Nondestructive Examination (NDE) Technology and Codes
Student Manual

Volume 1

Chapter 4.0

Introduction to Visual Examination

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4.0 INTRODUCTION TO VISUAL EXAMINATION

Learning Objectives:

To enable the student to:

1. Understand the basic concepts and use of Visual Examination (VT) and the qualification/ certification of examiners.

2. Become familiar with general applications of VT.

3. Recognize the equipment used for VT.

4. Understand the processes and techniques by which VT is applied to the examination of materials, components, and structures.

5. Know the importance of the qualification and certification of personnel in VT.

6. Recognize the advantages and limitations of VT.

4.1 History

The oldest and most commonly used NDE method is Visual Examination (VT). It may also be the least understood and least effectively used of all methods. There is a difference between just looking at an object and really seeing it through a trained eye. VT may be defined as 'an examination of an object using the naked eye, alone or in conjunction with various magnifying devices, without changing, altering, or destroying the object being examined."

In VT the most important tools are the eyes. Visual acuity is of prime importance to the visual examiner. According to recent statistics, at least 50 percent of the American population over twenty years of age is required to wear some type of corrective lenses. However, in the early stages of eyesight failure, either many persons are not aware that they need corrective lenses or they just do not wear them.

As with any sensitive tool, the most important tools in VT must be checked for accuracy at regular intervals to ensure that they remain accurate and sensitive. Most codes require that VT examiners have annual eye tests to check:

- Near vision acuity,
- Far vision acuity, and
- Color perception.

Although the eyes are the most important tool, in many situations they are not sensitive enough, not accurate enough, or cannot get to the area to be examined. In those cases, the use of optical aids is necessary in order to complete the visual examination.

4.2 Personnel Qualification and Certification

The training and qualification requirements for VT were debated vigorously over many years within the NDE community. Many argued that SNT-TC-1A should not include VT, feeling it was not necessary and was being pushed on industry by the utilities. However, the proponents of VT as an NDE Method prevailed, and the recommendation for training and experience were added to the 1988 edition of SNT-TC-1A. Prior to 1988, and still within many companies today, alternate programs are used. In addition, the Electric Power Research Institute's (EPRI) NDE Center developed extensive training programs to meet the VT examination requirements of ASME Section XI for In-service Examination of Nuclear Power Plants.

Outside the power industry, the need for experienced, well-trained weld examiners was recognized. In the late 1970's, the American Welding Society developed its Certified Welding Inspector (CWI) program to meet this need. Section 4.9.3 provides a brief overview for this program.

4.2.1 Visual Acuity

One of the more obvious prerequisites is that the VT examiner should have sufficient visual acuity to perform an adequate examination. Consideration should be given to sufficient near and far vision with natural or corrected vision. A documented periodic eye test is a requirement of many codes and specifications and is generally considered good practice. An eye test by a qualified examiner is a prerequisite for certification by AWS as a CWI or a Certified Associate Welding Inspector (CAWI). Vision tests are also required by ASME Sections V and XI for VT Examiners.

4.2.2 Equipment

A VT that requires the use of special tools or equipment will depend upon the application and possibly the degree of accuracy required for the examination. Some tools may need special qualifications prior to use, as in the example of calibrations. Although this presents an outline of VT examination aids, there are many different concepts and other variations of equipment. As a general rule, those tools which comply with a particular code and specification, adequate for measuring to the accuracy of the acceptance criteria, or which satisfy the need of the examination, should be used.

4.2.3 Experience and Training

Another obvious prerequisite is that the VT examiner should have sufficient knowledge and skill to perform the examination successfully and meaningfully. Knowledge and skill can be imparted or obtained through the educational and training processes. Both processes can be formal (classroom) or on the job. The variety of methods and processes of imparting or obtaining knowledge and skill is many, but the art of good judgment does not always come easily or readily. Sufficient time should be allowed for different individuals to properly grasp key points pertaining to: joint preparations, welding preheat, interpass temperature, weldment distortion, welding consumables, and other materials. Additionally, sufficient exposure to the many types of workmanship variances should be allowed.

4.2.4 Procedures

Development of standard procedures covering examination methodology and acceptance criteria is a consideration that may add considerably to consistency and accuracy. Such procedures are normally prepared by the employer and typically consist of detailed instructions which interrelate the various fabrication processes, the customer's detailed requirements, and baseline examination criteria. Items such as who performs an examination, when to perform an inspection, how to perform an examination, and where to perform an examination are typically included in the procedure. Detailed specific examination factors can be included such as: workmanship, pictorials, attribute checklists, equipment requirements, and other items.

Article 9 of Section V stipulates that VT, when required by the referencing Code sections, must be done in accordance with a procedure. Article 9 also contains specific items that must be included in the procedure. Section XI also requires that VT be included in accordance with a written procedure.

4.2.5 Certification

Article 9 of Section V does not specifically address the certification of VT examiners. It does state, however, the requirements of the referencing code.

Qualifications in accordance with a prior edition of either SNT-TC-1A or CP-189 are considered valid until recertification. Recertification must be in accordance with SNT-TC-1A (2006 Edition), ANSI/ASNT CP-189 (2006 Edition), or ACCP.

Section XI requires that personnel performing NDE be qualified and certified using a written practice prepared in accordance with ANSI/ANST CP-189 as amended by Section XI. IWA 2314 states that the possession of an ASNT Level III Certificate, which is required by CP-189, is not required by Section XI. Section XI also states that certifications to SNT-TC-1A or earlier editions of CP-189 will remain valid until recertification at which time CP-189 (1995 Edition) must be met.

A Level II VT examiner, who is a high school graduate, must complete one of following for Section V and only the CP-189 requirements for Section XI.

The SNT-TC-1A requirements are:

	Training	Experience
Level I	8 hours	70* hrs/130 hrs**
Level II	16 hours	140* hrs/270 hrs**

NOTES:
*Time in Method
**Total time required in NDT

1. To certify to Level II directly with no time at Level I, the training and experience for Levels I and II are combined.
2. Training hours may be reduced with

additional engineering or science study beyond high school. Refer to Chapter 2 and SNT-TC-1A.

3. Refer to Chapter 2 for details regarding Level III requirements.

The CP-189 requirements are:

	Training	Experience
Level I	8 hours	65*/130**
Level II	16 hours	135*/270**

*Hours in VT
** Total Hours in NDE

NOTES:

1. Experience is based on the actual hours worked in the specific method.
2. A person may be qualified directly to NDT Level II with no time as certified Level, providing the required training and experience consists of the sum of the hours required for NDT Level I and NDT Level II.
3. The required minimum experience must be documented by method and by hour with supervisor or NDT Level III approval.
4. While fulfilling total NDT experience requirement, experience may be gained in more than one (1) method. Minimum experience hours must be met for each method.

4.3 Principles of Visual Testing

VT is the observation, either directly or indirectly, of a specimen by an examiner in such a fashion as to determine the presence or absence of surface discontinuities or irregularities. VT should be the first NDE method to be applied to a specimen. Other NDE methods may or may not be required after VT. The procedure is usually quite simple.

VT was probably the first method of NDE employed by man. Today, VT remains foremost for detecting and evaluating discontinuities. It has developed into a multitude of difficult and elaborate optical investigation techniques.

Some optical examinations are based upon simple laws of geometrical optics. Others depend upon rather complicated properties of light, such as wave characteristics. The unique advantage of many optical examinations is that they often yield quantitative data (in addition to qualitative information) more readily than many other forms of NDEs.

4.3.1 Applications

Luminous-energy NDEs are used primarily for examining exposed or accessible surfaces of opaque materials and test objects (such as the majority of partially or entirely assembled and finished products) and also for examining the interior of transparent test objects (such as glass, quartz, some plastics, liquids, and gases). For all types of objects, VT serves to determine the number, size, shape, surface finish, reflectivity, brightness, hue and other color characteristics, exposed cracks and discontinuities, and fit and functional characteristics.

4.3.2 Visual Factors

Vision involves a number of factors such as perception of light, form, color, depth, and distance. A perception of form is possible because light from an object is focused in the eye and an image is formed. This visual image is affected by the lens system of the eye in almost the same way that any lens will bring rays of light to a focus and form an image. The focus of the lens system in the eye can be changed like that of a camera. A diaphragm, the sight hole or iris, regulates the quantity of light admitted through the pupil. The retina is a light-sensitive plane upon which the image is formed. Adjustments of the focus are made by changing the thickness and curvature (i.e., the focusing power, of the lens). Increasing the lens thickness is called accommodation. This is done by the action of tiny muscles attached to the lens.

4.3.3 Human Eye

About 38 percent of all nerve fibers entering or leaving the central nervous system affect vision. The eye contains 128 million primary visual receptors that connect to more than one million neurons in each optic nerve.

The eye can sense a flash of light of only 10 photons of energy. This is equivalent to detecting the light of a candle from 16½ miles away. Astronauts have been able to see the smoke of a train from 100 miles above the earth.

If the eyes have become adapted for night vision, a test image can just be seen against a dark background if only one cell out of every 6,000 rod cells receives one quantum of light per second. This is called threshold vision. Bright moonlight is 20,000 times brighter than the light needed for threshold vision and that is why a newspaper can be read in bright moonlight. A severe deficiency in vitamin A may totally abolish night vision.

To appreciate the range of brightness to which the human eye can adjust, consider that a sunny day at high noon is one billion times brighter than a starlit night. Human eyes normally work in tandem. Shine a light into one eye and both pupils become smaller. Look to the right and both eyes will look in that direction.

In the center of the retina is a small area called the fovea which is packed with about six million “cone” cells. These cone cells are only about 1.5 microns in diameter and each connects directly to a neuron providing resolution sharpness and color perception provided sufficient illumination exists. But under dim light, the cone cells are practically blind and the human eye must rely upon the 115 million “rod” cells, which comprise the balance of the retinal sensors in each eye. Unlike the cone cells, rod cells work in groups to feed impulses to a neuron. A larger the group of rod cells working together for more sensitivity when the light is low. These peripheral parts of the retina are nearly one million times more sensitive to light than the central fovea.

When stepping from the bright sunlight into a dark theater, nothing can be seen at first, as the dark adaption process begins. Initially, there is a rapid rise in sensitivity for about 30 seconds followed by a slower increase until, after 5 to 9 minutes, sensitivity increases over 100 times. For the next 20 to 30 minutes, sensitivity continues to increase by a factor of 1,000 to as much as 10,000 as the pigments in the rod cells regenerate.

In addition to the 10,000 increase in sensitivity by the retinal rod cells, other changes in the eye, including the dilation of the pupil to allow more light to enter the eye, add to the effect so that the final result is to make the increase in light sensitivity equal to 100,000 times. It is interesting that the adaptation required when coming from the dark into the light is accomplished within only a few minutes.

