Designation: E 751 – 01

Standard Practice for Acoustic Emission Monitoring During Resistance Spot-Welding[1]

This standard is issued under the fixed designation E 751; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes procedures for the measurement, processing, and interpretation of the acoustic emission (AE) response associated with selected stages of the resistance spot-welding process.

1.2 This practice also provides guidelines for feedback control by utilizing the measured AE response signals during the spot-welding process.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Agencies Performing Nondestructive Testing[2]

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *ASNT Standards:*[3]

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[4]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to acoustic emission testing, see Section B of Terminology E 1316.

4. Significance and Use

4.1 The AE produced during the production of a spot-weld can be related to weld quality parameters such as the strength and size of the nugget, the amount of expulsion, and the amount of cracking. Therefore, in-process AE monitoring can be used both as an examination method, and as a means for providing feedback control.

5. Basis of Application

5.1 *Personnel Qualification*—

5.1.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, NAS-410 or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

5.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

5.3 *Procedures and Techniques*—The procedures and techniques to be used shall be as described in this practice unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6. Ordering Information

6.1 If the spot-weld monitoring or process control methods described in this practice are performed as a service, the following items should be addressed in the purchase specification, and are subject to agreement between the purchaser and the supplier:

6.1.1 Description of the welded parts in terms of geometry, dimensions, number and position of welds, and materials.

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[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission.

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[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

6.1.2 Description of the welding machine, type and dimensions of the electrodes, type of weld controller, welding schedule, and distance between the welding head and the controller.

6.1.3 Location and mounting method for the acoustic emission sensors, and design of the mounting fixture, as appropriate.

6.1.4 In the event that the process is actually controlled by acoustic emission, the circuit requirements associated with the electronic interface to the weld controller to ensure synchronous operation.

6.1.5 The performance and limiting AE parameters which were predetermined.

6.1.6 Method of recording or reporting (that is, form and content of the report), if applicable.

6.1.7 Technical qualifications of the personnel performing the examination. These should be based on a documented program that certifies personnel for conducting AE examinations.

7. Principles of Application

7.1 The resistance spot-welding process consists of several stages. These are the set-down of the electrodes, squeeze, current flow, forging, hold time, and lift-off. Various types of acoustic emission signals are produced during each of these stages. Often, these signals can be identified with respect to the nature of their source. The individual signal elements may be greatly different, or totally absent, in various materials, thicknesses, and so forth. Fig. 1 is a schematic representation showing typical signal elements which may be present in the AE signature from a given spot-weld.

7.2 Most of the depicted AE signal features can be related to factors of weld quality. The AE occurring during set-down and squeeze can often be related to the condition of the electrodes and the surface of the parts. The large, often brief, signal at current initiation can be related to the initial resistance, and the cleanliness of the part. For example, burning through of certain oxide layers contributes to the acoustic emission response during this time.

7.2.1 During current flow, plastic deformation, nugget expansion, friction, melting, and expulsions produce AE signals. The signals caused by expulsion (spitting or flashing, or both) generally have large amplitudes and can be distinguished from the rest of the acoustic emission associated with nugget formation. Fig. 2 shows typical AE response signals during current flow for both d-c and a-c welding.

7.2.2 Following termination of the welding current, some materials exhibit appreciable AE noise during solidification which can be related to nugget size and inclusions. As the nugget cools during the hold period, AE can result from solid-solid phase transformations and cracking.

7.2.3 During the lift-off stage, separation of the electrode from the part produces signals that can be related to the condition of the electrode as well as the cosmetic condition of the weld.

7.3 Using time, and amplitude or energy discrimination, or both, the AE response corresponding to each stage can be separately detected and analyzed. Although the AE associated with each stage of the spot-welding process can be relevant to weld quality, this practice only gives detailed consideration to the AE generated by nugget formation and expansion, expulsion, and cracking.

8. Apparatus

8.1 *Acoustic Emission System*:

8.1.1 The AE sensor should be a contacting type having an appropriate frequency response within the range from 0.1 to 1.0 MHz. Free resonances associated with electrode vibrations may necessitate the use of sensors with a frequency response in the range from 0.30 to 1.0 MHz.

