ÉTUDE DU MARCHÉ SUR LES ÉQUIPEMENTS DE SOUDURE ÉLECTRIQUE

Rapport présenté au Ministère de l'Expansion
Economique Régionale du Canada

TOME II

la technique et les applications des équipements de soudure électrique

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TOME II

LES SOUDEUSES ELECTRIQUES

ET LEURS APPLICATIONS

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LES SOUDEUSES ELECTRIQUES ET LEURS APPLICATIONS

TABLE DES MATIERES

LISTE DES ABREVIATIONS

C.C.	:	Courant continu
C.A.	:	Courant alternatif
K.W.	:	Kilowatt
SEE	:	Soudure avec électrode enrobée
SFG	:	Soudure sous flux granulé
SSFG	:	Soudure sous flux gazeux
SFGT	:	Soudure sous flux gazeux avec électrode au tungstène
SFGFS	:	Soudure sous flux gazeux avec fil solide
SFF	:	Soudure avec fil fourré
SAP	:	Soudure avec arc plasma
SPP	:	Soudure par joint
SJC	:	Soudure par joint continu
SPB	:	Soudure par bossage

PREFACE

Dans le cadre d'une étude du marché sur la soudure électrique au Canada, ce texte a été rédigé pour faciliter la compréhension des diverses technologies utilisées pour souder avec l'électricité comme principale source énergétique. Cette synthèse s'adresse aux gestionnaires et aux spécialistes en mise en marché.

Chacune des technologies est groupée par catégorie et pour chaque sous-catégorie on trouvera une description du:

1- Procédé.
2- Principe de fonctionnement.
3- Sources d'énergie.
4- Applications et coût ou prix.

Montréal, Mars 1977

INTRODUCTION

Les soudeuses électriques peuvent se regrouper en sept (7) grandes catégories, à l'intérieur desquelles on retrouve une variété de sous-catégories ou procédés. Pour les fins de cette étude, nous suggérons le classement des catégories proposées par l'"American Welding Society". Vu que les textes traitant de soudure utilisent généralement la langue anglaise en Amérique du Nord et que les termes techniques ne peuvent tous être traduits sans perdre de leur signification, nous inclurons les termes français et anglais tout au long de cette partie. Les termes américains et l'abréviation des procédés faciliterons les efforts du lecteur qui veut approfondir le sujet en consultant notre principal référence*. Dans le texte suivant, chaque procédé est numéroté séparément et inclut quatre sections, notamment: une description du procédé, son principe de fonctionnement, les sources d'énergie ou de courant et ses applications.

Une de nos sources d'information technique utilisées tout au long de cette partie est le "Welding Handbook".* Ce dernier classifie les procédés de soudure de la façon suivante:

CATEGORIE I: Soudure à arc

1. Soudage avec électrode enrobée
2. Soudage sous flux granulé
3. Soudage sous flux gazeux
4. Soudage sous flux gazeux et fil solide ou fourré
5. Soudage avec arc plasma
6. Soudage sous laitier granulé ou gazeux
   - Sous-section: les sources d'énergie

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* Welding Handbook - American Welding Society, 1976. Volume 1 à 5

CATEGORIE II: Soudure par résistance électrique

7. Soudage par point

8. Soudage par joint continu

9. Soudage par bossage

CATEGORIE III: Soudure par étincelage

10. Soudage par étincelage

CATEGORIE IV: Soudure par physique d'état solide

11. Soudage par bossage et compression

CATEGORIE V: Soudure par faisceau d'électrons

12. Soudage par faisceau d'électrons

CATEGORIE VI: Soudure par faisceau de laser

13. Soudage par faisceau de laser

CATEGORIE VII: Soudure par étamage

14. Variétés de techniques d'étamage

LA SOUDURE A ARC ELECTRIQUE

"ARC WELDING"