The human eye can resolve detail far beyond what would appear to be its theoretical limits. Visual acuity, often called sharpness or resolution by some, is measured in terms of the angle subtended at the so-called nodal point of the eye by the smallest object that can be distinguished from its background. The light path passes through a single point near the inner surface of the lens which is the nodal point, and then the light spreads out again to form an image on the retina of the eye. In dim light, the angle amounts to half a degree and the image produced on the retina covers thousands of rod cells, but in bright daylight, much smaller objects subtending only half a minute of arc can be resolved. The half minute of arc at the nodal point produces an image on the retina of only one and one-half microns in size, which is the same as the diameter of one cone cell. So to distinguish one small object from another, there must be at least one unstimulated cone cell between them. In other words, the two images must be at least 1.5 microns apart on the fovea.

Under certain circumstances, such as a single line against a uniform background, precise testing shows that the eye can actually resolve between 0.5 and 4 seconds of arc, which is about 60 times greater than the theoretical limit.

4.3.3.1 Refractivity

In the normal eye the length of the eyeball and the refractive power of the cornea and lens are such that images of objects at a distance of 20 feet or more are sharply focused on the retina when the muscles of accommodation are relaxed. Defects in these relationships require correction by glasses. In a farsighted individual for instance, the situation can be corrected by glasses made of convex lenses. These bring light from distant objects to a focus without contracting the accommodation muscles which make the lens more convex. In the nearsighted person, light rays from distant objects focus in front of the retina. This causes a blurring of the image of all objects located beyond a critical distance from the eye. By use of concave lenses, thicker at the edge than in the center, distant object can be seen clearly.

4.3.3.2 Distance Judgment

Binocular vision is an important aid in accurate judgment of distance. Distance judgment is the basis for depth perception, or stereoscopic vision. Stereoscopic vision depends, at least in part, upon the fact that each eye gets a slightly different view of close objects. The right eye sees a little more of the right-hand surface of the object. The left eye sees a little less of this surface but more of the left surface. When the images on the two retinas differ in this regard, the object is seen as three dimensional, possessing depth.

4.3.3.3 Mechanism of Vision

The photographic plate used in the camera is represented in the eye by the retina, which contains the end plates of the optic nerve. These receptors are extremely complicated structures called rods and cones. Nerve impulses arise here and are conducted along the visual pathways to the occipital region of the brain. The mechanism of converting light energy into nervous impulses is a photochemical process in the retina.

4.3.3.4 Light Receptors

The two kinds of light receptors in the retina, the rods and the cones, differ in shape as well as in function. At the point where the optic nerve enters the retina, there are no rods and cones. This portion of the retina, called the blind spot, is insensitive to light. On the other hand, the maximum visual acuity at high brightness levels exists only for that small portion of the image formed upon the center of the retina. This is the fovea centralis, or “spot of clear vision.” Here the layer of blood vessels, nerve fibers, and cells above the rods and cones is far thinner than in peripheral regions of the retina.

Daylight vision, which gives color and detail, is performed by the cones, mainly in the fovea centralis. These have special nerve paths. At least three different kinds of cones are present, each of which is in some way activated by one of the three fundamental colors.

4.3.4 Color and Color Vision

Color vision is one of the most interesting aspects of the human eye. It is a function of the light-adapted eye and is dependent upon the acuity of the cones. Light, of course, is the specific stimulus for the eye, but the eye is sensitive only to rays of certain wavelengths. Within those wavelengths the stimulus must have a certain minimum intensity. The sensation of color varies according to the intensity of the light, the wavelength of the different radiations, and the combinations of different wavelengths. In daylight vision, yellow is the brightest color.

4.3.4.1 Color Characteristics

Every color has three physical characteristics: tone or hue, saturation or purity, and brightness or luminosity. Hue is that characteristic of color associated with the color name, such as green or blue. It may be described by the wavelength of a hue in the spectrum which visually matches the dominant hue. Purples do not exist in the spectrum, but the spectrum furnishes a hue complementary to that of any purple. This is true whether the hue is lavender, magenta, or any other variation of the family of purple. Although an estimated seven million or more distinguishable colors exist, only a few main colors are distinguished for practical reasons. Their wavelengths are as follows, in nanometers (nm): violet, 380 to 450; indigo, 425 to 455; blue, 450 to 480; green, 510 to 550; yellow 570 to 590; orange, 590 to 630; red, 630 to 730. Light from a limited portion of the spectrum is called monochromatic.

Another color characteristic is saturation. For example, if one adds more and more pure white paint to a pure blue paint, the dominant hue may remain fairly constant while a series of tints is produced. Beginning with 100 percent saturation, the blue becomes less and less saturated.

A tone or hue also varies in brightness according to the intensity of radiation. If pure black paint is mixed with pure blue paint, the brightness or reflection factor is changed by adding more and more black, darker and darker shades are produced. In fact, a series of shades is produced, beginning with the original color and ending in black.

4.3.4.2 Brightness Characteristics

The brightness contrast is generally the most important factor in seeing. The brightness of a diffusely reflecting colored surface depends upon its reflection factor and the quantity of incident light (foot-candles of illumination). Excessive brightness (or brightness within the field of view varying by more than 10 to 1) causes an unpleasant sensation called glare. Glare interferes with the ability of clear vision and critical observation and judgment. Glare can be avoided by using polarized light or other polarizing devices.

4.3.4.3 Spectrum Limits of Visibility

The eye perceives all the colors in the solar spectrum between violet (380 nm) and red (770 nm). Compared with the entire electromagnetic spectrum, only a rather minute portion is visible, as shown in Figure 4-1. The response of the human eye varies considerably at the different wavelengths throughout this visible range. It peaks in brightness response at a frequency near 550 to 560 nm in daylight. Its acuity and contrast sensitivity decrease rapidly as the energy level of illumination is lowered. The tendency toward ocular fatigue is accelerated either by the presence of glare or by efforts to see at low levels of illumination or in light outside the optimum frequency range (470 to 610 nm).

4.3.4.4 Color Changes

The critical evaluation of colors and color changes represents one of the basic principles of almost all kinds of visual inspection. Corrosion, oxidation, rusting of metals and alloys, or deterioration of organic materials is often accompanied by a change in color. For example, minute color changes on the surface of fresh meat, not yet detectable by the human eye, are detected by photoelectric devices designed for the automatic inspection of meat before canning. This is a form of “nondestructive testing”.

4.3.5 Observer Differences

It should be recognized that the visibility of an object is never independent of the human observer. Human beings differ inherently in the speed, accuracy, and certainty of seeing, even though they may possess average normal vision. Human beings vary particularly in threshold measurements and in their interpretations of visual sensations. Their psychological feelings, tensions, and emotions influence their appraisals of the visibility of objects and influence their performance of visual tasks under many conditions. In other words, they differ considerably because they are human.

4.3.6 Lighting

Very few indoor areas offer sufficient light to perform a proper visual examination. Sunlit areas are excellent for general examination, but may not be sufficient for examining internal areas such as bores and deep crevices. High density fluorescent ceiling lighting offers good general inspection lighting. For more specific overall lighting, there are often options. One is a portable stand with an incandescent flood or spotlight bulb and reflector similar to those used by photographers. This gives a high-intensity source of light for a fairly large area. The stands are adjustable up and down, and the head swivels in all directions. This is a good light source for photographic recording. A word of caution on this type of light: bulb life is usually short (6 hours), and considerable heat is generated.

When considering such equipment, sturdy construction is important. Two things to look for are heavy-duty swivel adjustments on the light head and adequate cooling for the lamp base. Although these heavy-duty lights are available, they are not as easy to find as the more common light-duty types. Heavy-duty lights are considerably more expensive, but easily worth the price.

The two other general lighting devices are swivel-arm incandescent and swivel-arm fluorescents. These come in a variety of shapes, sizes, intensities, and swivel-arm types. They provide less intensity and illuminate a smaller area than the flood or spotlight type previously described. They are good for smaller areas and have longer lives. The fluorescent type has less intensity, but produces fewer shadows and is cooler operating. Many of the incandescent types have variable intensity controls. These lights can also be used in conjunction with magnifying devices.

The examiner should have adequate illumination, either natural or artificial, while performing VT. This may be determined using a fine line, approximately 1/32 inch (0.8 mm) in width, drawn on a 18 percent neutral gray card. The card should be placed near the area under examination; if this fine line is distinctly visible, the illumination is adequate. Generally, a flashlight will provide sufficient lighting. Some codes specify minimum foot candles of illumination that are required while performing visual inspection; for example, 15 foot candles (fc) for general examination, and a minimum of 50 fc for the detection of small discontinuities.

As with any type of examination, once completed, any rejectable area should be identified in some manner to assure that it will be located and repaired properly. Many methods are available, so specific conditions may dictate which marking system would be most effective. One method commonly used is to record type, size, and location of the discontinuities so that they can be located, identified, and repaired. Perhaps more effective, however, is the identification of the rejectable area by marking directly on the part.

Some conditions may require utilization of both methods. Whatever method is used, it is all part of a very important function.

4.3.7 Specific Lighting Devices

Specific lighting devices are of high intensity and permit light to be concentrated on a small spot. Incandescent lighting devices are most common. They typically utilize an adjustable transformer, one or more diaphragms, adjustable heads, and are most commonly sold as microscope lights. The disadvantage of microscope lights is that they burn out and overheat easily, do not have sufficient intensity, and produce an image of the light bulb filament on the subject being illuminated.

Several other devices for high-intensity, highly localized lighting also exist. Two of these are like the microscope lights previously described. One uses a halogen source of very high intensity; the other uses a carbon arc light source. The latter offer the brightest light available, but requires adjustments and arc replacement. A third device is a fiber optic unit. This allows highly specific, high intensity light to be brought very close to an object, even in confined quarters. It is excellent for high magnification viewing and extreme close-up photography.

4.4 Imaging Equipment

4.4.1 Mirrors

Mirrors are invaluable because they allow the examiner to look inside pipes, threaded and bored holes, castings, and around corners. The dental mirror is a common tool in most examiners' tool kits. It is usually a small, circular mirror set on a 6-inch-long handle at about a 45° angle. It allows the examiner to view areas not available for direct viewing. The movable-end mirror uses a pivoting control arm that allows the examiner to view the inside of the object, see around corners, and allows the examiner to move the mirror to scan the entire area of interest.

4.4.2 Magnification

An object appears to increase in size as it is brought closer to the eye. In determining magnifying power, the true size of the object is seen when the object is 10 inches from the eye. The 10-inch distance is used as a standard because this is the typical distance an object is held from the eye during examination. Linear magnification is expressed in diameters. The letter X is normally used to designate the magnifying power of a lens (e.g., 10X). Magnification can thus be defined as the ratio of the apparent size of an object seen through a magnifier (known as the virtual image) to the size of the object as it appears to the unaided eye at 10 inches.

4.4.2.1 Focal Length

The focal length is the distance from the lens to the point at which parallel rays of light striking one side of a lens is brought into focus on the opposite side. For lenses of short focal length, light from a source 30 to 40 feet away can be considered parallel. The focal length can be determined by holding a lens such that light coming through a window, for example, will allow the image of the window or other object to focus sharply on a sheet of paper held behind the lens. The distance from lens to paper is then the focal length. Once the focal length is known, the magnification of the lens can be determined, and vice versa. The shorter the focal length, the greater the magnifying power. The distance of the eye from the lens must be the same as the focal length. A lens with a one-inch focal length, for example, will have a magnifying power of 10 (10X). This is true if the lens is held one inch from an object, and the eye is placed one inch from the lens. In summary, the following formula determines magnifying power for a positive lens.

