UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of APPLICATION OF TEXAS UTILITIES GENERATING COMPANY, ET AL. FOR AN OPERATING LICENSE FOR COMANCHE PEAK STEAM ELECTRIC STATION UNITS #1 AND #2 (CPSES)	Docket Nos. 50-445 and 50-446

AFFIDAVIT OF JACK DOYLE

Q: Mr. Doyle, do you have any comments regarding Applicants' 1/17/84 Motion for Reconsideration of Memorandum and Order (Quality Assurance for Design)?

A: Yes, I do.

Specifically, on page 12, last paragraph, continued on page 13: Not only is this paragraph inaccurate, but a Senior Vice President of Gibbs & Hill (the Architect/Engineer at Comanche Peak), Mr. Scheppele, went to great lenths to prove that what went on outside my little box was none of my concern. See my Deposition/Testimony, CASE Exhibit 669, pages 257-260, for example.

On page 20, regarding Mr. Kerlin: I had indicated that Mr. Kerlin held a responsible position, not necessarily a supervisory position. One point is certain: I was not of equal rank with Mr. Kerlin; it is my understanding that I was in fact two grades lower in rank, as was Mr. Walsh (even though Mr. Walsh was the group leader).

On page 20, re: "Had Mr. Doyle reported this alleged deficiency to his supervisor . . ." etc.: This is not true. For example, I complained of cinching up of U-bolts and lack of inclusion of the structure of the support in seismic calculations. (See CASE Exhibit 669, Doyle Deposition/Testimony, pages 29 and 30; see also page 95, lines 15-24 and page 105, lines 1-17.) Every time such problems were brought to the attention of Mr. Krishnan, our supervisor at Comanche Peak, he either ignored the problems or told us to forget it. In reference to instability, it was a useless attempt in any event, since by his own testimony, Mr. Krishnan admitted that he had no idea what instability is. (Tr. 3940/1 through 3941/25, 3942/7 through 3943/23, 4908/15 through 4909/25, 4913/13-25, 4939/22-25, 4945/4-12, 4954/1-22, 4967/14-25, 4972/8-25 through 4975/13.)

On page 21, 2nd paragraph: Applicants' argument is without merit. During testimony by Applicants' witnesses, the instability problem was admitted to exist and again by Applicants' own admission corrective action was not instituted until sometime much later. (See CASE Proposed Findings, Section III.) Beyond this, the problem at Comanche Peak was more severe due to rotational problems of the clamp about the pipe. The problem (which was corrected) at the Fast Flux Test Facility (FFTF) involved clamps and struts (double pin ended), not box frames and U-bolts with a clearance to the pipe.

Page 21, last sentence, regarding "potentially unstable supports": I disagree. The testimony was in reference to <u>unstable</u> supports and in this particular case, like in pregnancy, the degree is irrelevant.

Page 21, footnote 22: The fact that an unstable support (rotational capability) exists in effect means that there is no support at this point.

And this fact means that a significant deficiency exists, as is attested to by the contents of NRC IE Bulletin 79-14, which was written to (among other reasons) address supports which were missing. In short, the instability addressed in these hearings is in reference to supports which could carry no load in one principal direction. See CASE Exhibit 669, Doyle Deposition/ Testimony, page 104, lines 1-8.

Page 23, last paragraph, continued on page 24: This paragraph is inaccurate. See for example, CASE Exhibit 669, Doyle Deposition/Testimony, pages 257-260 (in reference to the box in which Applicants like to place employees). See also the reference in the Circuit Breaker (given out onsite at Comanche Peak) to "disgruntled and misguided former employees"; and the reference of counsel for the Applicants to me as a non-expert to whom the Board should not listen in preference to Applicants' and NRC Staff's experts (in the May 1983 hearings regarding the upper lateral restraint). The intent of Applicants' counsel and experts has already been demonstrated in the record and the Board has correctly interpretted that intent.

Page 26, last paragraph, continued on page 27, regarding the argument in reference to 1084 supports and the 30 or 40 field tours. This argument, without listing what numbers of supports were done by each member of the group, is deceptive. (Also, Applicants have supplied no documentation relating to what per cent of the total supports at Comanche Peak this represents.) The production of Mark Walsh and me was always at the top of the group (this is by raw numbers only). In fact, I made a special effort to do the more complex (and time-consuming) problems. Mark Walsh and I obviously were doing a considerable amount of work and therefore had less time to wander about than is insinuated in Applicants' pleading. In fact, the 30 or 40 field tours referenced usually involved far less than one hour each. If more engineers were encouraged to go out into the field and look at what is actually in place, more problems would probably be caught.