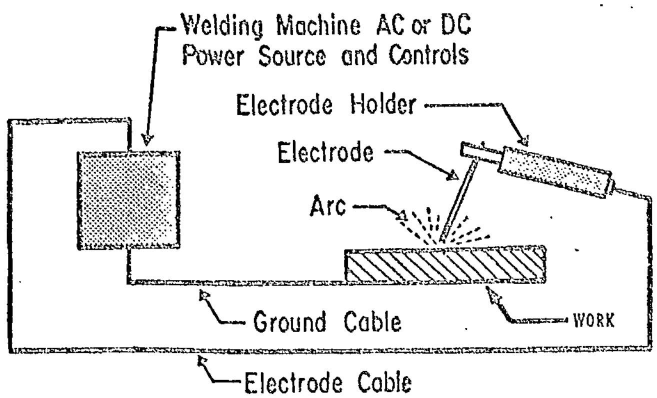
CATEGORIE I

SOUDURE A ARC ELECTRIQUE (Arc Welding)

La soudure à arc électrique (Arc Welding) comprend plusieurs techniques de soudure dont le dénominateur commun est l'usage d'un arc électrique comme source de chaleur pour faire fondre et souder les métaux. Il existe six (6) catégories majeures de soudure à arc électrique. Elles sont les suivantes:

1. Soudage avec électrode enrobée (Shielded Metal Arc Welding)
2. Soudage sous flux granulé (Submerged Arc Welding)
3. Soudage sous flux gazeux (Gas Shielded Arc Welding)
4. Soudage sous flux gazeux avec fil solide ou fourré (Gas Metal & Flux Cored Arc Welding)
5. Soudage avec arc plasma (Plasma Arc Welding)
6. Soudage sous laitier granulé ou gazeux (Electrogas & Electroslag Welding)

1. SOUDURE AVEC ELECTRODE ENROBEE: (SEE)
"Shielded Metal Arc Welding): (SMAW)*



—Elements of a typical welding circuit for shielded metal-arc welding

Exemple d'un circuit typique pour la soudure avec électrode enrobée.

FIGURE: I

* Abréviation du nom américain et correspond à l'appellation industrielle du procédé au Canada et aux Etats-Unis.

1.1 Description

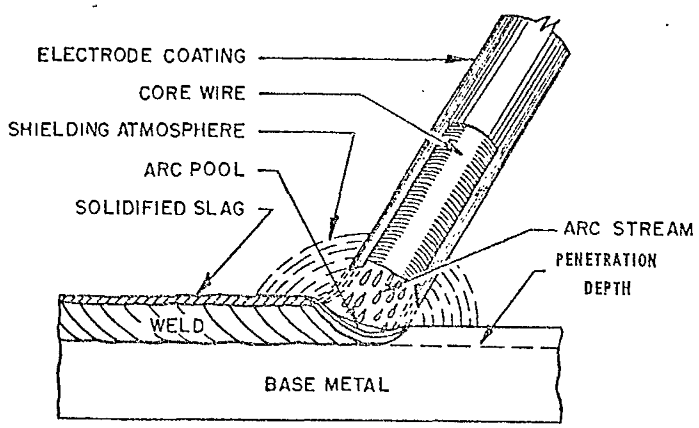
La soudeuse à arc électrique se compose d'une machine à souder qui utilise une source de courant électrique continu (C.C.) ou alternatif (C.A.) et de deux câbles dont l'un est relié à un manche qui soutient l'électrode et l'autre à la pièce à souder. (Voir figure 1)

Quand l'électrode prend contact avec la pièce à souder, le circuit électrique se referme et un arc électrique surgit entre l'extrémité de l'électrode et la surface de la pièce à souder.

La catégorie "Soudage avec électrode enrobée" emploie des électrodes qui se consument et qui sont recouvertes d'une couche extérieure de silicates, fluorides, carbonates, oxydes ou cellulose.