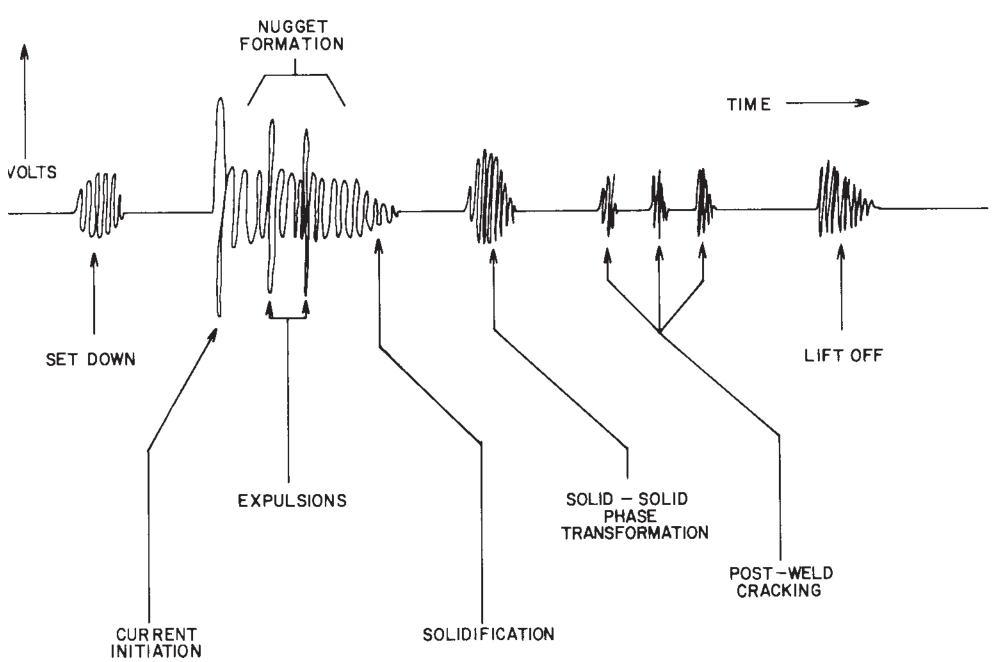

FIG. 1 Typical AE Response Signals During Resistance Spot Welding

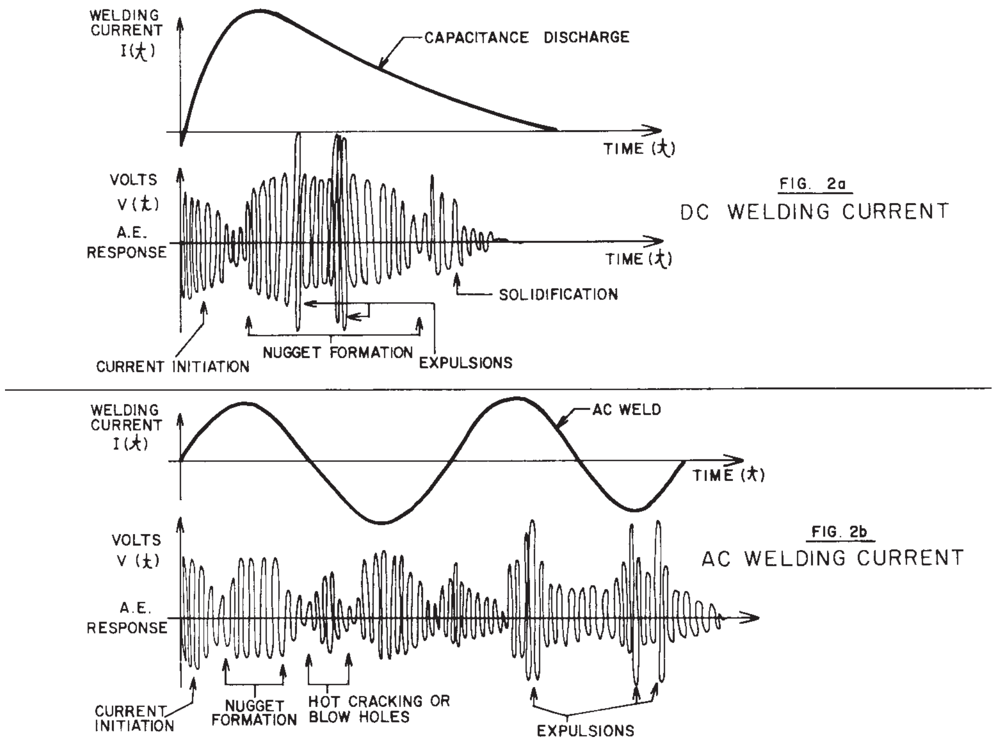

FIG. 2 Typical AE Response Signals During Current Flow

8.1.2 The electronic instrument should contain adjustable amplification over the range from 40 to 100 dB, or an equivalent amplification and adjustable threshold. The instrument should be capable of performing time and amplitude or energy discrimination. Using some timing reference, it is necessary to detect the AE contained within a certain time interval and within a certain signal or energy amplitude range. This is required for each characteristic stage of the AE signal that is to be separately measured. Thus, the instrument should contain one or more signal amplitude or energy level detectors, timing gates, and counters. It should also contain a comparator and signaling output if it is used for on-line monitoring.

8.1.3 If feedback control is to be used, the instrument should facilitate the selection of an optimum AE level, and it should generate an appropriate control signal whenever this level is exceeded. This control signal should terminate the welding synchronously with the zero-crossing points of the weld current.

8.2 *Support Equipment*—An analog or digital waveform recorder is normally used for performing measurements. A means for detecting current initiation independent from the AE signals should be available.

8.3 *Data-Recording Devices* (optional)—If it is desired to record processed AE data permanently, a digital printer, tape recorder, or similar device must be interfaced with the AE instrument.

8.4 *Audio or Visual Alarm*—An alarm can be used in applications where the acceptability of individual spot welds is to be determined in real-time, and where no record of rejected welds is necessary.

8.5 *Print-out Device*—A print-out device may be used to provide a permanent record, and it is usually employed as follows:

8.5.1 Whenever a permanent record is necessary to document the quality of individual welds, the printer should print out such information as is necessary to segregate and identify rejectable welds.

8.5.2 When the joined parts contain a large number of spot-welds, and the integrity of the product does not depend on the quality of individual welds but rather on the number of unacceptable welds expressed as a percentage of the total number of welds. The print-out should consist of a weld sequence number and a running percentage of unacceptable welds when the individual spot-welds are identifiable by sequence number.

8.5.3 If weld identification is not possible, then the welding apparatus should be equipped with an automatic marking attachment. With the markings and the records, the acceptability of the welded part can be based on the percentage of unacceptable welds and their location distribution.

9. Procedure