It should also be noted that Mark Walsh and I saw many other problems during those field tours which the Board should probably also consider; I did not bring them up previously because I didn't have specifics regarding them. If the Board is interested, we could relate further problems detected in the course of our employment.

Page 28, first paragraph, in reference to U-bolt material: Applicants appear to be implying that we are dealing with two different animals here, but we are not. SA-307 is merely the designation for A36 type steel used as bolting material. See ASTM Standard Specification for Structural Steel, A36-77, Table 1 and item 3, Apurtenant Materials; or Section 2, Part A of ASME, which does not include Item 3 or Table 1 but only recognizes SA307 as low carbon bolting material.

Beyond this, the mechanical and chemical properties of SA307 bolts and SA36 rods which are threaded are identical and Applicants acknowledge that "SA-36 and SA-307 materials have equivalent material properties" (page 28, first paragraph of Applicants' pleading).

Page 28, second paragraph: Friction occurs whenever cinching is utilized to resist shear to prevent rotation of the U-bolt. Applicants are depending on cinching and thus friction between the pipe and the U-bolt to prevent rotation. Applicants are therefore not in compliance with ASME XVII-2462. See also ASME NF-3324.6 a.4, 1983 Edition.

Page 29: But this cinching up is not the practice intended by the manufacturer of the U-bolts, and this can be confirmed by reference to the gap allowed for pipe expansion by the manufacturer of the U-bolt. The inside dimensions of the U-bolt are larger than the pipe outside diameter to allow for expansion.

Page 29, last paragraph: The word is not insufficient; the key word is that the force is unpredictable and therefore could be greater than or less than anticipated.

Page 31, in reference to (stiff) quoted portion: But these are not conventional pipe clamps; these are cinched-up U-bolts which introduce a problem of point loading and pre-torquing versus the common area loading only that exists with a pipe clamp. (See CASE Exhibit 669B, Attachment to Doyle Deposition/Testimony, items 11YY, 11ZZ, 11AAA, and 11BBB.)

Page 31, middle of page, regarding pre-tensioning: Applicants have made a factual error: we are not concerned only with the piping, but with the U-bolt and the piping combination, as has been indicated in our testimony and in CASE's Proposed Findings. Beyond this, the pretorquing stresses induced by whatever type of clamp (sitff or otherwise) is equatable with the stresses in the pipe, as was pointed out in Board Notification 82-105A.

Page 32, first paragraph: Applicants are incorrect in stating that calculations do not exist for thermal expansion between U-bolts and pipes. See CASE Exhibit 763, Surrebuttal Testimony of Jack Doyle, page 13.

Page 32, last paragraph: Applicants may now consider local stresses for integral attachments, but they do not consider them for non-integral attachments, as was indicated by inference in Applicants' pleading, page 31 (stiff clamps vs. U-bolts).

Page 34, indented portion: This is in reference to procedure, but does not consider the limitations on the particular procedure; for example, the minimum weld which is required to insure that cracking does not exist or Beta angles which insure that the weld assumed actually exists, etc. These prohibitions go beyond the basic procedure. For example, in the case of minimum weld requirements, there are no tests which will preclude this requirement, because it relates to cracking of the weld relative to the stiffness of the joint and may or may not be present in any given series of tests. To avoid this requirement, a new procedure would be required controlling the welding itself; for example, preheating and control of the cooling rate of the total affected structure to eliminate the thermally induced strains which result in the craking of the weld. These procedures do not exist at Comanche Peak. The fillet weld applications are approached as if they were, in fact, prequalified.

Page 34, continued on page 35, footnote 36: The Board should note that if the drag angle requirement and work angle requirement is unknwon to Applicants, then it is obvious that this consideration has been violated. See Welding Handbook, 7th Edition, Volume 2, Copyrighted 1978, pages 69-72, Electrode Orientation (Attachment A hereto), which states, in part:

> "Electrode orientation, with respect to the work and the weld groove, is important to the quality of a weld. Improper orientation can result in slag entrapment, porosity, and undercutting."

Further, on page 71, Figure 2.14 of that document, the orientation for drag angle, push angle, and work angle are diagramatically depicted. On page

72, Table 2.3, the angular limitations for work angle, etc., are given. If the designer is not made aware of welding limitations, then his design will reflect this shortcoming and result in potentially deficient welds.

