur because the demagnetizing field did not line up in the axis of the residual field and/or the demagnetizing field has insufficient demagnetizing strength.

Some testing has been conducted on a 4340 steel shaft wherein extremely high fields, induced through magnetic particle inspection and exceeding 500 gauss, oriented axially when in the open air condition. This unit was demagnetized by automatic cycling utilizing cross-demagnetization to a level below 12 gauss at each end, with levels below 2 gauss in the journal and other shaft areas. After being transported a distance of some 100 miles and after a period of two weeks in a non-magnetizing environment the fields were again measured and were found to be 50 to 60 gauss at these same locations. Reapplication of cycling demagnetization reduced the fields once again to the 10 to 11 gauss level at the extremities. Following this demagnetization, there was no reoccurrence or reappearance of the original strong field. Demagnetization fields were oriented perpendicular to the measured residual field intentionally. Additional testing over a period of time is required to provide scientific proof of this condition.

THE EXTENT OF MAGNETISM FOUND IN TURBOMACHINERY

The primary concern in turbomachinery is the damage from currents which are generated by magnetism. Because of this, three classifications have been assigned to components based on their critical nature. Maximum allowable magnetic field levels for the three classifications are:

A. Three gauss or lower for bearings, seals, journals, collars, gears and other oil film surfaces.

B. Six gauss or lower for all other portions of bearings, seals, journals, collars and gears.

C. Eight gauss or less for casings, pipes, etc., remote from the oil film surfaces.

Levels are for components in a fully disassembled state in free air as measured by a calibrated Hall probe instrument.

These values are acceptable as consistent unipolar and possibly dipolar magnetization. Multipoles, even within these levels, may still give problems, so it is wise to remove the poling effects. Larger fields are sometimes permitted where it is clear that they will not cause destructive currents and where there is limited downtime or excessive cost of demagnetization. Obviously, this does represent a certain risk.

Unfortunately, it is necessary to evaluate the magnetic fields in a disassembled state. It is in the assembled state that the highest levels of magnetism occur providing capabilities of generating damaging currents. Fully satisfactory methods of measuring such internal fields have yet to be developed.

An interim measure, developed by John Sohre and recommended for turbomachinery users, is to monitor the alternating field levels at partings of casings and bearing housings while the unit is running utilizing an ordinary telephone pickup and tape recorder unit. Numerous analyses have been made of such tapes with respect to magnetic field frequencies and strengths; however, no positive relationship has yet been found with respect to bearing damage. Still, there is the obvious condition where an increase in magnetic field is expected to manifest itself as a higher recorded level of audio frequency noise. Efforts are also being made to relate static and other type audio noise disturbances as being related to current discharge through an oil film or a similar interface within the unit. While it is not possible to measure current discharge at the time this noise occurs on the tape, it may be possible to evaluate in the laboratory if it is reasonable to expect that such a condition does occur.

The three different classifications listed above are covered here with respect to residual fields found on measured components prior to demagnetization in the open air.

Critical Components

These may be considered to be those which experience damage from currents either of a gradual or sudden nature requiring shutdown of the train. First and foremost among these are bearing pads, sleeves and seals. Obviously, when these are non-magnetic, only the earth's field strength can be measured on the free, open-air unit. Even when these are made of magnetic material, fields are generally low, indicating that they are usually a conduit for either the magnetic field or electric current. In some instances, hardened buttons or rockers produce high field levels, sometimes in the range of 15 to 20 gauss; however, in absence of these type items, the pads rarely have fields in excess of 6 gauss. Current damage can occur on non-magnetic components as readily as on magnetic components, as is indicated from spark tracks and frosting noted on bronze bearing pads as well as aluminum bearings.

An example of damage to an aluminum bearing sleeve can be noted by viewing Figures 2, 3, and 4. In addition, bearing currents are not confined to turbomachinery and have been found on ball and roller bearings as well. An example of this is shown on Figure 5 which is a 60X magnified view of a tapered roller bearing used in a thrust application on a 1200 RPM shaft. Damage occurs in lines rather than in random discharge pattens noted on bearing pads and sleeves. This would indicate that a timing of the race and ball rotation is critical to when the current flows.