9.1 *Sensor and Preamplifier Attachment*—The sensor should be mounted to the lower (grounded) electrode or electrode holder. If the measurements are to be made only as a periodic sampling of weld quality, a liquid couplant may be used provided that it is periodically replenished and standardization of the system response is maintained. For sustained monitoring, such as on-line AE examination or control of each nugget, the sensor should be permanently mounted using an epoxy adhesive or a similar material. A preamplifier is usually positioned near the sensor. However, when the instrumentation is located less than 1 m from the sensor, the gain otherwise supplied by the preamplifier may be incorporated into the main amplifier of the instrument.

9.2 *Preliminary Measurements*—The AE signal from a single spot-weld should be displayed on a waveform recorder. A wire coil or Hall effect sensor positioned near an electrode can be used as a current sensor, thus providing a timing reference and trigger signal for viewing and measuring the AE signal. This reference signal can be also obtained through an appropriate interconnection to the weld controller. Having established a typical AE trace, characteristic stages should be identified and one or more selected as an AE examination parameter. For example, weld quality indicators may be obtained from the AE response to nugget formation, expulsion, or cracking.

9.2.1 *New Applications*—If the instrumentation was not previously applied to a specific welding problem, preliminary measurements must be made to determine the instrument settings and the conditions for monitoring. The weld controller settings are determined from normal welding considerations. First, the complete AE response should be observed on the oscilloscope. Next, the gain of the instrumentation should be set to the maximum value where the AE signals, representing the selected examination parameter, do not saturate the amplifier. This step will ensure that the measurement will be made with the best obtainable signal-to-noise ratio. Next, the detection threshold level should be established at a value that is slightly above (or below) the peaks of the AE signals that are to be excluded from the measurement. The timing control is referenced to the onset of the weld current and consists of a delay and a time interval. These time intervals should be selected so that the monitoring is restricted to the time interval when relevant signals are present. Finally, the count multiplier should be set to a value that allows utilization of the maximum number of significant digits in the readout. The finalized settings of the weld controller and the AE instrumentation should be recorded along with a photograph of the total acoustic emission signal. The counts obtained from individual welds should also be recorded. These records should be kept on file for future reference. Special considerations associated with each of the various examination parameters are discussed in 10.1-10.4 through .