Page 34, last paragraph, and page 35, first full paragraph: If the Beta angle was incorporated May 11, 1982 (before intended plant completion anticipated during May 1982, while Mark Walsh and I were still at Comanche Peak), what procedure was used to perform the welds required during the period 1974-1982? (Applicants have again provided no documents.) And if, as the Applicants state, the program established for qualifying welds precluded consideration of each of the AWS criteria, why did this Beta criteria have to be added in mid-1982? Also, Applicants have presented no documentation that ITT Grinnell or NPSI follows the same Beta guidelines.

It appears that Applicants have proved our point.

Page 36, last paragraph, continued on page 37: The fact that something is done all the time is irrelevant, and is in fact a cause for concern, because it could just mean that they have been doing it wrong all the time. The purpose of minimum welding is to prevent weld cracking internally during cooling. Covering potential cracks with more weld material will not eliminate the internal cracks generated from improper welding previously. It may look good on the surface, but you can't tell what's underneath. To the best of my knowledge, in no code, including AWS, is the procedure for violation of minimum welds correction spelled out, since the Codes do not anticipate violation of standards as being a generic practice. See AWS Commentary, on Structural Welding Code -- Steel, 3rd Edition, Section 2, Design of Welded Connections, 2.7.1. Minimum Fillet Weld Sizes for Prequalified

Joints. NOTE: The minimum weld size is required to prevent cracking, not to act as a safety factor for loads which were not included in the analysis.

Page 37, last paragraph: The generic stiffness study which accompanied the NRC Staff affidavits on open items showed clearly that the loads on support points went up significantly when generic stiffness values were replaced with actual stiffness values. And when all the stiffnesses in the system (which is not the case in this study) are included, the actual stiffness value will be far less than those assumed in the generic stiffness study submitted by the NRC Staff.

The generic stiffness study does not indicate that with a 200% increase in load a problem does not exist throughout the plant. It only indicates that on that particular system, which had relatively light loading, no problem existed, probably because the stresses in the supports due to the light loads were only a few thousand psi and doubling or tripling would have no significant effect on the stress ratio. However, on other systems, as little as a 20% or 30% increase in loading could have a significant effect on stress ratios.

Page 37, last paragraph: As an example, using 7th Edition AISC steel tubes, the following will clarify the point. Assuming two conditions with a horizontal run of pipe, 20" off a wall, and supported by cantilever-type supports, two supports would exhibit the following: For one case, assume 800 lb. vertical load downward on a 3x3x1/4" tube with a moment of inertia of 3.16"^{4} and a section modulus of 2.10"^{3}. The stress would be 7,620 psi. Assuming an allowable of 24,000 psi, the stress ratio would be .3175. The deflection would be .024 inches. This would be within all of the allowables for this type of support at Comanche Peak.

On the other hand, for a 20" cantilever 4x4x3/8" tube with a moment of inertia of 10.2"^{4} and a section modulus of 5.1"^{3} and a 4,000 lb. vertical load, the stress level would be 15,686 psi. With the same 24,000 psi allowable, the stress ratio would be .6536. The deflection for these conditions would be .037 inches. Again, this would be within the allowables at Comanche Peak.

If the loads were to be increased by 60%, it can be seen from the above that the support with the 800 lb. load would still be within the allowables. But if we assume that since this is the case for the first instance that it also must be true for all cases, it is obvious that we would be wrong, since in the case of the 4,000 lb. load, the stress ratio would exceed 1 and the deflection level would be marginal relative to a 1/16" allowable. Beyond this, as the generic stiffness study showed, the variation can be greater than 60% increase and in fact can be well over 100% (200% of the original load and in some cases, far higher per cent, as was pointed out in the generic stiffness study in which one case indicated loads increased over 600%). Also, there are many supports with stress ratios of more than .654. I know because I worked on a number of them myself.

Page 39, last paragraph, continued on page 40: The problem goes beyond these tests (which were made with single bolts), since each bolt or two bolts of a group must be capable of carrying the full load or a substantial portion of the load assigned the group, and not the group load divided by the number of bolts. The interaction of the loads vs. a bolt system is dependent on the location of each of the bolts in oversize holes vs. the bearing area which is available to transmit the loads.

Q: Mr. Doyle, do you have any comment regarding Applicants' proposal that additional hearings be held on the closed Walsh/Doyle items?