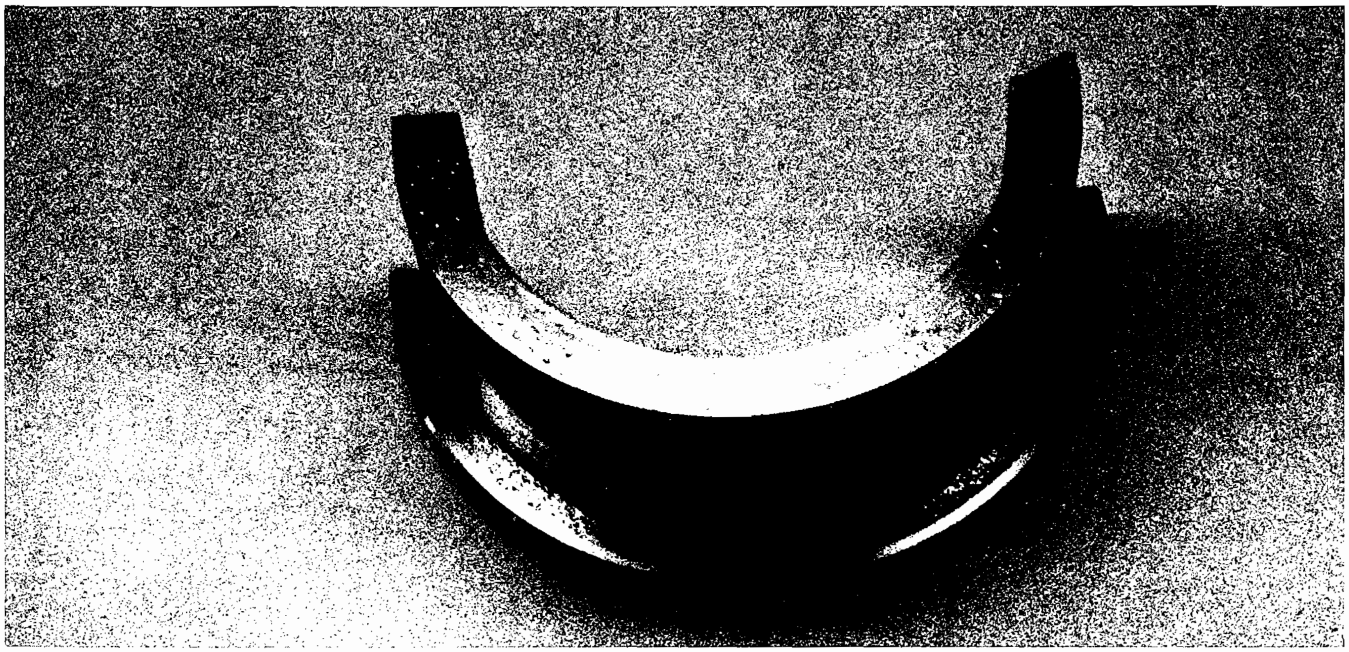

Figure 2. Aluminum Bearing Sleeve — Electric Current Erosion on Collar.

Figure 3. 60X Magnification of Collar Electric Current Erosion of Figure 2.