Magnifying Power = 10 / Focal Length (4-1)

With a simple method of determining focal length, it is easy to determine magnification.

4.4.2.2 Magnifying Devices

Various types of magnitude devices exist. These devices are commonly categorized as follows:

- Hand-held lenses, single and multiple;
- Pocket microscopes;
- Self-supporting magnifiers;
- Magnifying devices that can be worn attached to the head; and
- Magnifying devices with built-in light sources.

The categories of magnifying devices are further described below:

Hand-Held Lenses - These are available as a lens by itself, a lens with a frame and handle, or a lens that folds out or slides out of its own case. The fold-out type may include one to four lenses that can be used alone or in conjunction with one another. The size generally varies from ½ inch to 6 inches in diameter. They are available with either glass or plastic lenses.

Pocket Microscopes - Another variety of the hand-held magnifier are pocket microscopes. These are generally small diameter tubes, about ½ inch in diameter and 6 inches in length, although they are also available in larger diameters. The smaller varieties are usually offered with magnification ranges of 25X to 60X. The subject end is cut at an angle or is somehow opened to allow maximum available light along with support. At these magnifications, the field of view and focal length are extremely limited, as is the available light. Auxiliary light is often a necessity. The larger-diameter units have lower magnifying power.

Self-Supporting Magnifiers - Self-supporting magnifiers are much like the hand-held magnifiers, except they free the hands to manipulate the object being observed. They are generally low-power magnifying devices like the hand-held lenses. Self-supporting magnifiers are available as lenses with heavy bases and movable viewers, and lenses that hang around the neck.

Magnifying Attachments - These magnifying devices are of two types. The visor type has an adjustable band that fits over the head. This band supports a lens holder that tilts up and down for use when needed. The lens system may be two separate lenses or a continuous strip lens. It is also available with a loupe accessory for additional magnification. These visors may be worn with or without eyeglasses. Magnification offered is generally low (1.5X to 3X), but can be as high as 10X to 15X. They make excellent visual examination devices because they can be comfortably worn for long periods of time and can be quickly tilted in place for use when needed. Loupes used without glasses can be held either in the eye socket by eye muscles, like a monocle, or on the forehead with a spring clip that wraps around the head. Loupes are also available that attach to eyeglasses as single or multiple lenses. These can be tilted in or out of use easily. The magnification range for such loupes is 2X to 18X.

Illuminated Magnifiers - Most magnifying devices are also available with built-in light sources. To see details, good lighting is important. This is particularly true at the higher magnifications since the lens-to-subject distance is so short. Most light sources are either battery powered with flashlight batteries or equipped to plug into a standard wall outlet. The lights are usually incandescent, but are also available with fluorescent and ultraviolet light sources.

4.4.3 Borescopes and Fiberscopes

Borescopes and fiberscopes are widely used for examining tubes, deep holes, long bores, and pipe bends, which have internal surfaces not accessible to direct viewing. They allow close and evenly magnified examination of internal surfaces for discontinuities. They can be used to view straight on or at various angles (Figure 4-2).

4.4.3.1 Borescopes

Borescopes come in many sizes, as illustrated in Figure 4-3. The smallest borescopes are tiny needle-like instruments used to look through very small drilled holes. The largest borescopes are 7 inches in diameter, 100 feet long, and are used for the examination of heat exchanger tubes and long runs of pipe.

Most borescopes are equipped with light sources located near the tip to illuminate the area being examined. They also have lenses offering different angles of view or mirror systems to allow viewing of specific areas of interest.

Borescopes are manufactured much like a telescope, and use a system of lenses to view the area of interest. The lenses serve to magnify the image as well as provide a way to get to an inaccessible area. Borescopes are manufactured for a variety of viewing conditions.

4.4.3.2 Fiberscopes

Fiberscopes (Figure 4-4) are used when the examination must be performed around curves and corners. They allow clear viewing at distances up to 300 feet and range in diameter from 1/10-inch up to 3/4-inch. The length and diameter depend on materials from which the fiberscope is manufactured. The fiberscope is made up of a multitude of very small glass fibers, which are manufactured so that light will transmit through them and not exit through the walls of the fiber. By forming a large number of fibers into a coherent bundle, the examiner is able to form a complete picture of the area he wishes to view. Fiberscopes also have a light source at the tip to illuminate the area of interest. The tip articulates up to 120^{o} up and down. Some fiberscopes also articulate, or move, from left and right. The light-guide jack is used to bring cold light from the light source out to the light tip. Most of the light sources have an illumination level control.

4.4.4 Electronic Imaging

4.4.4.1 Closed Circuit Television

Examination of vessels and component internals are frequently performed with remote closed circuit television camera equipment. Therefore, it is important to understand some of the basics of the closed circuit television system in order to appreciate its use and limitations.

The TV camera tube is a critical component of the closed circuit TV system in that it converts what it “sees” into electrical impulses and thus determines the frames and quality of the final image reproduced at the receiver. For high resolution at the receiver, the camera tube must separate the object being televised into as many picture elements as possible. The higher the number of elements produced, the greater the detail resolution capability at the receiver.

TV camera tubes are divided into two classifications based on how they produce the electrical image within the tube. The first method is by a process called photoemission, in which electrons are emitted by a photosensitive surface when light reflected from the object is focused onto the surface. Television tubes that utilize the photo emission method are called image orthicon tubes. The second method is by photoconduction. In this process, the conductivity of the photosensitive surface changes in relation to the intensity of the reflected light from the scene being focused onto the surface. Tubes utilizing the photoconduction process are called vidicon tubes and are the primary tubes used in industry.

4.4.4.2 Cathode-ray Tube (Viewing)

The two most important aspects of a cathode-ray tube related to visual interpretation are brightness and contrast. As the electron beam scans the back side of the fluorescent screen, not all of the light emitted is useful. For example, 50 percent of the light travels back into the tube, 20 percent are lost in the glass of the tube by internal refraction, leaving only 30 percent to reach the observer.

Image contrast is reduced by light returned to the screen after being reflected from some other point. The four main sources of this type of interference are described below:

Halitation - If the electron scanning beam were held in one spot, the visible spot on the screen would be surrounded by rings of light. These rings are caused by a phenomenon termed halitation (Figure 4-5). Light rays leaving the fluorescent crystals at the inner surface of the glass are refracted. Rays that form an angle greater than 45° are reflected back into the glass by the outside surface of the glass. Where these reflected rays strike the fluorescent crystals, they produce visible rings on the screen, causing a hazy glow surrounding the beam spot. The end result of this phenomenon is to reduce the maximum possible detail contrast.

Reflections Due to Screen Curvature - Reflection caused by curvature of the screen also results in a loss of contrast. Contrast increases as the surface becomes flatter.

Reflections at the Surface of the Screen Face - A portion of light is also reflected when it reaches the outside surface of the glass (the glass-air surface). These light rays are reflected back and forth between the inner and outer surface of the glass, with some of the light being emitted and the balance being absorbed.

Reflections from Inside the Tube - Reflections from the inside surfaces of the tube can decrease the field contrast of the image. By adding an extremely thin film of aluminum to the back of the fluorescent screen, this condition can be almost eliminated.

Resolution - The resolution of the television system is the number of lines in the picture. The electron beam produces the picture by repeatedly drawing lines of varying brightness across the tube. There is a 525-line signal in the visual broadcast picture, with approximately 480 lines actually forming the picture and the rest being used in the return of the beam from the bottom to the top of the picture. There is also a resolution in terms of lines in the horizontal direction, even though there are no actual lines on the screen. TV monitors are designed to have equivalent horizontal and vertical resolution. The closed circuit television systems used for industrial examinations have a much higher resolution than a broadcast system, usually about 1,000 lines.

4.4.4.3 Digital Imaging

Digital imaging can provide significant improvement in the interpretation of visual and radiographic images. Frequently, these images contain more information than the human eye can see because the human eye is biologically limited in distinguishing gray level differences and detecting edges. For example, while radiographic film contains sufficient sensitivity to detect density differences of 0.05 to 0.1 percent (approximately 1,000 to 2,000 gray levels), the human eye can only resolve gray levels which differ by at least 2 percent (approximately 32 to 64 gray levels). A boundary or edge condition can be distinguished only when two adjoining areas of an image differ by 12 percent in density.

Enhancement systems utilize digitization to provide information in a format acceptable to standard computers. Initial picture information can be generated from a variety of analytical probes, such as X-rays, gamma-rays, ultrasonics, visible light, or scanning electron microscope. After the image information is transferred by the appropriate use of mathematical models, the resulting image enhancement can then be displayed for further visual analysis by the user.

Existing enhancement techniques are applicable to both "old" information, videotapes, and "new" data produced from various analytical probes.

4.4.5 Photographic Techniques

The purpose of this section is to provide some useful techniques that will yield better results when trying to photograph various plant components in conjunction with visual examination.

4.4.5.1 Depth of Field

Depth of field can be defined as the overall sharpness of focus apparent in a photograph. When trying to photograph a subject, only a single plane through the subject is actually in focus. This plane is called the principal plane of focus. When working at higher magnifications, this effect becomes even more significant. In a typical 35mm camera, the lens diaphragm is used to provide a degree of control over the thickness of the principal plane of focus or depth of field.

Focusing should normally be done with the lens diaphragm all the way open for best accuracy and image brightness. This step establishes the principal plane of focus. If the lens diaphragm opening is now reduced, portions of the subject both in front and in back of the principal plane of focus now appear sharper. Closing the lens diaphragm increases this effect. By adjusting the lens diaphragm, the examiner can effectively control the depth of field and thereby predetermine what will and will not be in focus (sharply defined) in the final picture.

Using a standard 35 mm camera and lens, the best control over depth of field can usually be obtained by focusing one-third into the region or area of the discontinuity of interest. This is because the depth of field or area of sharpness (using a 55 mm lens) extends farther behind the principal plane of focus than in front of it. As magnification is increased (90 mm and 120 mm lenses), the reverse is true.

A good general principle is that depth of field is only affected by two main factors: lens diaphragm opening and the image or subject magnification.

Since most discontinuities being photographed will be three dimensional, there is another factor to consider. The magnification will be exact only at the principal plane of focus.

Where measurements of overall size of a discontinuity are to be made directly from the final print, the principal plane of focus must be at the widest part of the subject.

4.4.5.2 Lighting

In general, when photographing power plant components or discontinuities, the light should be correctly oriented to the subject. Where possible, the lighting should be provided from the top in relation to the subject being photographed. Lighting should also be provided from one direction on most three dimensional objects to avoid ambiguity in relief. If supplementary lighting is required, it should be slightly weaker and more diffused than the main lighting source.