A: Yes, I do. It seems incongruous that after 18 months, we now find ourselves facing an Applicant who was all too willing to decide the issue on the evidence available in September of 1982 now wishing to go on to a new presentation under new ground rules. And this would appear to be an unprecedented procedure in any legal forum. Without resorting to profanity, I can think of no words to express my feeling on the Applicants' new desire to pursue this matter ad infinitum until such point as Applicants can convince themselves or the Board that Applicants are correct.

The Five Volumes of the Welding Handbook, Seventh Edition

1 Fundamentals of Welding

2 Welding Processes–

Arc and Gas Welding and Cutting, Brazing, and Soldering

3 Welding Processes–

Resistance and Solid State Welding and Other Joining Processes

4 Engineering Applications–Materials

5 Engineering Applications–Design

Attachment A

Welding Handbook

Seventh Edition, Volume 2

Welding Processes– Arc and Gas Welding and Cutting, Brazing, and Soldering

W.H. Kearns, Editor

AMERICAN WELDING SOCIETY
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proper control of the molten weld pool. For vertical and overhead welding, the optimum amperages would be likely to be on the low end of the allowable range.

Amperage beyond the recommended range should not be used. It can overheat the electrode and cause excessive spatter, arc blow, undercut, and weld metal cracking. Figures 2.13(B) and (C) show the effect of amperage on bead shape.

ARC LENGTH

The arc length is the distance from the molten tip of the electrode core wire to the surface of the molten weld pool. Proper arc length is important in obtaining a sound welded joint. Metal transfer from the tip of the electrode to the weld pool is not a smooth, uniform action. Instantaneous arc voltage varies as droplets of molten metal are transferred across the arc, even with constant arc length. However, any variation in voltage will be minimal when welding is done with the proper amperage and arc length. The latter requires constant and consistent electrode feed.

The correct arc length varies according to the electrode classification, diameter, and covering composition; it also varies with amperage and welding position. Arc length increases with increasing electrode diameter and amperage. As a general rule, the arc length should not exceed the diameter of the core wire of the electrode. The arc usually is shorter than this for electrodes with thick coverings, such as iron powder or "drag" electrodes.

Too short an arc will be erratic and may short circuit during metal transfer. Too long an arc will lack direction and intensity, which will tend to scatter the molten metal as it moves from the electrode to the weld. The spatter may be heavy and the deposition efficiency low. Also, the gas and flux generated by the covering are not as effective in shielding the arc and the weld metal from air. The poor shielding can cause porosity and contamination of the weld metal by oxygen or nitrogen, or both. The quality of the weld will be poor.

Control of arc length is largely a matter of welder skill, involving the welder's knowledge, experience, visual perception, and manual dexterity. Although the arc length does change to some extent with changing conditions, certain fundamental principles can be given as a guide to the proper arc length for a given set of conditions.

For downhand welding, particularly with heavy electrode coverings, the tip of the electrode can be dragged lightly along the joint. The arc length, in this case, is automatically determined by the coating thickness and the melting rate of the electrode. Moreover, the arc length is uniform. For vertical or overhead welding, the arc length is gaged by the welder. The proper arc length, in such cases, is the one that permits the welder to control the size and motion of the molten weld pool.

For fillet welds, the arc is crowded into the joint for highest deposition rate and best penetration. The same is true of the root passes in groove welds in pipe.

When arc blow is encountered, the arc length should be shortened as much as possible. The various classifications of electrodes have widely different operating characteristics, including arc length. It is important, therefore, for the welder to be familiar with the operating characteristics of the types of electrodes he uses in order to recognize the proper arc length and to know the effect of different arc lengths. The effect of a long and a short arc on bead appearance with a mild steel electrode is illustrated in Figs. 2.13(D) and (E).

TRAVEL SPEED

Travel speed is the rate at which the electrode moves along the joint. The proper travel speed is the one which produces a weld bead of proper contour and appearance, as shown in Fig. 2.13(A). Travel speed is influenced by several factors. Some of these are

(1) Type of welding current, amperage, and polarity
(2) Position of welding
(3) Melting rate of the electrode
(4) Thickness of material
(5) Surface condition of the base metal
(6) Type of joint
(7) Joint fit-up
(8) Electrode manipulation

When welding, the travel speed should be

adjusted so that the arc slightly leads the molten weld pool. Up to a point, increasing the travel speed will narrow the weld bead and increase penetration. Beyond this point, higher travel speeds can decrease penetration; cause the surface of the bead to deteriorate and produce undercutting at the edges of the weld; make slag removal difficult; and entrap gas (porosity) in the weld metal. The effect of high travel speed on bead appearance is shown in Fig. 2.13(G). With low travel speed, the weld bead will be wide and convex with shallow penetration, as illustrated in Fig. 2.13(F). The shallow penetration is caused by the arc dwelling on the molten weld pool instead of leading it and concentrating on the base metal. This, in turn, affects dilution. When dilution must be kept low (as in cladding), the travel speed, too, must be kept low.