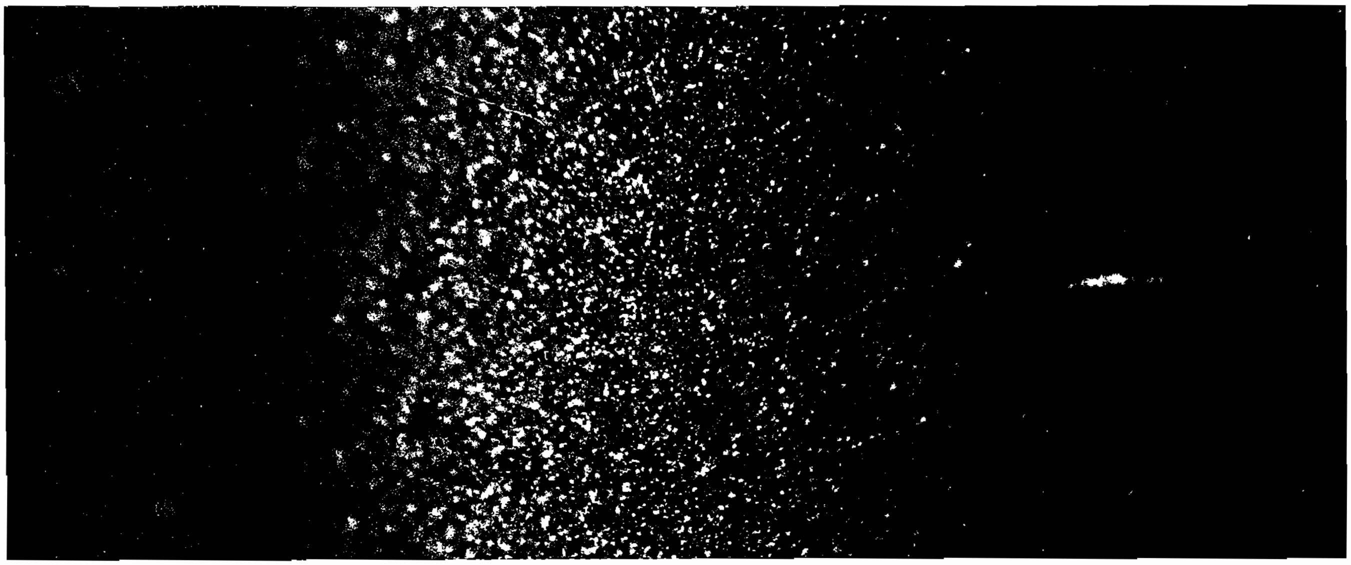

Figure 4. 60X Magnification of Electric Current Spark Track in the Bearing Load Area of Figure 2.

Other critical components are the mating parts for those mentioned above, namely the shaft journal and seal areas as well as thrust collars. The shaft journals have rarely been found to have field levels in excess of 10 gauss; however, high through shaft fields have been found. Sometimes an occasional highly magnetic local spot in the range of 15 to 20 gauss appears as if someone put a magnetic clamp or similar device onto the shaft. The thrust collar, on the other hand, is often machined on a magnetic chuck and may show very strong regions of alternately north and south poles across its face. This magnetism must be removed, otherwise a strong set of local eddy currents occurs.

Couplings and gears are also critical items. These were found to have field strengths varying up to 50 gauss. Usually high fields in these items have resulted from lack of proper demagnetization following magnetic particle inspection testing or from the use of magnetic chucks during machining.

Primary Components

These are areas which may originate or focus magnetism causing magnetic currents to flow resulting in damage to components of the "crtiical" category mentioned above. Shafts have been found to have the greatest potential for conducting magnetism and retaining high residual levels. These are usually high alloy steel with an accompanying hard magnetism capable of high residual energy storage. The ability of shafts to retain magnetism has been very apparent. Some which have been magnetic particle inspection tested retained levels as high as 30 gauss even though they were supposedly demagnetized. Also, shafts have been found to have high residual magnetism after having operated for some period of time, even though they were reportedly installed in a demagnetized state. Where there has been a sudden crash accompanied by excessive bearing currents, shafts have always been found to have high levels of residual magnetism, usually oriented axially. Magnetic fields have reached hundreds of gauss in the open air, the highest levels being located at the corners at the very ends of the shaft.

Also in this classification are items mounted on the shaft, such as wheels, blades, and shrouds, all of which may carry through the character of the shaft magnetism or which may show an individual-type magnetism having various magnetic polarities and strengths as if these had been magnetized during earlier inspection or machining. Magnetic fields on these items reach 25 to 30 gauss in the open air condition.