9.2.2 *Repeated Applications*—If AE monitoring was previously applied to a particular controlling or monitoring problem, the purpose of the preliminary measurement is to reestablish the known and recorded original test conditions. The heat and the weld time settings on the weld controller, and the gain, threshold level, timing, and other settings on the AE instrumentation should be made identical to those on record. A few sample welds should be made to verify that the general appearance of the total AE signal exhibits the expected characteristic features, and that the average count falls within the range of past measurements.

10. Weld Quality Parameters That Produce AE

10.1 *AE During Nugget Formation*:

10.1.1 When the material in the welding zone is heated, the pressure applied by the top electrode will plastically deform the material and AE will be generated. The amplitude of the AE signals associated with this process is affected by both electrode pressure and the "cleanliness" of the parts. These AE signals may be gated out since they provide no useful information relative to the quality of the weld.

10.1.2 Further heating results in melting within the welding zone and growth of the nugget. Nugget formation and expansion produce AE signals that can be correlated with the strength of the weld.

10.1.3 As soon as the welding current starts to decrease, the nugget begins to solidify and residual stresses will be present in and around the weldment. If these residual stresses are severe, hot cracking will occur between cycles of a-c welding.

10.1.4 By selecting a time and amplitude interval, measurements of the AE response for several samples may be correlated with weld strength or nugget size as determined from other tests. In this way, a minimum acceptance level of AE corresponding to acceptable weld quality may be established.

10.1.5 A storage scope or other device to record AE response should be used to verify the several stages of AE generation and detection shown for d-c and a-c spot welding in Fig. 2.

10.2 *AE from Expulsion*:

10.2.1 Expulsion occurs after a sufficient weld is formed. Within the weld period, it will occur sooner if the electrodes are clean or thinner material is welded. It will occur later if the welding conditions have deteriorated or thicker stock is welded with the same controller setting.

10.2.2 Expulsion, however, is not desirable. It removes material from the weld nugget area. It may automatically be kept to a minimum when the expulsion signals are used to generate a feedback signal to control the welding process (see Section 11).

10.2.3 Where a feedback control arrangement is not used, expulsion may be knowingly tolerated from production-oriented considerations. In this case, several test coupons should be welded and the resulting weld strength or other quality parameter should be determined through destructive testing. Weld strength may be correlated with a suitable measure of the expulsion AE. In this way, a maximum acceptable level of expulsion AE can be determined and used to segregate unacceptable welds or welded parts.

10.3 *AE from Phase Transformation*—In certain carbon steel alloys, material in and near the spot-weld undergoes martensitic phase transformation as the nugget cools. The total volume of material experiencing the transformation is related to both the nugget size and the area of fusion bonding. Therefore, the AE response during phase transformation may be related to the strength of the weld. A waveform recorder should be used to isolate the phase transformation stage of the AE signal. By selecting a time and amplitude interval, a measure of the phase transformation AE for several samples may be correlated with the weld strength or size, as determined from other tests. In this way, a minimum acceptable level of AE corresponding to acceptable weld quality may be established.

10.4 *AE from Cracking*—The AE resulting from post-weld cracking can be monitored during the time interval between current termination and lift-off (or, in some cases, between phase transformation and lift-off). A waveform recorder or a storage oscilloscope may be used to identify the cracking interval by monitoring the AE response from cracking for several samples. The extent of cracking should be independently determined either through metallographic examination or by fatigue testing. A single large crack, or several small cracks, may give the same AE response. For applications where crack size affects quality evaluation, AE monitoring should be supplemented by other examination methods.