A common problem in trying to photograph plant components (for example piping welds) is high spots caused by unwanted reflections of the flash unit on the subject itself. Such reflections can usually be eliminated by moving the flash unit to direct the secularly reflected light away from the lens. Another effective method of eliminating subject reflections is to bounce the flash off a piece of white cardboard.

4.4.5.3 Film

The actual size of the negative directly affects the quality of any enlargements. The larger the size of the negative, the better quality any enlargement will be. Selecting the speed of the film is another important decision. Several factors influence this decision. Among them is the amount of light available on the subject and the size of the print to be made from the negative. High speed film requires less light but produces “grainy” prints. Graininess increases as the size of the enlargement increases. Slow speed films are used where very fine detail is required. The drawback of slow speed film is that it requires more light on the subject being photographed.

4.5 Measuring Equipment

Drawings and specifications provide the dimensions and allowable tolerances. The type of measuring device to be used is largely dictated by the design tolerances and the accessibility of the dimension to be measured. Generally, dimensions with tolerances given in fractions may be measured using steel rules while dimensions with tolerances given in decimals require greater precision.

Numerous types of measuring devices with varying degrees of precision are available. “Precision” refers to the ability of an instrument to reproduce its own measurements. Precision should not be confused with the term “accuracy,” which is the degree of conformance of a measurement to the actual value. Reliability is the probability of achieving desired results. More specific definitions of the terms: precision, accuracy, and reliability are given in Table 4-1.

4.5.1 Linear Scales

Linear measurements are those measurements that involve only a single straight-line dimension. Since all linear measurement gages (or rules) are designed on the basis of the international inch and are scaled from the basic linear scale, it is necessary to know how to read and use a rule before proceeding on to other measuring tools.

A scale is graduated in proportion to a unit of length. The divisions of a rule are increments of a unit of measurement. The draftsman uses an architect's scale whose divisions represent feet and inches or an engineer's scale whose graduations are in decimal divisions of the foot.

4.5.2 Steel Rules

Rules are essential and so frequently used on a variety of work that they are supplied in a number of different styles. The most common rules are steel and are graduated in fractions of an inch or decimal part of an inch. The better quality rules meet the accuracy standards of the NIST.

4.5.3 The Vernier Scale

The steel rule previously discussed is classified as a non-precision measuring instrument and basically is used when fractional measurements are adequate. Many precision measuring instruments available today are capable of measuring in decimal units to a precision factor of 0.0001 inch. This precision is made possible by the simple method of amplifying the discrimination of the basic linear scale.

One of the simplest ways to amplify discrimination is the vernier scale. The vernier scale system is used on various precision measuring instruments such as the vernier caliper, vernier micrometer, vernier height and depth gages, gear tooth verniers, and vernier protractors. In addition, many industrial machines use the vernier scale system, such as the handwheel scale of a jig borer.

4.5.4 Vernier Calipers

Vernier calipers are highly accurate measuring instruments capable of measuring in thousandths of an inch and are similar to ordinary slide calipers but are more accurate (Figure 4-6). The vernier caliper is made up of an L-shaped frame with a fixed jaw as one of the legs of the frame. Graduations are accurately engraved on the long leg of the frame. These graduations are called the main scale. The length of the main scale determines the size of the calipers. Sizes range through standard lengths of 6, 12, 24, 36, or 48 inches. The most commonly used sizes are 6 and 12 inches in length. A sliding bar or sliding jaw has a vernier scale attached to each side. The two jaws of the vernier calipers are made of hardened steel.

Vernier caliper beams have two sets of graduations; one for inside and one for outside measurements. These graduations may be on the same side of the beam, with one set along the upper edge and the other near the bottom of the beam, or the outside graduations may be on the front side of the beam and the inside graduations on the back. If graduations are on both sides, the outside readings on the front are read from left to right, and the inside readings on the back are read from right to left. The reason that two sets of graduations are required is that outside readings are made between the caliper jaws and inside readings are made between them. When the jaws are closed, the zero line on the inside vernier scale falls on a number of graduations beyond the zero line on the beam. The distance is the thickness of both nibs, since this width must be included in all inside measurements.

4.5.5 Dial Calipers

The dial caliper (Figure 4-7) is considerably more expensive than the vernier caliper. The dial mechanism is more subject to malfunction than the simple vernier scale. The accuracy of the reading mechanism of the dial caliper is a function of length of travel. Accuracy to 0.001 inch per 6 inches of travel is usually claimed. In contrast, the accuracy of the vernier reading is the same any place along the scale. In either case, the accuracy of the main scale must also be considered. The dial caliper is used by less skilled personnel or for quick checking of dimensions with relatively wide tolerances. Therefore, the vernier caliper remains the instrument of choice for skilled people doing precision work.

4.5.6 Micrometer

A micrometer (Figure 4-8) in the hands of a skilled operator can be used to reliably measure within 0.001 inch. The instrument's inherent precision is usually between 0.0005 and 0.001 inch. The micrometer operates on the principle that a screw accurately made with a pitch of 40 threads per inch will advance 1/40th (.025) of an inch with each complete turn. This screw thread is on the spindle and revolves in a fixed nut concealed by a sleeve. The sleeve on a 1-inch micrometer is marked longitudinally with four lines per inch corresponding with the number of threads on the spindle. Each fourth line is numbered with the digits from 0 through 9 to indicate the .000 through .900 readings. The beveled edge of the thimble is marked into 25 divisions around the circumference and is numbered from 0 to 24. When the micrometer is closed, only the 0 line of the thimble should be aligned with the horizontal or axial line of the sleeve. If the 0 line of the thimble is not aligned with the horizontal or axial line on the sleeve, the sleeve may be adjusted to 0, using a spanner tool generally provided with each instrument.

4.5.7 Micrometer Depth Gages

Micrometer depth gages are used in a manner similar to the application of calipers for measuring depth, except that the reading is obtained from a micrometer sleeve and thimble.

4.5.8 Dial Indicator

The dial indicator (Figure 4-9) is one of the mostly widely used measuring instruments today. It consists of a graduated dial with an indicating hand, a contact point attached to a spindle, and a gear or level-amplifying mechanism.

4.5.9 Balanced Dials

Most gages have a balanced dial that have consecutively numbered graduations on both sides of zero. Dimensional comparisons are indicated as plus or minus variations from the nominal zero point. These dials are suited to bilateral tolerances. It is also possible to have a continuous dial reading typically in the clockwise position.

The single greatest advantage of dial indicators over fixed gages is their ability to visually display not only whether the test piece meets dimensional limits of the specifications (GO-NO-GO), but by how much it varies from the nominal dimensions. Many operations require the variation factor to be gaged rather than indicating the limits.

Combined with various accessories, dial indicators provide a wide range of gaging applications such as:

- Internal, external and height measurements;
- Concentricity and alignment of shafts;
- Close tolerance adjustments of equipment;
- Bore and hole diameter and depth, taper, bell mouth, and barrel;
- Surface flatness and finish;
- Pipe flange alignment; and
- Mounting on production machines for truing work, checking run out, concentricity, and alignment.

4.5.10 Combination Square Set

The combination square set (Figure 4-10) consists of a blade and a set of three heads: squar-e, center, and protractor. The combination square set is used universally in mechanical work for assembly, layout, and work-in-progress examinations. Although the three heads combine the function of several tools and serves a wide variety of purposes; normally only one head is used at a time.

4.5.11 Thread Pitch Gages

Thread Pitch Gages are used to determine the number of threads per inch and the thread pitch on screws, bolts, nuts, pipe, and other threaded parts. (See Figure 4-11) The teeth on the various leaves of the thread pitch gage, which correspond to the standard thread forms, are used like a profile gage.

4.5.12 Thickness Gages / Feeler Gages

Thickness gages such as bevel protractors are used for gaging clearance between objects such as bearing clearance, gear play, pipe-pipe flange clearance, or gaging narrow slots. Commonly called feeler gages, they are available in sets that contain leaves ranging in thickness from 0.0015 to 0.200 inch.

4.5.13 Levels

Levels are tools designed for use in determining whether a plane or surface is truly horizontal or vertical. Some levels are calibrated to indicate the angle on inclination in degrees in relation to a horizontal or vertical surface.

4.6 Visual Examination of Welds

4.6.1 Prior to Welding

Prior to welding, some typical action items requiring attention by the VT examiner include:

- Review drawings and specifications.
- Check qualification of procedures and personnel to be utilized.
- Establish check points.
- Prepare a plan for recording results.
- Review materials to be utilized.
- Check for base metal discontinuities,
- Check fit-up and alignment of weld joints.
- Check preheat, if required.

4.6.2 During Welding

During welding, a number of items require control so that the resulting weld will be satisfactory. Visual examination is the primary method for controlling this aspect of the fabrication. It can prove to be a valuable process control tool. Some of the aspects of fabrication that can be checked include:

- Quality of weld root bead,
- Joint root preparation prior to welding the second side,
- Preheat and interpass temperatures,
- Sequence of weld passes,
- Subsequent layers for apparent weld quality,
- Cleaning between passes, and
- Conformance with the applicable procedure (i.e., voltage, amperage, heat input, speed).

Any of these factors, if ignored, could result in discontinuities that could cause serious quality degradation.

4.6.3 After Welding

Many feel that VT commences once the welding has been completed. However, if all of the previously discussed steps have been taken before and during welding, this final phase of VT will be accomplished easily. It simply provides a check to ensure that the steps taken have resulted in a satisfactory weld. Some of the various items which require attention after welding has been completed are:

- Final weld appearance,
- Final weld size,
- Weld length,
- Dimensional accuracy,
- Amount of distortion, and
- Post-weld heat treatment.

The purpose of final examination is to ensure the weld's quality. Most codes and specifications describe the extent of the discontinuities that are acceptable, and many of these can occur on the surface of the completed weld.

4.6.4 Weld Examination Gages

4.6.4.1 Fillet Weld Gage

The fillet weld gage offers a quick means of measuring most fillet welds of 1/8 inch (3.2 mm) through 1 inch (25 mm) in size. It measures both convex and concave fillet welds. To measure a convex fillet weld (Figure 4-12), the blade representing the specified fillet weld size with the concave curve should be selected. The lower edge of the blade is placed on the base plate with the tip of the blade moved to the upright member. To measure a concave fillet weld (Figure 4-13), the blade representing the specified fillet weld size with the double concave curve should be selected. After placing the lower edge of the blade on the base plate with the tip touching the upright member, the projection formed by the double curve should just touch the center of the weld face. This will measure throat size for the specified weld size. However, if the center portion of the gage does not touch the weld, the weld has insufficient throat size.

4.6.4.2 Multipurpose Gage

Several multipurpose welding gages are available on the market today. A multipurpose gage is capable of performing many measurements, such as measuring convex and concave fillet welds, weld reinforcement, and root opening. The numerous and various gages available cannot all be detailed in the manual; therefore, the instructions with each gage should be followed carefully. An example of a multipurpose weld gage is the Palmgren gage (Figure 4-14).