1.2 Principe de fonctionnement

Un arc électrique survient lors du contact de l'électrode et de la surface de la pièce à souder. Cet arc est une source de chaleur intense (à des températures supérieures à 9000°F ou 5000°C). L'arc fait fondre l'extrémité de l'électrode et la surface de la pièce qui lui est adjacente. Il en résulte que le métal fondu de la pièce se joint aux produits en fusion de l'électrode et de sa couche externe. D'infimes globules de métal ainsi regroupés se mélangent grâce à la gravité, l'attraction moléculaire et la tension de la surface et refroidissent, créant ainsi la fine couche de soudure.



—Schematic representation of the shielded metal arc

Représentation de soudure avec l'électrode enrobée
FIGURE: 2

En plus de maintenir l'arc électrique et de fournir le remplissage, la couche externe de l'électrode (electrode coat) fournit des agents qui empêchent la contamination de la soudure par l'oxygène ou l'azote de l'air ambiant, prévenant ainsi la création d'oxydes ou de nitrides qui affaibliraient la soudure. Une soudure avec électrode enrobée qui est bien faite est aussi résistante que le métal soudé, sinon davantage. La figure 2 représente le produit de cette technique de soudure.

1.3 Sources d'énergie

La soudure à arc électrique (SEE) nécessite un courant électrique dont l'intensité est suffisante pour faire fondre la surface du métal et l'électrode et dont le voltage est assez élevé pour maintenir l'arc électrique.

Dépendant de l'électrode utilisée, l'ampérage se situe entre 10 et 500 ampères. Quant au voltage, il varie entre 17 et 45 volts. Le courant est continu (C.C.) ou alternatif (C.A.), selon le genre de métal à souder.

Le facteur clé qui détermine le choix de la source de courant est le type d'application et d'utilisation. Les critères sont la facilité de manutention, la qualité de la soudure et le coût. Il n'existe pas de choix optimum standardisé. Chaque genre de soudure nécessite un choix de courant et d'électrode différent.

Sachant que la longueur de l'arc électrique (i.e. la distance de l'extrémité de l'électrode à la surface de la pièce) en augmentant, hausse le voltage et baisse l'ampérage, donc la chaleur dégagée, la première variable qui influence le choix de la machine est la stabilité du courant ou du voltage. La machine à voltage constant est en général, préférée pour des soudures automatiques et celle à courant constant est supérieure pour la soudure manuelle.

Une deuxième variable qu'il faut prendre en considération est le voltage de la machine quand le circuit est ouvert (sans charge). Ce dernier se situe, en général, entre 50 et 100 volts; le voltage de l'arc électrique se situe entre 18 et 36 volts, dépendant de la longueur de l'arc et du genre d'électrode.

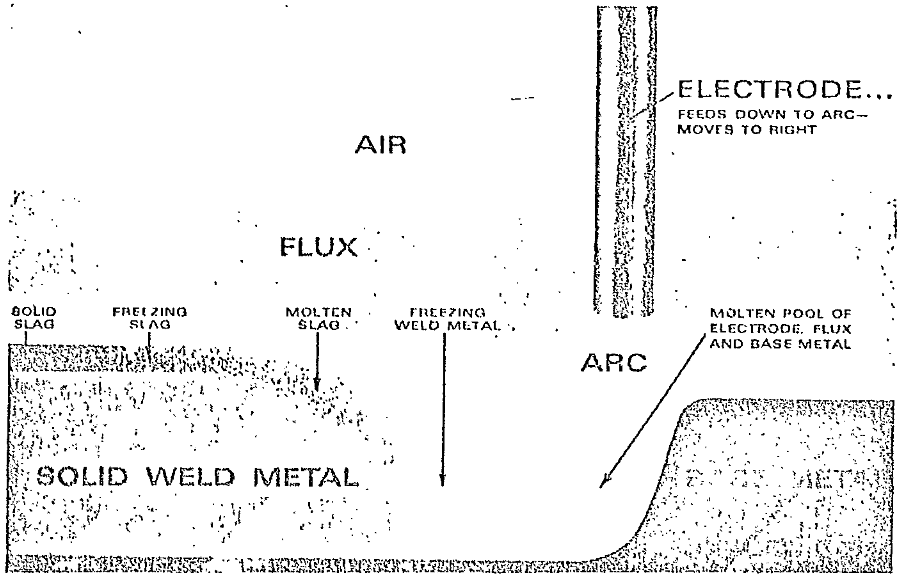
Ces variables analysées, le choix final est fait en fonction de la capacité requise de la machine qui dépend de l'épaisseur du métal à souder et de la quantité de soudure à effectuer. Un facteur essentiel à considérer est le cycle d'utilisation défini comme le temps de soudure (durée de l'arc) en pourcentage du temps d'utilisation de la machine, sans que cette dernière ne surchauffe.