Travel speed also influences heat input, and this affects the metallurgical structures of the weld metal and the heat-affected zone. Low travel speed increases heat input and this, in turn, increases the size of the heat-affected zone and reduces the cooling rate of the weld. Forward travel speed is necessarily reduced with a weave bead as opposed to the higher travel speed that can be attained with a stringer bead. Higher travel speed reduces the size of the heated-affected zone and increases the cooling rate of the weld. The increase in the cooling rate can increase the strength and hardness of a weld in a hardenable steel, unless preheat of a level sufficient to prevent hardening is used.

ELECTRODE ORIENTATION

Electrode orientation, with respect to the work and the weld groove, is important to the quality of a weld. Improper orientation can result in slag entrapment, porosity, and undercutting. Proper orientation depends on the type and size of electrode, the position of welding, and the geometry of the joint. A skilled welder automatically takes these into account when he determines the orientation to be used for a specific

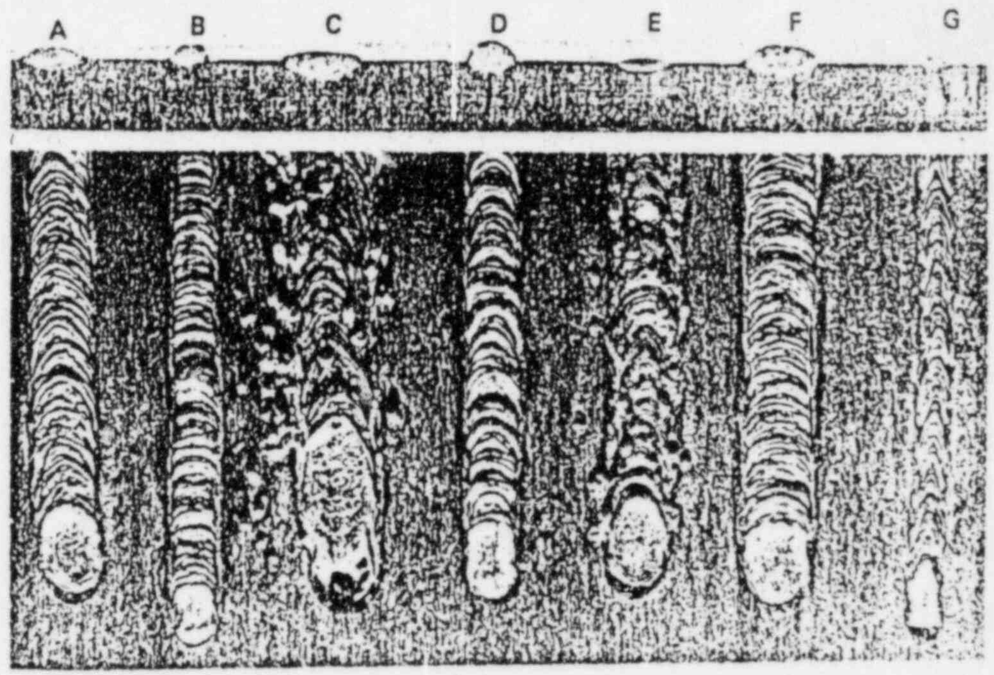

Fig. 2.13—The effect of welding amperage, arc length, and travel speed on covered electrode weld beads: (A) proper amperage, arc length, and travel speed; (B) amperage too low; (C) amperage too high; (D) arc length too short; (E) arc length too long; (F) travel speed too slow; (G) travel speed too fast

joint. Travel angle and work angle are used to specify electrode orientation.

Travel angle is the angle which the electrode makes with a reference line that both lies in a plane through the axis of the weld and is perpendicular to that axis. *Work angle* is the angle which the electrode makes with a surface of the base metal in a plane perpendicular to the axis of the weld. When the electrode is pointed in the direction of welding, the *forehand* technique is being used. The travel angle, then, is known as the *push angle*. The *backhand* technique involves pointing the electrode in the direction opposite that of welding. The travel angle, then, is called the *drag angle*. These angles are shown in Fig. 2.14.