4.6.4.3 Taper Gage

The taper gage is inserted into the opening of a joint to measure root opening (gap). The root opening measurement is taken from the gage at the point where the gage becomes snug in the joint.

4.6.4.4 Hi-Lo Gage

The Hi-Lo gage (Figure 4-15) also called a mismatch gage, is used to measure the internal alignment of a pipe joint. After the gage has been inserted and adjusted, the thumb screw is tightened, and the tool is removed for measurement of misalignment.

4.6.4.5 Ferrite Gages

The presence of a small fraction of the magnetic delta ferrite phase in an otherwise austenitic (nonmagnetic) weld metal has a pronounced influence in the prevention of both centerline cracking and fissuring. The amount of delta ferrite in as-welded weld metal is largely, but not completely, controlled by a balance in the weld metal composition between the ferrite-promoting elements and the austenite-promoting elements. An austenitic stainless steel weld will have a tendency to develop small cracks or fissures if there is insufficient delta ferrite structure. These small fissures tend to be located transverse to the weld interface in weld beads and base metal that were reheated to near the melting point.

4.7 Remote Visual Inspection (RVI)

4.7.1 Fiber-optic Borescopes, Fiberscopes, and Video Image Scopes

Fiber-optic borescopes, fiberscopes, and video image scopes enable an examiner to see inside equipment, components, or structures that have closed or hidden areas that would not ordinarily be accessible to visual examination. The images brought back from inaccessible work sites can be electronically captured, enhanced, analyzed, and a hard copy made for future reference.

Rigid Borescopes vs. Flexible Fiberscopes - The difference between rigid borescopes and flexible fiberscopes is that the former have a series of lenses to relay the image. The lenses are encased in a stainless steel sheath or working length in diameters that range from 6 mm to 16 mm. The smaller sized borescopes, 1.2 mm to 4 mm, do not have relay lenses. Instead they have a special rigid image-relaying solid rod or a quartz fiber bundle in a steel tube. Also encased within the steel tube is a fiber-optic bundle that conveys light from the light source to the worksite. Unlike the flexible fiberscope, the borescope requires straight line access to the examination area, since it cannot bend.

Straight line access is not necessarily difficult to attain, if the examiner studies the equipment under inspection, refers to blueprints, and plans the work. Many modern manufacturers provide access ports for borescopes in their machinery.

Flexible fiberscopes, on the other hand, have separate fiber-optic optical bundles, which are image and illumination systems encased in a flexible sheath or insertion tube. The flexible tube can be worked around corners and into places that do not have straight line access. The image formed by the objective lens in the tip or distal end is relayed back to the eyepiece, not by a series of lenses, but by a special bundle of fibers called the image bundle. The image is an array of pixels or small dots of color that form an image in the way that a mosaic forms a picture.

An electronic variation of the optical fiberscope is the video image scope. Instead of only an objective lens at the distal end of the flexible insertion tube and an image bundle to convey the image, the video image scope has a very small video camera and a lens in the distal end. The camera, which is based on charge coupled device (CCD) compact chip technology, sends back a color video image to the unit, where it is displayed on a video monitor.

4.7.2 Liquid Penetrant Examinations Combined with RVI

Black light techniques are being developed with fiber-optic equipment. One flexible fiberscope has an integral light guide cable especially designed to transmit ultraviolet (UV) light and an extra working channel for the transmission of fluids and special tools. Borescopes are available with integral quartz light guides for the transmission of UV light. Current limitations of this technique include the necessity of cleaning the surface before developer is applied and the requirement of cleaning the remaining developer and dye from the surface after examination to avoid corrosion or residue. These requirements have generally limited UV inspection with fiberscopes to shop locations, where the equipment is wholly or partially disassembled and capable of being thoroughly cleaned after inspection.

A working channel fiberscope and newly designed working tools that address cleaning and residue and UV light sources enable the examiner using penetrants to reach locations that are difficult or impossible to see with the unaided eye, even in the disassembled condition.

Equally important, fiberscopes and borescopes afford magnification of the image that allows the examiner using penetrants to magnify the smallest discontinuities and to document them. In addition, these instruments make possible accurate documentation through photography or video recording and precise measurement.

4.7.3 Magnetic Particle Examinations Combined with RVI

Like PT, fiberscopes and borescopes are growing in use with MT as VT aids for areas that are inaccessible to the unaided human eye. These areas include internal surfaces, threaded holes, keyways, etc. Another advantage of these instruments is the ability to magnify small discontinuities and to document them with photography or by video, then measure them with great accuracy. A growing technique makes use of a working channel in a fiberscope to blow or pump the MT medium to the remote examination area.

4.7.4 Ultrasonic Examinations Combined with RVI

Ultrasonic scanners for fiberscopes have been developed for industrial use based on previous medical use. They are capable of penetrating very small access openings. The scope has an ultrasonic transducer that rotates 360° in a balloon attachment filled with water as transmission medium. The balloon fits snugly against the wall of the component under study and transmits the sound waves to it. The transducer detects the reflected sound waves, and their signals are displayed. The ability to make examinations with an industrial fiberscope equipped with an ultrasonic transducer and transmitting device presents an opportunity for expanding remote internal examination in dramatically new areas.

4.7.5 Eddy Current Examinations Combined with RVI

Fiberscopes have been used in experiments and actual industrial use to provide ET of components. In one such application, a system has been developed that uses a fiberscope with two working channels. One channel carries the eddy current probe and the other carries a marking device to indicate the location of the discontinuity. A video camera is adapted to the fiberscope and the process is watched on a TV monitor and recorded on video tape. The system is used to examine turbine blades. In use, the probe, which protrudes about 10 mm in front of the distal tip so that it is in the field of view, is manipulated by the fiberscope to the location of the suspected area. A discontinuity can be measured for depth and length by ET instrumentation. In many cases it is desirable to mark the location with the marking device. In this application, the marking device consists of a probe on a wire contained in the second working channel. The probe has a high voltage transformer connected to it and grounded to the turbine. The marking probe is manipulated by the scope and located at the end of the discontinuity. Then, a spark is induced between the probe and the blade; the spark leaves a small trace. Future examinations will reveal if the discontinuity has grown in length.

4.8 Specific Applications for Power Generation

A rapidly growing area of fiberscope and borescope development lies in instruments developed for specific applications. Thus a scope can be designed to solve a single problem or a special combination of problems. For example, there are custom-made scopes to withstand high pressures and temperatures and scopes designed to work in high and ultrahigh vacuums. Other scopes can be designed to convey color images to a spectrometer for measurement; others, to measure high temperatures or to work in a highly corrosive environment.

Power generation plants use borescopes and fiberscopes extensively to reduce maintenance and avoid unscheduled outages (a shut down of the plant and a loss of output of electricity during the shut down). Among the equipment examined in power plants are steam and gas turbines.

4.8.1 Steam Turbines

Steam turbines are also extensively examined with fiberscopes and borescopes. Steam is supplied to the turbine at superheated temperatures and high speeds. The turbine is driven by the force of the steam passing over the turbine blades. The turbine in turn drives the electric generator, producing electricity. The turbine blades range in size from small to large and are examined closely with fiber-optic scopes for corrosion, erosion, cracking, tip clearances, etc. It is important to monitor discontinuities because of the potential loss of efficiency or even catastrophic failure.

4.8.2 Surface Condensers and Heat Exchangers

In power plants, the steam that drives the turbine is cooled and condensed in a special heat exchanger called a surface condenser. This condenser consists of a large chamber containing thousands of feet of tubes that carry cooling water. A vacuum is maintained in the chamber to extract additional energy from the expanding steam. As the exhaust steam cools in the condenser, condensate is collected at the bottom of the chamber and returned to the boilers for another cycle. It is important that the cooling water tubes maintain their integrity so that the cooling water does not leak into the condensate and contaminate its purity. Maintaining condensation purity is especially important in nuclear plants.

It is also important to minimize mineral deposits or “scale” on the inner walls of the tubing. Deposit buildup on the tube wall reduces the cooling effect by inhibiting thermal exchange between the steam and the cooling water. Inefficient cooling means less efficient turbine operation. This adds to the cost of producing electricity. Borescope examination of the tube interior will detect mineral deposit buildup.

Cooling water tubes are made of various materials such as copper, nickel, stainless steel, and titanium. To examine these tubes, long fiber-optic devices are needed. Many other smaller auxiliary heat exchangers in the power plant also require borescopes, fiberscopes, or video-image scopes to examine in the same way that the surface condenser is inspected for deposits and corrosion.

Additionally, other power plant equipment that can be examined by a borescope includes piping, valves, boilers, motors, and drives. Boilers are extensively examined with borescopes, fiberscopes, and video image scopes. Checks include boiler fittings for security; boiler feet for cracks and distortion; tube inner walls for corrosion, erosion, pitting, blockage and weld integrity; tube externals for corrosion, combustion buildup and fretting against tube supports; and boiler drums for scaling and buildup of chemicals.

4.9 Visual Examination Code Requirements

A brief summary of VT sections is taken from the following:

ASME: American Society of Mechanical Engineers
ANSI: American National Standards Institute
AWS: American Welding Society

4.9.1 ASME-Section V

A brief summary of the requirements for VT examination as contained in Article 9 follows:

- A report of the demonstration that the procedure was adequate is required.
- An annual vision test is required (J-1 letters).
- Direct Visual Examination is defined as a VT where the eye can be placed within the 24" of the surface to be examined and at an angle not less than 30° to the surface.
- Minimum light intensity of 100 foot candles at the examination surface.
- Remote Visual Examination is an acceptable substitute for Direct Visual Examination where accessibility is a problem.
- Translucent Visual Examination is a supplement of Direct Visual Examination and uses artificial lighting as an illumination to view a translucent object or material.

4.9.2 ASME Section XI

A summary of ASME IWA-2211 VT-1 requirements follows:

- The VT-1 visual examination is conducted to detect discontinuities and imperfections on the surfaces of components, including such conditions as cracks, wear, corrosion, or erosion.

- Direct VT-1 visual examination may be conducted when access is sufficient to place the eye within 24 inches of the surface to be examined and at an angle not less than 30° to the surface. Mirrors may be used to improve the angle of vision. Lighting, natural or artificial, shall be a minimum of 50 foot-candles (fc) and / or the ability to resolve a character of 0.044”.

- Remote VT-1 visual examination may be substituted for direct examination. Remote examination may use aids, such as telescopes, borescopes, fiber optics, cameras, or other suitable instruments, provided such systems have a resolution capability at least equivalent to that attainable by direct visual examination.

A summary of ASME IWA-2212 VT-2 requirements follows:

- The VT-2 visual examination is conducted to detect evidence of leakage from pressure retaining components, with or without leakage collection systems, as required during the conduct of system pressure test.

- VT-2 visual examinations are conducted in accordance with IWA-5000, "System Pressure Tests".

A summary of ASME IWA-2213 VT-3 requirements follows:

- The VT-3 visual examination shall be conducted to determine the general mechanical and structural condition of components and their supports, by verifying parameters of clearances, settings, physical displacements, and to detect discontinuities and imperfections such as loss of integrity at bolted or welded connections, loose or missing parts, debris, corrosion, wear, or erosion.