1.4 Applications

Le processus "SEE" est surtout appliqué pour souder des épaisseurs variant de 1/8 à 3/4 de pouce. Il est aussi utilisé pour des pièces métalliques qui ne sont pas horizontales.

Le processus de soudage avec électrode enrobée ne nécessitant qu'une source de courant C.A. ou C.C. de 10 kilowatts ou moins, la soudeuse "SMAW" est très pratique dans les secteurs de la construction, les pipelines, les chantiers maritimes ainsi que dans le domaine de l'entretien. Le coût, quoique approximatif, se situe entre $500 et $1,000. L'entretien de ces soudeuses est relativement simple.

2. SOUDAGE SOUS FLUX GRANULE: (SFG)
(Submerged Arc Welding): (SAW)*



—Schematic representation of the submerged arc welding process

Représentation du procédé de soudage sous flux granulé.
FIGURE: 3

2.1 Description

Le processus "SFG" inclut les mêmes composantes que celles avec électrode enrobée, notamment la machine, les câbles, le manche et l'électrode, mais diffère du fait que l'électrode n'est pas recouverte de la couche externe. Par contre, un agent appelé "flux" (ou granule) est ajouté sur la surface à souder. Ce "flux" va jouer plusieurs rôles, comme nous le voyons à la figure 3.

2.2 Principe de fonctionnement

L'extrémité de l'électrode est immergée dans le "flux"; elle entre en contact avec la pièce à souder et referme ainsi le circuit électrique, créant un arc électrique qui fera fondre le "flux". Une fois le "flux" fondu,

* Abréviation du nom américain.

il devient conducteur d'électricité et le contact entre l'électrode et la pièce n'est plus nécessaire pour maintenir l'arc électrique. Le métal provient de la fonte de l'électrode même ou bien d'un autre fil ajouté au processus.

Vu que l'extrémité de l'électrode est toujours immergée dans le "flux", il en résulte que l'arc électrique n'est pas visible. Il n'y a pas d'étincelles, ni de fumée qui se dégagent. La partie supérieure du "flux" ne fond pas et peut être réutilisée. Par contre, la couche de "flux" adjacente à la surface de la pièce se liquéfie et permet une augmentation considérable du courant électrique et donc de la chaleur.

Le "flux" est, en outre, un isolant de la chaleur qui permet à l'arc d'être concentré sur des surfaces infimes. Il isole aussi la soudure contre des effets nocifs de l'oxygène et l'azote. La soudure qui en résulte fait preuve de ductilité, résistance à la corrosion, uniformité, ainsi qu'un bas degré d'azote. Le poids de "flux" utilisé est de 1 à 1.5, le poids du métal ajouté.

2.3 Sources d'énergie

Le courant continu (C.C.) est préférable pour le "SFG", vu qu'il permet un meilleur contrôle de la pénétration et de la vitesse de l'électrode et un démarrage plus rapide du processus. Il est donc plus avantageux dans les cas suivants: a) pour des soudures précises et rapides, b) pour un meilleur contrôle de l'arc et c) pour des cas où les contours sont compliqués et la vitesse rapide.

Le courant alternatif (C.A.) est utilisé quand il existe plus d'un arc et plus d'une électrode ou fil, afin d'éviter les champs magnétiques qui surgiraient si deux arcs de courant continu (C.C.) se trouvaient à proximité.