Typical electrode orientation and welding technique for groove and fillet welds, with carbon steel electrodes, are listed in Table 2.3. These may be different for other materials. Correct orientation provides good control of the molten weld pool, the desired penetration, and complete fusion with the steel base.

A large travel angle may cause a convex, poorly shaped bead with inadequate penetration, whereas a small travel angle may cause slag entrapment. A large work angle can cause undercutting, while a small work angle can result in lack of fusion.

WELDING TECHNIQUE

The first step in SMAW is to assemble the proper equipment, materials, and tools for the job. Next, the type of welding current and the polarity, if dc, need to be determined and the power source set accordingly. The power source must also be set to give the proper volt-ampere characteristic (open-circuit voltage) for the size and type of electrode to be used. After this, the work is positioned for welding and, if necessary, clamped in place.

The arc is struck by tapping the end of the electrode on the work near the point where welding is to begin, then quickly withdrawing it a small amount to produce an arc of proper length. Another technique for striking the arc is to use a scratching motion similar to that used in striking a match. When the electrode touches the work, there is a tendency for them to stick together. The purpose of the tapping and scratching motion is to prevent this. When the electrode does stick, it needs to be quickly broken free. Otherwise, it will overheat, and attempts to remove it from the workpiece will only bend the hot electrode. Freeing it then will require a hammer and chisel.

The technique of restriking the arc once it has been broken varies somewhat with the type of electrode. Generally, the covering at the tip of the electrode becomes conductive when it is heated during welding. This assists in restriking the arc if it is restruck before the electrode cools. Arc striking and restriking are much easier for electrodes with large amounts of metal powders in their coverings. Such coverings are conductive when cold. When using heavily covered electrodes which do not have conductive coatings, such as E6020, low hydrogen, and stainless steel electrodes, it may be necessary to break off the projecting covering to expose the core wire at the tip for easy restriking.

Striking the arc with low hydrogen electrodes requires a special technique to avoid porosity in the weld at the point where the arc is started. This technique consists of striking the arc a few electrode diameters ahead of the place where welding is to begin. The arc is then quickly moved back, and welding is begun in the normal manner. Welding continues over the area where the arc originally was struck, re-fusing any small globules of weld metal that may have remained from striking the arc.

During welding, the welder maintains a normal arc length by uniformly moving the electrode toward the work as the electrode melts. At this same time, the electrode is moved uniformly along the joint in the direction of welding, to form the bead.

Any of a variety of techniques may be employed to break the arc. One of these is to rapidly shorten the arc, then quickly move the electrode sideways out of the crater. This technique is used when replacing a spent electrode, in which case welding will continue from the crater. Another technique is to stop the forward motion of the electrode and allow the crater to fill, then gradually withdraw the electrode to break the arc. When continuing a weld from a crater, the arc should be struck at the forward end of the crater. It should then quickly be moved to the back of