- VT-3 examinations also include examinations for conditions that could affect operability or functional adequacy of snubbers, and constant load and spring type supports.

  Lighting shall be a minimum of 50 fc and / or the ability to resolve a character of 0.105"

4.9.2.1 Supplemental Qualifications of VT Examination Personnel

Section XI, IWA-2300 includes additional requirements for VT examiners that should be addressed in the CP-189 Written Practice:

- Training, qualification, and certification of VT examiners must comply with the requirements of Appendix VI. This Appendix specifies the qualification requirements for VT examination personnel who will be performing VT-1, VT-2, and VT-3 examinations. It also contains Supplement 1, which describes the subjects to be included in the VT training course.

- IWA-2316 provides for Alternative Qualifications of VT-2 examination personnel:
  - 40-hour plant walk down experience, and
  - at least 40-hours of training in the Section XI requirements and plant-specific VT-2 procedures.

- IWA-2317 provides for Alterative Qualifications of VT-3 examination personnel:
  - at least 40-hours of plant experience, and
  - at least 8-hours of training in the Section XI requirements and plant-specific VT-3 procedures.

4.9.3 AWS Certified Welding Inspector

As in all format certification programs, the goal is to assure uniformity of a basic block of knowledge. To assure this uniformity and to set minimum standards for Welding Inspectors the American Welding Society (AWS) created its Certified Welding Inspector (CWI) program in 1976. The program consists of:

- Basic Body of Knowledge,

  - The Welding Inspector,
  - Documents Governing Welding Inspection and Control of Materials,
  - Weld Joint Geometry and Welding Terminology,
  - Welding and Nondestructive Testing Symbols,
  - Mechanical and Chemical Properties of Metals,
  - Destructive Testing,
  - Welding Metallurgy for the Welding Inspector,
  - Welding Procedure and Welder Qualification,
  - Welding, Brazing and Cutting Processes,
  - Weld and Base Metal Discontinuities,
  - Nondestructive Testing, and
  - Visual Inspection as an Effective Quality Control Tool.

- Minimum of five (5) years relevant work experience,

- Three part test covering fundamentals, practical on-the-job situations and a specific code (selected by the examinee). The test is administered at test sites around the country, and

- Vision Test.

Once the potential candidate meets the above requirements, he will be issued a certification from AWS. The certification is valid for three years. To renew the certification, the CWI must submit documentation showing continued work in the welding discipline or be re-examined.

4.10 Records

An examiner should be able to maintain adequate records, including writing clear and concise reports. Reports should include comments on the general character of the work, how well it stayed within prescribed tolerances, difficulties that occurred, and any discontinuities or rejectable conditions. Any repairs should be explained. Copies of these records should go to all persons entitled to receive them, and a copy should be kept for the examiner's own files. It should be remembered that facts well known at the time of the writing may not be recalled so clearly, completely, or accurately later. Checklists are helpful and can be used to document examination points during fabrication.

4.11 Advantage and Limitations of Visual Testing

4.11.1 Advantages

The advantages of VT are:

- Simplicity,
- Speed,
- Low cost (usually),
- Extensive training usually not necessary,
- Minimal equipment needed, and
- Can be performed while specimen is in use.

4.11.2 Limitations

The limitations of VT are:

- Only surface conditions can be detected or measured,
- Poor or variable resolution of eye,
- Fatigue,
- Distractions, and
- Some equipment is expensive.

Table 4-1. Precision, Accuracy, and Reliability

	PRECISION	ACCURACY	RELIABILITY
General Meaning	Exactness Degree of exactitude	Desirability	Probability of achieving desired results
Measures	Fineness of readings	Ratio of correct to incorrect readings	Probability of correct readings
Method of Stating	Within a 3-inch circle, plus or minus 0.001 inch	5 out of 10 50% of full scale	90% reliable
Specific Meaning	The lower the standard deviation of measurement, the higher the precision	The number of measurements within a specified standard as compared to those outside	The probability of performing without a specific function under given conditions for a specified period of time

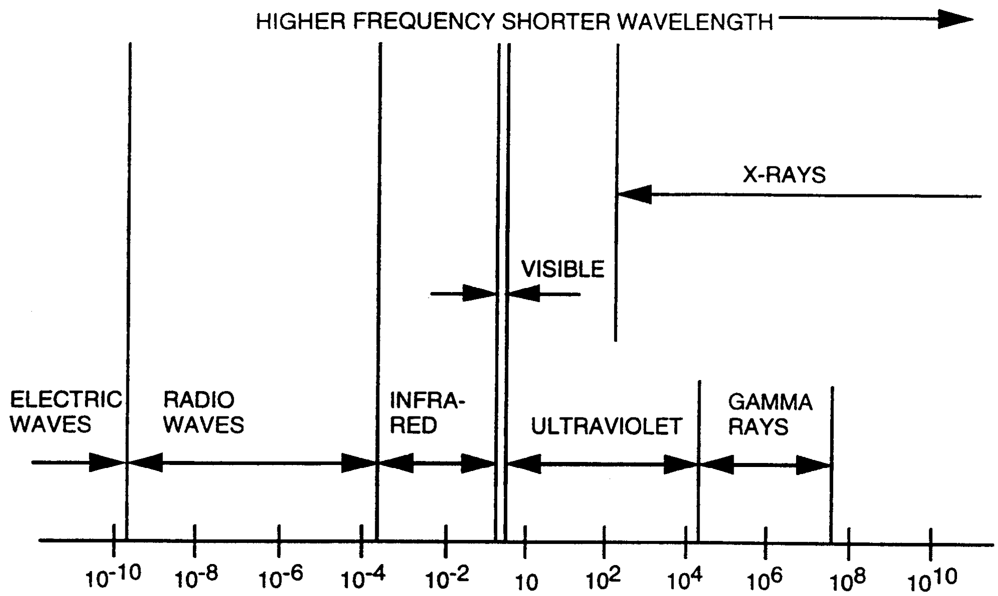

Figure 4-1 Electromagnetic Spectrum

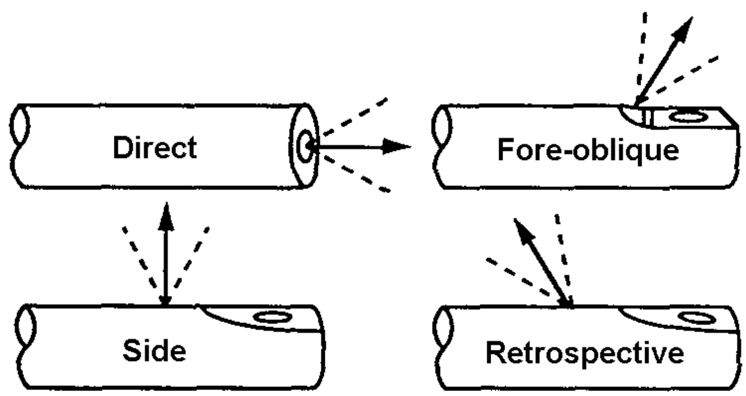

Figure 4-2 Direction of View (DOV)