Similar to the shaft-mounted components with respect to residual magnetism are the nozzle rings, diaphragms and other interstage elements. These are usually of a high alloy steel and are often found to have very high levels of magnetism in the open air reaching up into the 50 gauss range. While they sometimes carry the character of the casing in which they are mounted, more often these have fields circumferentially oriented and occasionally have poles around the circumference especially indicative of testing or machining with magnetic chucks. Usually these elements are in halves and placing them together produces an extreme field at the parting.

Also in the "primary" classification are the seal and bearing housings. These generally have low residual fields since they are usually of a mild steel; however, this is not always the case, so they may require demagnetizing. They constitute a significant conduit for through current or flux from the casing into the bearing pads, seals and thrust units.

Finally, the main casing and appendages to this main casing are considered. These almost always provide a through conduit for magnetizing fields and may have residual field retention as well. Magnetic fields have been found to reach as high as 25 gauss in casings, especially at the corners, and on dowels or bolts. These may focus the casing fields and, along with their own residual magnetism, can register fields upwards of 100 gauss. These latter fields can usually be demagnetized locally without difficulty. Sometimes the casings and the bearing housing partings have experienced current arcing damage. Since this does not require a shutdown it is not regarded as a critical damage. This has been observed in several instances, particularly on the turbine casing.

Secondary Components

Next are the areas considered to be "secondary". These are areas which are conduits or remote sources for residual magnetism. These include the bases on which the train is mounted, plus the structural steel and supports, as well as piping and the interconnected valves, heat exchanger and other items which constitute a magnetically coupled system. These items will probably not experience damage, but their role can be most instrumental in producing or supporting

Figure 5. 60X Magnification of Electric Current Frosting on a Tapered Roller Bearing.

troublesome magnetic fields. It is rare that the magnetism in these elements, when disassembled and laid out as individual pieces, can be detected in any great amount. Still, in an assembled state, they have the potential of creating a very high field. Residual magnetism is usually produced within these elements through welding, either directly on them or where welding current flows to ground through them or as enclosed by a magnetic loop. This latter may occur when the welder has pulled the welding electrode cable through a closed magnetic loop of which the compressor train is one of the components and when the ground return current path is through the structure to the ground electrode outside this loop. In either of these cases, the exact source of magnetism cannot easily be located and it is necessary to measure the field when the compressor and its structure and piping interconnections are made in the fully assembled or a semi-assembled state. A proper demagnetized train requires checking the field and demagnetizing as the final assembly is being made. This is in addition to individual component demagnetization, which has already been covered. Magnetism found in piping and around structures varies considerably. Levels can be as high as 100 gauss. To make these measurements requires a certain degree of skill with regard to locating the magnetic path, which in the fully assembled state will produce very high magnetic fields.

PRESENT STATE OF THE ART OF DEMAGNETIZING

Over the past few years many firms have utilized all of the various types of demagnetizing equipment to be discussed here. First, there are the low voltage, high current units. These include magnetic particle inspection power supplies, direct current welder and DC generators, usually as a part of an M-G set. All utilize a heavy single conductor insulated cable usually 2/0 or 4/0 in size. Because of the large cable diameter, they are very stiff and are extremely difficult to position or to coil around the suspected residual magnetic source. Major problems exist with respect to polarity reversal and the limited range of current steps. Because of the high current involved it is not practical to have an automatic reversing switch in order to change polarity, a necessary feature for proper down cycling and demagnetization. Furthermore, equipment which requires very small steps at the bottom to remove residual, especially in closed magnetic loops or minor configurations, usually cannot be obtained with this equipment. Thus a certain amount of residual may remain in the equipment.