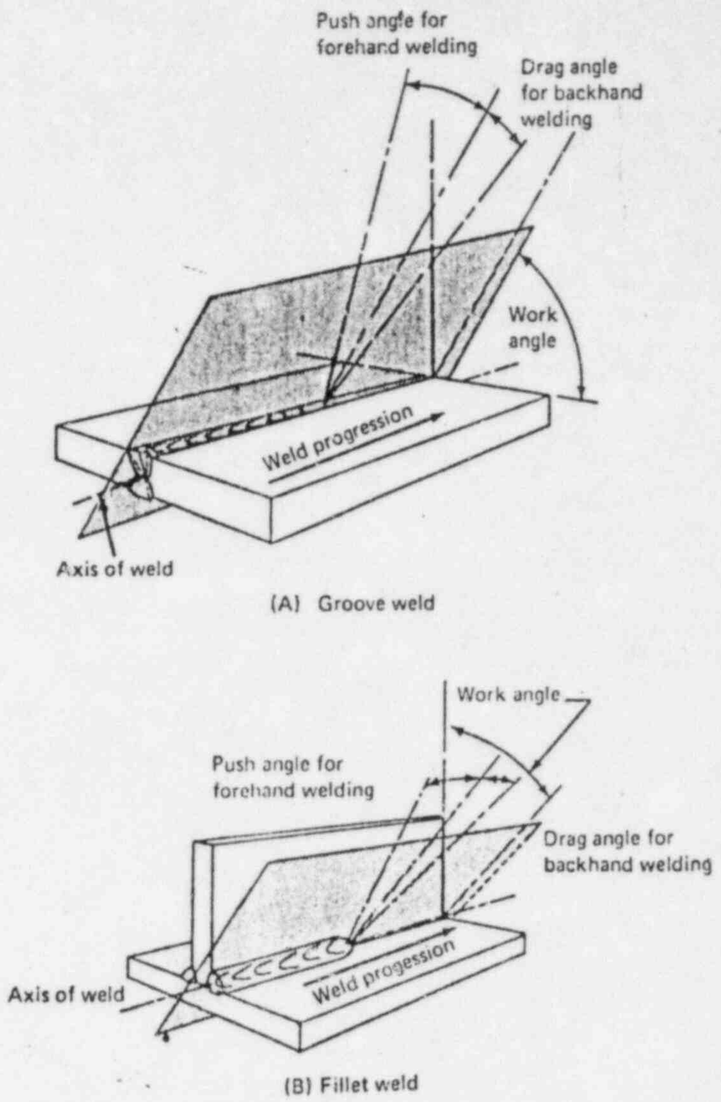

Fig. 2.14—Orientation of the electrode

the crater and slowly brought forward to continue the weld. In this manner, the crater is filled, and porosity and entrapped slag are avoided. This technique is particularly important for low hydrogen electrodes.

SLAG REMOVAL

The extent to which slag is removed from each weld bead before welding over the bead has a direct bearing on the quality of a multiple pass weld. Failure to thoroughly clean each bead increases the probability of trapping slag and, thus, producing a defective weld. Complete and efficient slag removal requires that each bead be properly contoured and that it blend smoothly into the adjacent bead or base metal.

Small beads cool more rapidly than large ones. This tends to make slag removal from small beads easier. Concave or flat beads that wash smoothly into the base metal or any adjoining beads minimize undercutting and avoid a sharp notch along the edge of the bead where slag could stick. Finally, it is most important that welders be able to recognize areas where slag entrapment is likely to occur. Skilled welders understand that complete removal of slag is necessary before continuing a weld.

WELDING GROUND

Proper grounding of the workpiece is a necessary consideration in shielded metal arc welding. The location of the ground is especially important with dc welding. Improper location may promote arc blow, making it difficult to control the arc. Moreover, the method of attaching the ground is important. A poorly attached ground will not provide consistent electrical contact, and the connection will heat up. This can lead to an interruption of the circuit and a breaking of the arc. A copper contact shoe secured with a C-clamp is best. If copper pickup by this attachment to the base metal is detrimental, the copper shoe should be attached to a plate that is compatible with the work. The plate, in turn, is then secured to the work. For rotating work, contact should be made by shoes sliding on the work or through roller bearings on the spindle on which the work is mounted. If sliding shoes are used, at least two shoes should be employed. If loss of contact occurred with only a single shoe, the arc would be extinguished.

ARC STABILITY

A stable arc is required if high quality welds are to be produced. Such defects as inconsistent fusion, entrapped slag, blowholes, and porosity can be the result of an unstable arc.

The important factors influencing arc stability are

(1) The open-circuit voltage of the power source

(2) Transient voltage recovery characteristics of the power source

(3) Size of the molten drops of filler metal and slag in the arc

(4) Ionization of the arc path from the electrode to the work

(5) Manipulation of the electrode

The first two factors are related to the design and operating characteristics of the power source. The next two are functions of the welding electrode. The last one represents the skill of the welder.

The arc of a covered electrode is a transient arc, even when the welder maintains a fairly constant arc length. The welding machine must be able to respond rapidly when the arc tends to go out, or it is short circuited by large droplets of metal bridging the arc gap. In that case, a surge of current is needed to clear a short circuit. With ac, it is important that the voltage lead the current in going through zero. If the two were in phase, the arc would be very unstable. This phase shift must be designed into the welding machine.

Some electrode covering ingredients tend to stabilize the arc. These are necessary ingredients for an electrode to operate well on ac. A few of these ingredients are titanium dioxide, feldspar, and various potassium compounds (including the binder, potassium silicate). The inclusion of one or more of these arc stabilizing compounds in the covering provides a large number of readily ionized particles and thereby contributes to ionization of the arc stream. Thus, the electrode,

Table 2.3—Typical shielded metal arc electrode orientation and welding technique for carbon steel electrodes

Type of joint	Position of welding	Work angle, deg	Travel angle, deg	Technique of welding
Groove	Flat	90	5-10*	Backhand
Groove	Horizontal	80-100	5-10	Backhand
Groove	Vertical-up	90	5-10	Forehand
Groove	Overhead	90	5-10	Backhand
Fillet	Horizontal	45	5-10*	Backhand
Fillet	Vertical-up	35-55	5-10	Forehand
Fillet	Overhead	30-45	5-10	Backhand

the power source, and the welder, all contribute to arc stability.