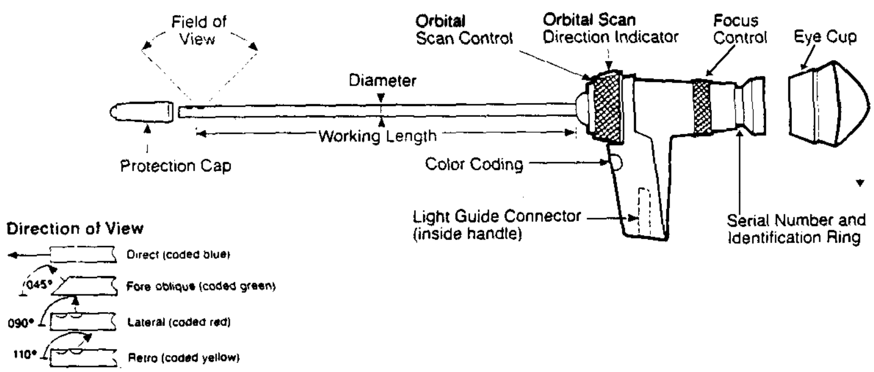

Figure 4-3 Typical Borescope

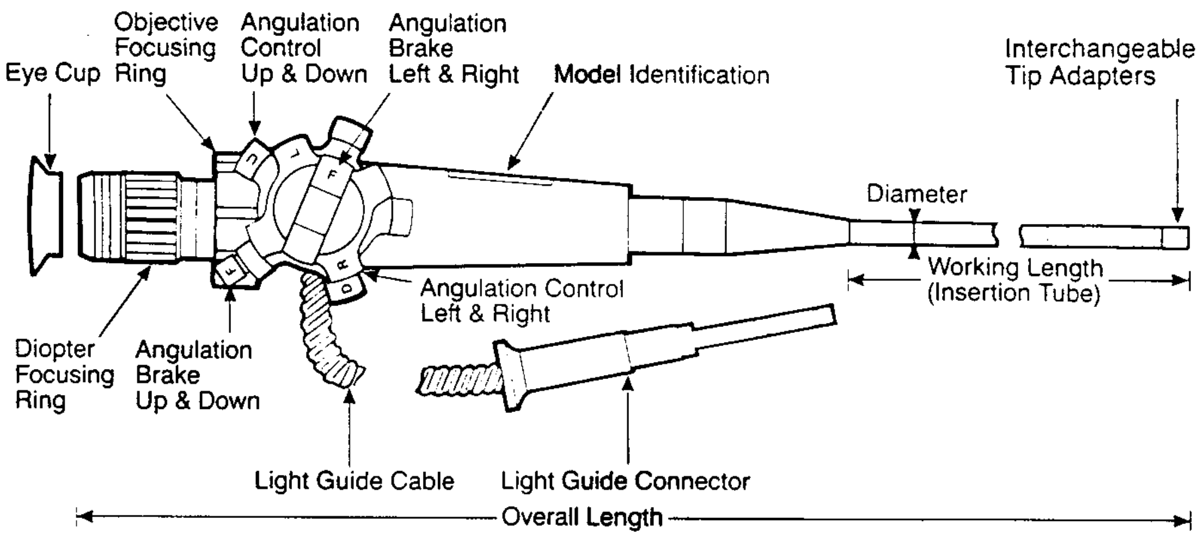

Figure 4-4 Fiberscope

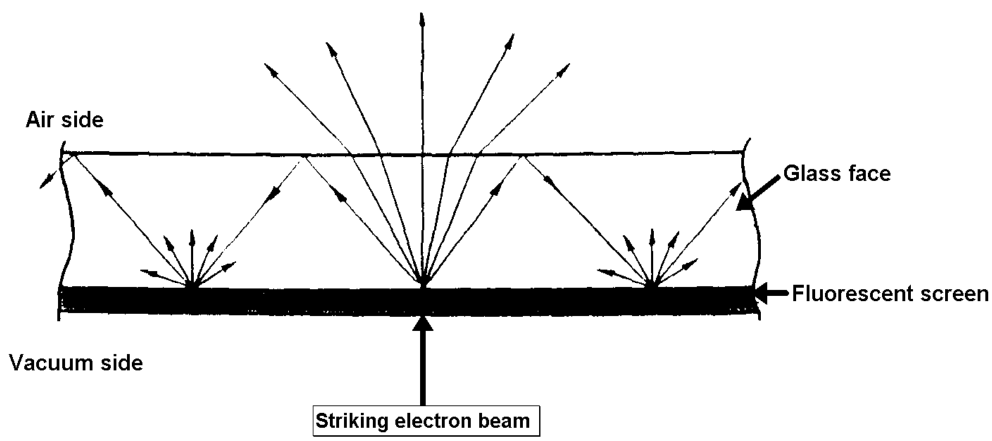

Figure 4-5 Halitation

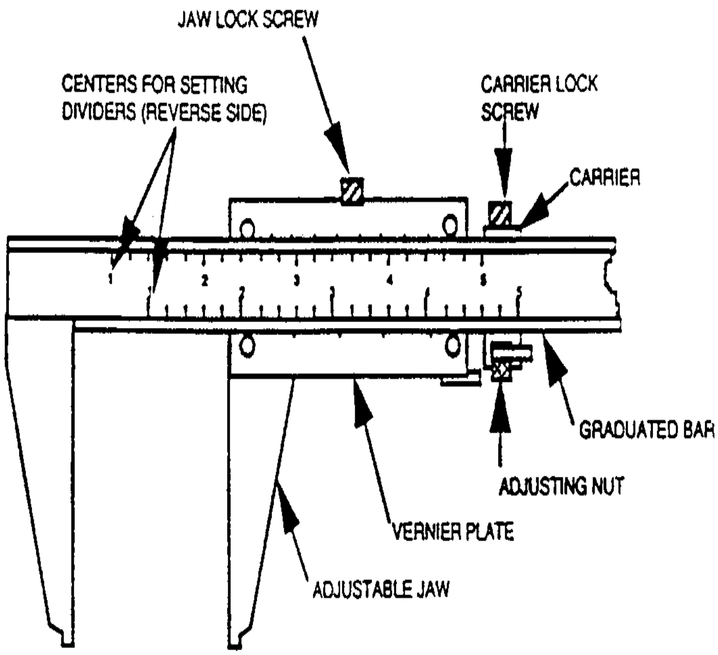

Figure 4-6 Vernier Caliper

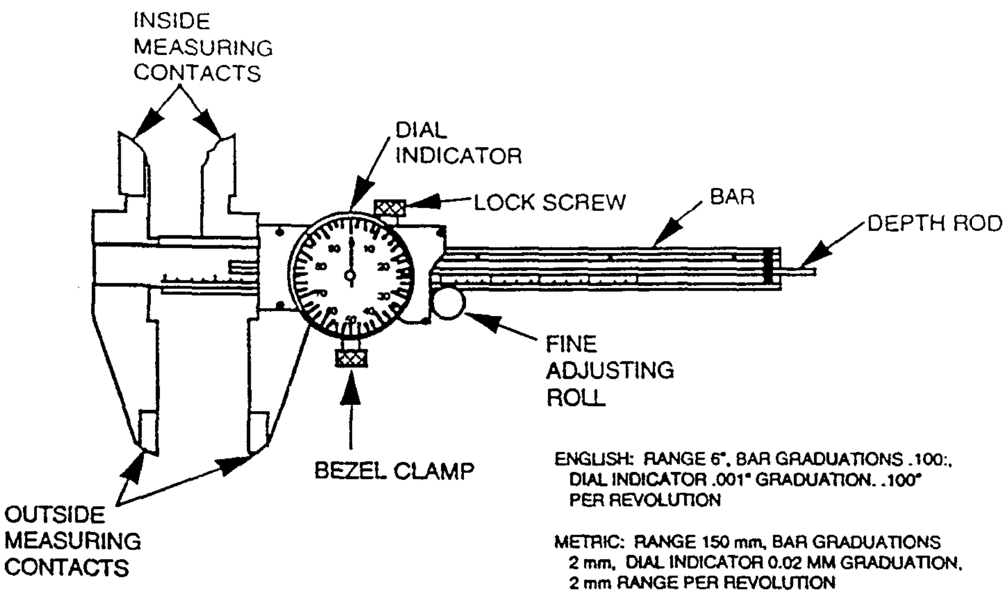

Figure 4-7 Dial Indicating Calipers

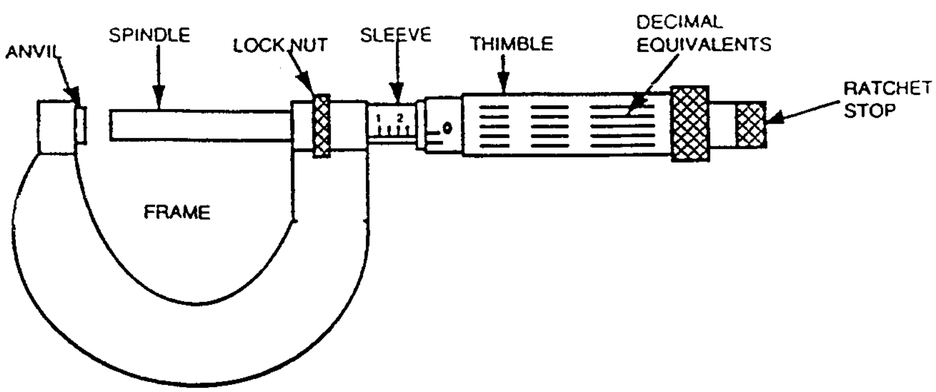

Figure 4-8 Micrometer

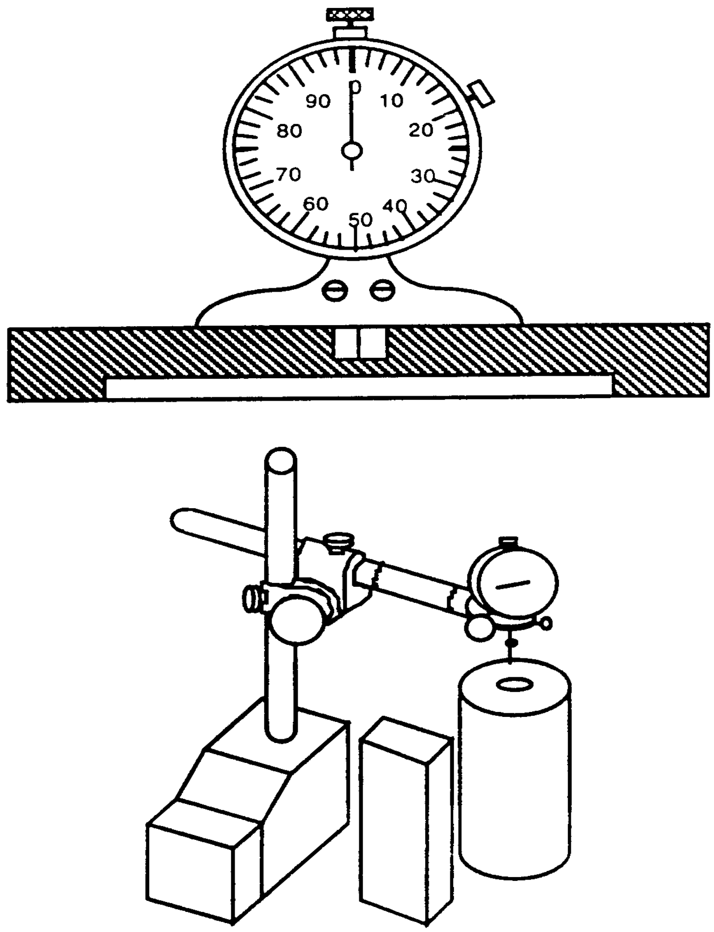

Figure 4-9 Dial Indicator