There is one advantage to the high current, low voltage source, in that current can be passed directly through the components. While this has a theoretical advantage, there are many practical and ultimate drawbacks in doing this. Some units have been demagnetized by passing thousands of amperes through the center of the shaft, alternately reducing these down to hundreds of amperes with very successful demagnetization of all full ring components. However, on segmented shrouds, or where discontinuities occurred in casings such as inlet and outlet piping or feet, there developed quite strong north and south polarities at the edges of the discontinuities. This is a magnetic condition which under certain circumstances could result in magnetic current problems.

Next to be considered is a common coil in a circular or rectangular shape utilizing alternating current as a source. This coil can be either a high voltage, low current coil of the conventional type, or it could be low voltage, high current coil. These coils fed from an AC source are very successful in demagnetizing thin wall components such as bearing housings, pads, sleeves, coupling components, bolts, nuts, etc. However, when the steel section exceeds a half inch in thickness and certainly when it exceeds one inch, the lack of penetration of the alternating field into the component prevents soaking in of the 60 Hertz cycling field. Often what is believed to have been demagnetized, has not, and strong internal fields continue to exist. Also with the AC supply, when the current to the coil is interrupted there is a good probability that high residual fields are induced. On the other hand, removal of the component from the field gradually, or a gradual reduction of the AC field through reduction of its voltage supply will downcycle the field and proper demagnetizing will occur in thin walled elements.

A demagnetizer which has been used because of its portability and suitability for placing of the coil, is the hand-held variable current unit. This has been used successfully by skilled operators in reducing magnetism of components and assembled parts. It has the advantage of having a light cable, approximately 5/16 inch in diameter, which can be placed into or around most areas requiring demagnetization. It operates from a 120 volt AC source. Unfortunately, its ground fault protection is not completely adequate. If there is improper polarity of wiring, it can result in the operator receiving a 120V shock and its ground fault tripping becomes inoperable. Furthermore, its components are undersized for the duty, such that they have to be replaced after two or three demagnetizing tasks. Use of this equipment can give a false sense of security in that a bucking-type field can be obtained giving the impression that full demagnetization has occurred, a situation which an unskilled operator might experience.

Developed to replace the hand-operated variable current unit is the Auto-Demag equipment, Figure 6. The small diameter multi-turn coil is used and therefore, one can place the coil in otherwise inaccessible areas. Furthermore, the Auto-Demag has programmed cycling with polarity reversal. By following the detailed instruction supplied with this equipment, a technician should be able to position the demagnetizing coil such that automatic cycling of the equipment should reduce residual magnetism in a satisfactory manner. If for some reason a trial location and cycling event did not succeed in reducing the field, other coil positioning or cycling conditions may be tried until demagnetizing has succeeded. The equipment has a hand operated variable current mode; however, it is recommended that this not be used except to determine initial settings for the automatic phase or for placing a bucking field into a piece of equipment with the full understanding that this does not constitute proper demagnetization but is a stop gap measure from the point of expediency and that a certain amount of risk is involved in leaving the equipment in this state.

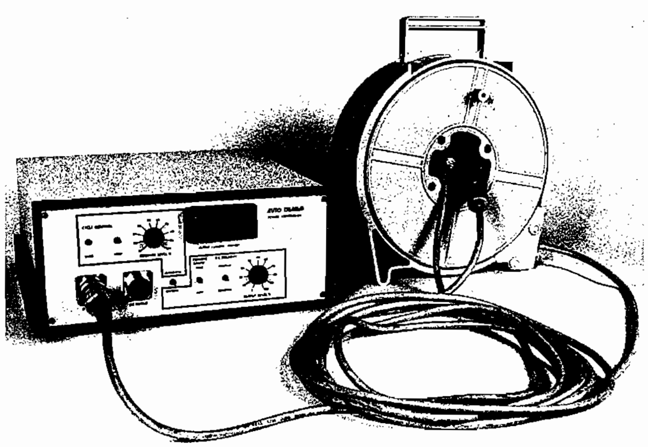

Figure 6. Auto-Demag Demagnetizing Equipment.