11. Typical Applications

11.1 Acoustic emission surveillance of spot-welding can take two forms, namely, monitoring and control. The purpose of on-line monitoring is to identify and segregate unacceptable welds for quality evaluation purposes. On-line control, on the other hand, utilizes the AE instrumentation to complete a feedback loop between the process and the source of welding current by automatically adjusting one or two process variables to compensate for deteriorating welding conditions.

11.2 Defective spot-welds occur randomly or gradually in the process. Randomly occurring defects are caused by extraneous changes in welding conditions, for example, changes in the composition, the geometry, or the surface conditions of the welded parts. Gradual deterioration of spot-welding, due to electrode wear, results in an increasing number of defective welds. The heat applied is proportional to the electrical resistance and weld time, and to the square of the weld current. Of these, only the time and current are process variables. Typical constant-heat curves are shown in Fig. 3. For example, if the initial settings of the controller were somewhere on Curve H_2, then after a large number of welds the surface area of the electrodes may increase and cause the current density to decrease. This is equivalent to a shift of Curve H_2 to Position H_3, and requires compensation by adjusting either the weld time or the weld current, or both.

11.3 *On-Line Monitoring*:

11.3.1 The purpose of on-line monitoring a spot-welding process by AE is to identify bad welds or parts. This information can serve as a basis for acceptance or rejection, or for establishing a schedule for repair. Theoretically, any one, or a combination of two or all three, of the weld quality parameters described in this practice can be used for this purpose. Selection of the parameters should be done by determining the most prevalent causes of defective welds in a particular welding application. Excessive post-weld cracking due to material properties, varying nugget volumes due to loose tolerances of the dimensions and surface conditions of the welded stock, and burning or excessive expulsion due to over-welding can be identified as randomly occurring defects by the corresponding AE response. If all these parameters are monitored simultaneously, the definition of an acceptable weld is: "A spot-weld with adequate nugget volume that is free of excessive expulsion and post-weld cracking and satisfies the average strength requirements." The limits for a gradual deterioration of weld conditions, represented by a gradually increasing number of defective welds, can also be detected by monitoring the expulsion as the only examination parameter for certain applications.

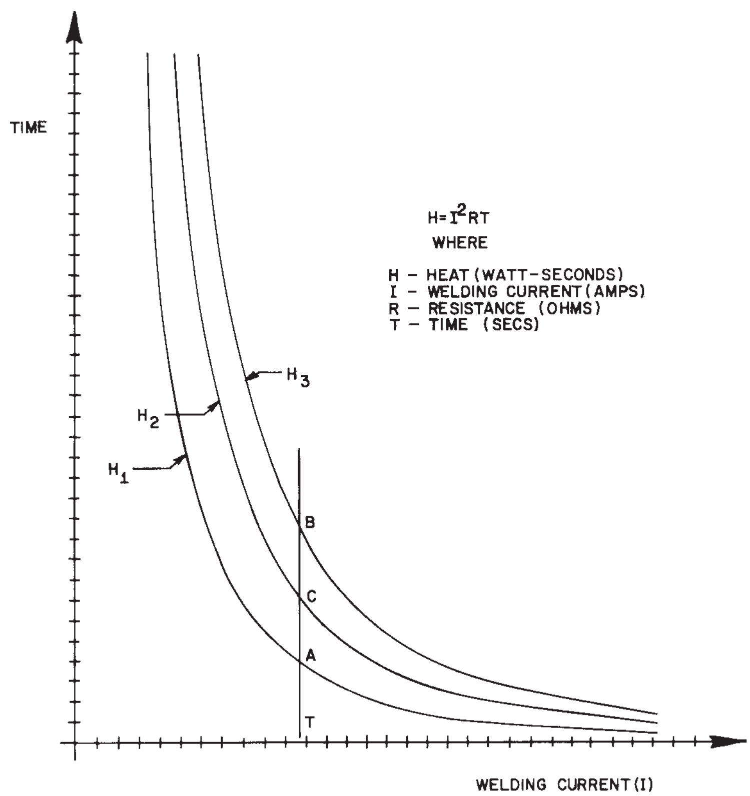

FIG. 3 Constant-Heat Curves for Typical Spot-Welding Applications

11.3.2 When the equipment described in 8.1 is used for the above purposes, then the signal output should be utilized as described in 8.4 and 8.5.