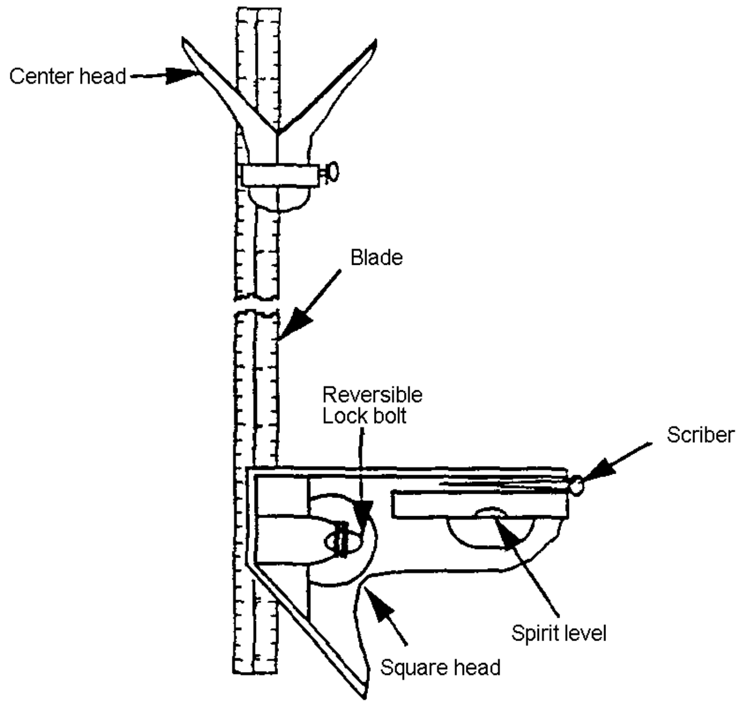

Figure 4-10 Combination Square Set

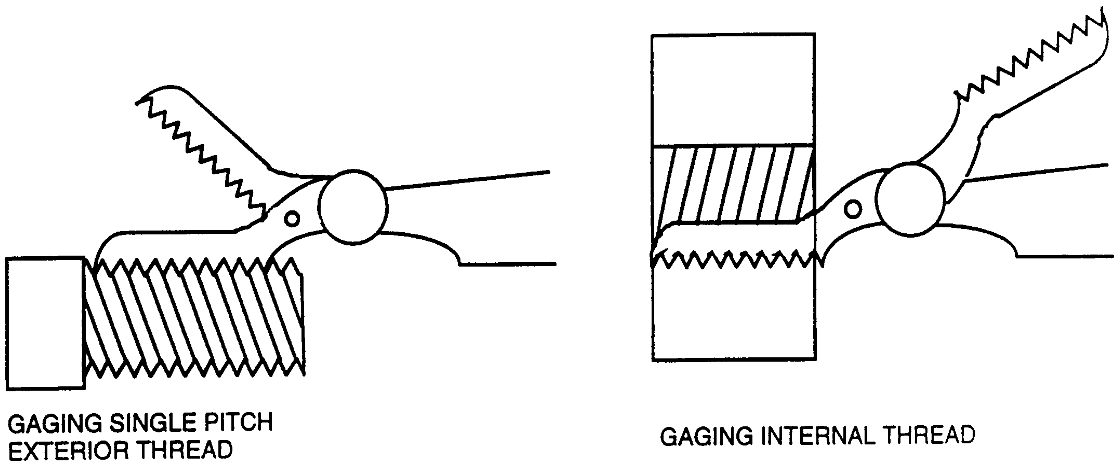

Figure 4-11 Thread Pitch Gages

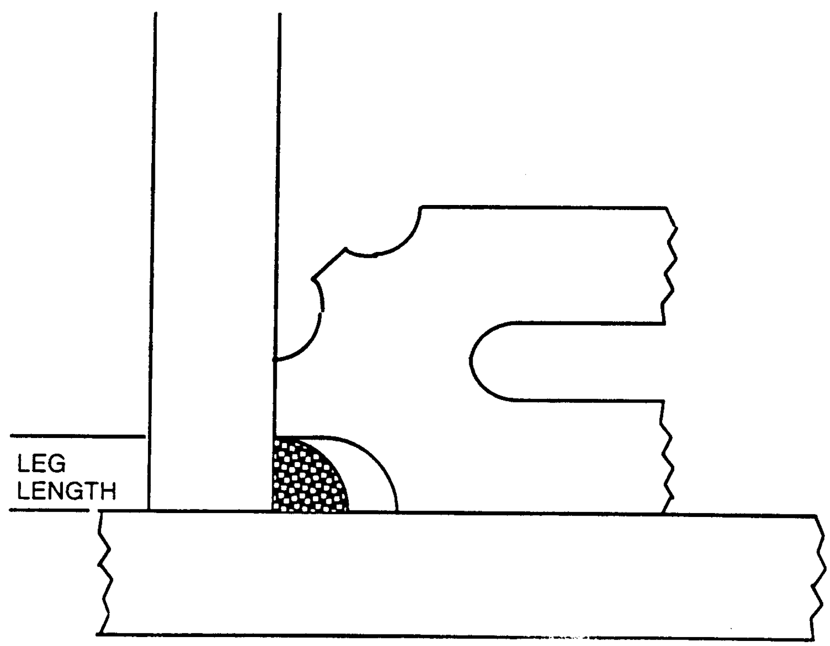

Figure 4-12 Measuring Convex Fillet Weld Size

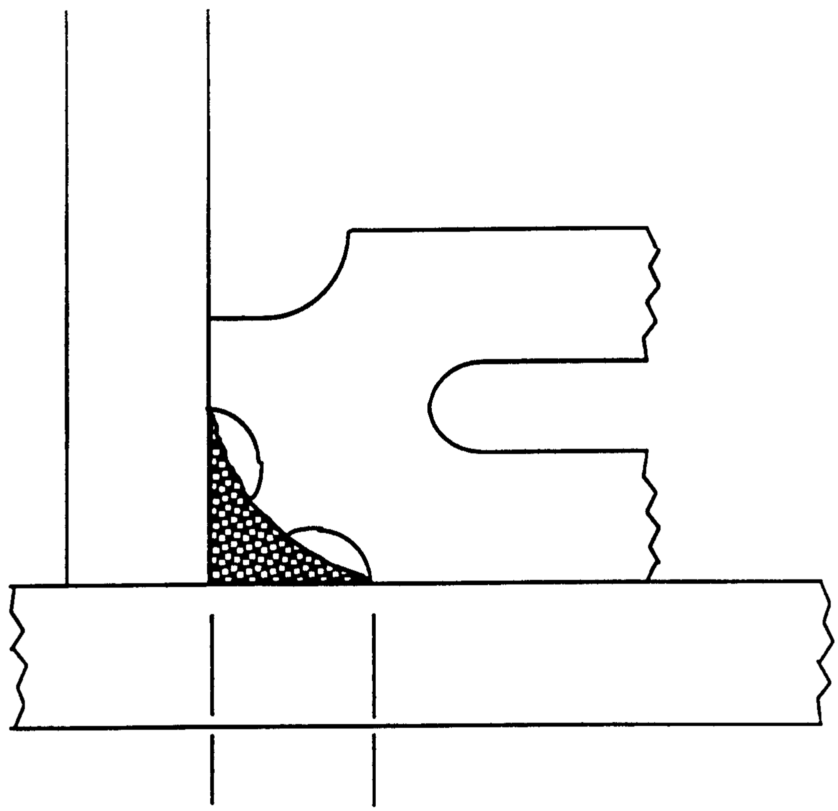

Figure 4-13 Measuring Concave Fillet Weld Size

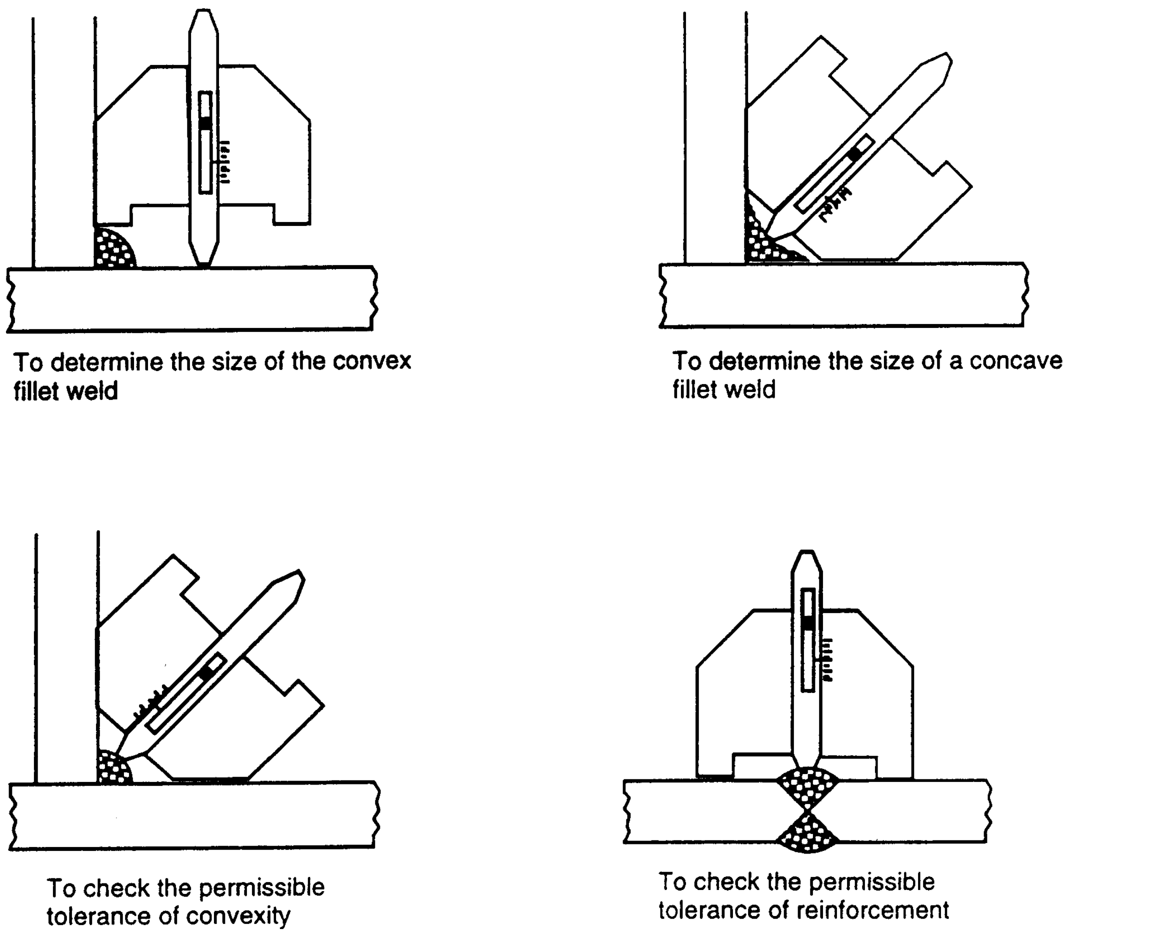

Figure 4-14 Palmgren Weld Gage

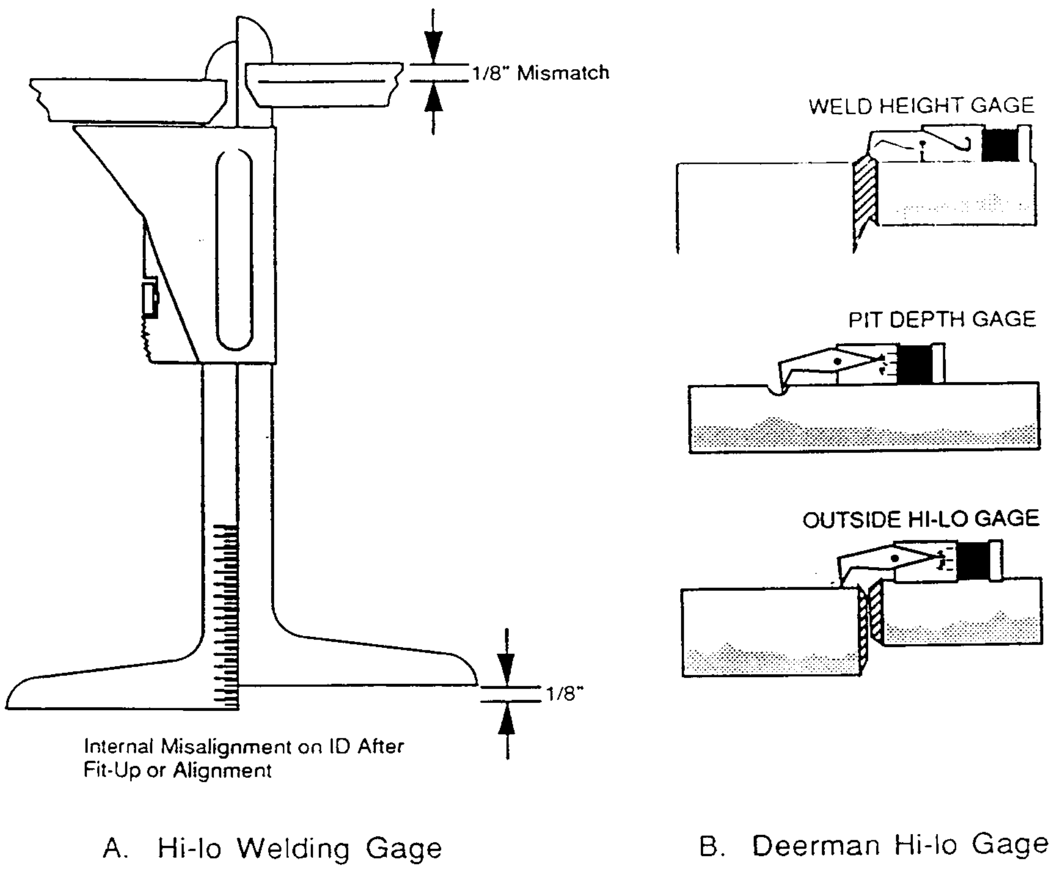

Figure 4-15 Weld Gages