CONTROLLING MAGNETISM AND SHAFT CURRENTS

As was stated earlier, the effects of magnetism can be suddenly disastrous or gradual to the point where a decision to shut down may have to be made. With respect to the former, the event is usually unannouced and unexpected and there is severe damage to the shaft, bearings, and the seals. A very high level of residual magnetic field is found in the damaged unit. No method can be proposed to assure control or limitation of this event.

On the other hand, the gradual build-up of magnetic effects are determined either by the phone pick-up with tape recorder measurements being made at selected locations, or by the level of brush current determined from a reliable shaft-mounted brush such as that developed by Mr. Sohre. A very positive indicative, though not necessarily caused by currents, is a change in shaft position, either dropping at the journal pads or moving axially towards the thrust bearing loaded position. One further positive determination for gradual deterioration is the extent of damage to the bearings and seals, as well as couplings and gears, at each time of disassembly where, at equal intervals, the extent of damage is increased. It is important, in all of these events, that the degree of damage and the level of fields as well as the phone pick-up recording be well documented and maintained in files for later comparison in evaluation of the condition of equipment. This will then provide a decision point for action. In any case, once magnetism is determined to be high utilizing a reliable gaussmeter with a Hall probe, then the need for demagnetizing is clear. Following this, efforts should be made to maintain the equipment in a demagnetized state. Some of the suggestions which may be put into action are given below.

Existing Installations

For the many units now installed and being manufactured, the prospect of residual magnetism causing problems is very real. Units should be maintained in a demagnetized state. Every effort should then be made to control and prevent remagnetization. These include:

- All components, upon receipt following purchase, repair or testing, should be entirely free of residual magnetism.
- Thorough deep soaked demagnetization should be conducted on any component following magnetic particle inspection or that is discovered to have high levels of magnetic fields.
- Welding on the compressor, turbine or its piping should be controlled very carefully. The ground clamp and the weld rod electrode cables should both be strung along the same path to the work area. Then the ground clamp should be connected to the same metal piece that is to be welded.
- All components should have ground straps interconnected to the structure or station ground grid. The ground grid should have a ground resistance of less than three ohms. Also, lightning rods and other tall structures should have cables firmly interconnected to the ground grid. They further must be routed so they are not near, nor do they link, magnetic circuits such as closed loop piping between the compressor or turbine to heat exchangers, condensors, boilers, etc. The goal is to provide a low impedence discharge path for the atmospheric discharge current, but in such a way that component magnetization cannot occur.
- Apply reliable brushes to the shafts to drain away any electrostatic charge and to shunt persistent electromagnetic currents around bearing and seal surfaces. Brushes must be continuously conducting. This may require the use of a properly designed wire bristle brush. Close initial monitoring of the brush currents and voltages is necessary to insure that there is no

compounding of magnetic fields due to the internal current paths. If this occurs, then brushes should be removed until components are demagnetized and there is assurance that remagnetizing currents are arrested.

Future Installation

Remagnetization and occurrence of bearing damage is expected to continue unless significant measures are taken to correct the problems. Some of these which must be considered are:

- Insulation of all bearings, seals, couplings, and other components through which damaging currents now flow.
- Installation of permanent brushes to shunt currents around the affected components.
- Selection of materials for the equipment which are magnetically soft rather than magnetically hard.
- Installation of coils in units at the time of original manufacture which can be used to effect demagnetization without having to dissassemble the equipment.
- Installation of sensors at the time of original manufacture to detect shaft currents and internal magnetic fields and thus provide for continuous monitoring.

Additional Consideration

Magnetic problems have received much attention because of forced down time and physical damage to components. Other effects, neglected up to now, deserve consideration. In these times of increasing energy costs, elimination of wasted energy and improved efficiency are eagerly pursued. Preliminary considerations indicate that elimination of circulating eddy currents due to residual magnetism could constitute considerable energy savings. These can exist in a machine even though the circulating current paths may not damage components. Demagnetization and prevention of future remagnetization are required for their elimination.

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