11.4 *AE Feedback Control of the Spot-Welding Process*:

11.4.1 Of the weld quality parameters described in this practice, only nugget formation and expulsion occur during the welding process. Therefore, these parameters may be used for controlling the weld process variables. The weld time and heat settings of the controllers usually produce an over-welded condition in industrial practice. This is done in order to cover variations of material, material dimensions and surface conditions, and to allow some wear of the electrodes before the next maintenance period.

11.4.2 The equipment described in 8.1.3 should have the following inputs:

11.4.2.1 Preamplified acoustic emission signal.

11.4.2.2 A pulse or step function from the weld controller which marks the onset of the current synchronously with a zero crossing point.

11.4.2.3 A pulse from the AE weld controller to actuate a "weld/no-weld switch" in the welder controller.

11.4.3 Acoustic emission feedback control automatically adjusts the required process variables. In practice, adjustment of the weld time is most common. After the AE weld parameters have been established as described in 9.2.1, the AE monitor may be interfaced with an existing welder controller as shown in Fig. 4.

11.4.4 *Nugget Formation As the Control Parameter*—For a given weld strength, the corresponding AE value is set on the AE controller. When a weld is made, a pulse (11.4.2.2) signals the initiation of the gating section of the AE controller to accept AE only during nugget formation. If the AE value is reached, the AE controller sends a pulse (11.4.2.3) to the welder in order to terminate the welding heat. The termination signal should be synchronous with the zero crossing of the weld current.

11.4.5 *Expulsion As the Control Parameter*:

11.4.5.1 If on Fig. 3 the curve H_1 represents the heat settings necessary to form a good nugget under initial and ideal welding conditions, and H_3 represents the actual controller settings, the time difference between two corresponding points on the two curves represents the amount of overwelding. Under initial conditions, expulsion occurs close to H_1.

11.4.5.2 As the electrode conditions gradually deteriorate, the occurrence of expulsion shifts upward with constant current. Intermediate conditions can be represented by the curve H_2. A shift requires adjustment of the weld current or weld time, or both. Acoustic emission feedback control automatically adjusts the required process variables. In practice, adjustment of the weld time is most common.

11.4.5.3 The input pulse in 11.4.2.2 is the timing reference for a single spot-weld operation. The feedback controller produces a time delay corresponding to the time between points *T* and *A* on Fig. 3. From time *A* on, acoustic emission is monitored and expulsion is detected when AE rises above the threshold level. The monitoring continues at least until the time corresponding to point *B*, on Fig. 3. If expulsion occurs earlier, the output of the feedback controller terminates the weld current (for example, at *C*), thereby overriding the controller setting, *B*.

11.4.5.4 For both AE weld control parameters, it is possible that the maximum controller settings can be reached without producing an acceptable weld. If this occurs, the electrodes have deteriorated beyond use and should be changed.

12. Keywords

12.1 cracking; electrode wear; expulsion; feedback control; in-process monitoring; nugget size; phase transformation; resistance spot-welding; weld strength

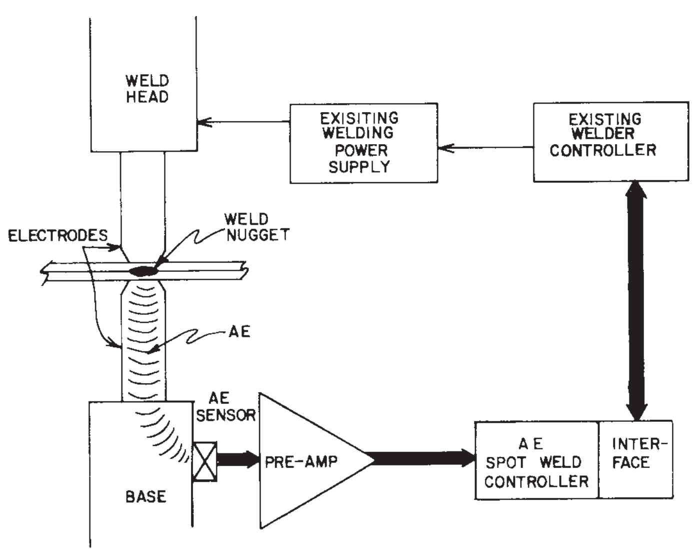

FIG. 4 AE Feedback Control of the Spot-Welding Process