ARC BLOW

Arc blow, when it occurs, is encountered principally with dc welding of magnetic materials (iron and nickel). It may be encountered with ac, under some conditions, but those cases are rare and the intensity of the blow is always much less severe. Direct current, flowing through the electrode and the base metal, sets up magnetic fields around the electrode which tend to deflect the arc from its intended path. The arc may be deflected to the side at times, but usually it is deflected either forward or backward along the joint. Back blow is encountered when welding toward the ground near the end of a joint or into a corner. Forward blow is encountered when welding away from the ground at the start of the joint, as shown in Fig. 2.15.

Arc blow may become so severe at times that a satisfactory weld cannot be made. Incomplete fusion and excessive weld spatter result. To those who are welding with iron powder electrodes or to those with other electrodes that produce a large amount of slag, foward blow is especially troublesome. It permits the molten slag, which normally is confined to the edge of the crater, to run forward under the arc.

The bending of the arc under these conditions is caused by the effects of an unbalanced magnetic field. When there is a greater concentration of magnetic flux on one side of the arc than on the other, the arc always bends away from the greater concentration. The source of the magnetic flux is indicated by the electrical rule which states that a conductor carrying an electric current produces a magnetic flux in circles around the conductor. These circles are in planes perpendicular to the conductor and are centered on the conductor.

In welding, this magnetic flux is superimposed on the steel and across the gap to be welded. The flux in the plate does not cause difficulty, but unequal concentration of flux across the gap or around the arc causes the arc to bend away from the heavier concentration. Since the flux passes through steel many times more readily than it

remain within the steel plates. For this reason, the flux around the electrode, when the electrode is near either end of the joint, is concentrated between the electrode and the end of the plate. This high concentration of flux on one side of the arc, at the start or the finish of the weld, deflects the arc away from the ends of the plates.

Forward blow exists for a short time at the start of a weld, then it diminishes. This is because the flux soon finds an easy path through the weld metal. Once the magnetic flux behind the arc is concentrated in the plate and the weld, the arc is influenced mainly by the flux in front of it as this flux crosses the root opening. At this point, back blow may be encountered. Back blow can occur right up to the end of the joint. As the weld approaches the end, the flux ahead of the arc becomes more crowded, increasing the back blow. Back blow can become extremely severe right at the very end of the joint.

The welding current passing through the work creates a magnetic field around it. The field is perpendicular to the path of current between the arc and the ground clamp. The flux field around the arc is perpendicular to the one in the work. This concentrates the magnetic flux on the ground side of the arc and tends to push the arc away. The two flux fields mentioned above are, in reality, one field. That field is perpendicular to the path of the current through the cable, the work, the arc, and the electrode.

Unless the arc blow is unusually severe, certain corrective steps may be taken to eliminate it or, at least, to reduce its severity. All or only some of the following steps may be necessary:

(1) Place ground connections as far as possible from the joints to be welded.

(2) If back blow is the problem, place the ground connection at the start of welding, and weld toward a heavy tack weld.

(3) If forward blow causes trouble, place

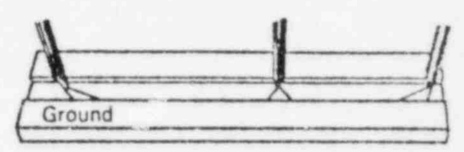

Fig. 2.15—The effect of ground location on magnetic arc blow

I have read the foregoing affidavit, which was prepared under my personal direction, and it is true and correct to the best of my knowledge and belief.

Jack J Doyle
(Signed)

Date: Jan 28 1984

STATE OF Massachusetts

COUNTY OF Worcester

On this, the 28th day of January, 1984, personally appeared Jack J. Doyle, known to me to be the person whose name is subscribed to the foregoing instrument, and acknowledged to me that he executed the same for the purposes therein expressed.

Subscribed and sworn before me on the 28th day of January, 1984.

Norma A. Porter
Notary Public in and for the
State of Massachusetts

My Commission Expires: MY COMMISSION EXPIRES JANUARY 9, 1987