Le courant peut être obtenu grâce à un générateur de courant continu (C.C.) à voltage variable, d'un générateur de courant continu (C.C.) à voltage constant, d'un "rectifier" ou bien d'un transformateur de courant alternatif.

La plupart de ces soudeuses utilisent un courant de 400 à 1500 ampères, toute exception faite de certaines machines qui peuvent atteindre 4000 ampères à 55 volts ou aussi bas que 150 ampères à 18 volts.

Le générateur à voltage variable est le plus commun dans la soudure "SAW". Si le courant nécessaire à la soudure excède la capacité du générateur, deux ou plusieurs générateurs peuvent être accouplés en parallèle.

2.4 Applications

Le processus "SFG" est généralement utilisé pour les soudeuses automatiques: les courants étant de haute intensité (600 à 2000 ampères), les coûts de soudure diminuent. Générallement l'appareil utilisant le processus "SFG" varie en prix de $2,000 à $10,000.

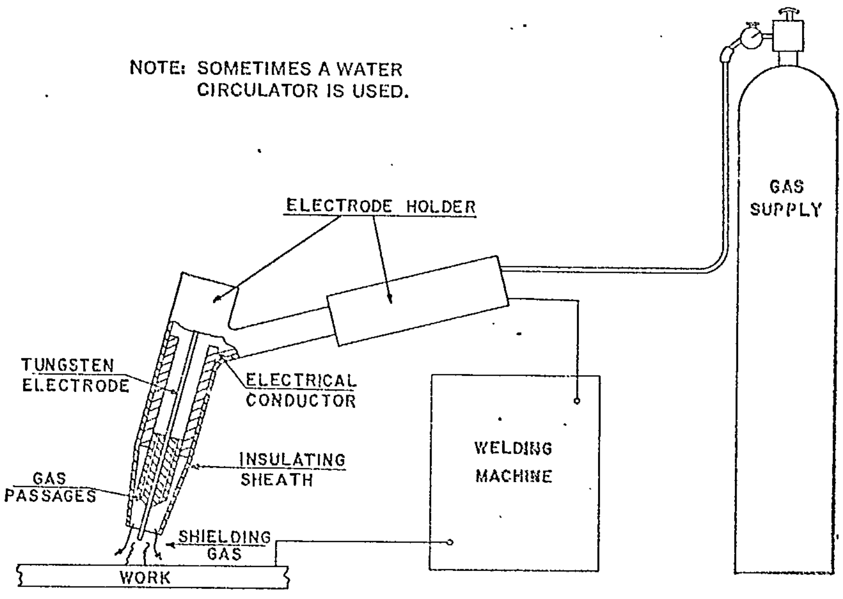
Le processus "SFG" est surtout employer pour des plaques épaisses en mode automatique à grande intensité de courant. Ce procédé peut atteindre une vitesse de soudage de 200 pouces/minutes.

La précision de la soudure, la vitesse et le coût non élevé rendent le processus "SFG" très avantageux pour les soudeuses mécanisées automatiques ou semi-automatiques.

SOUDAGE SOUS FLUX GAZEUX: (SSFG)
(Gas Shielded Arc Welding): (GSAW)*

Définition: Le processus de soudage sous flux gazeux consiste à produire une chaleur intense sous la protection ou à l'intérieur d'un volume de gaz. Cette chaleur peut être créée, comme nous l'avons vu plus tôt, par une électrode refermant un circuit électrique au contact de la pièce à souder. Plusieurs variations peuvent exister: l'électrode peut être recouverte ou non, le gaz peut être inerte ou non, il peut y avoir pression ou non et il peut y avoir un "filler" ou non. Le processus avec électrode au tungstène**, en est une variante ainsi qu'avec fil solide.

3. SOUDAGE SOUS FLUX GAZEUX AVEC ELECTRODE AU TUNGSTENE (SFGT)
(Gas Tungsten Arc Welding): (GTAW)**



—Schematic diagram of gas tungsten-arc equipment

Schéma d'un équipement pour soudage sous flux gazeux avec électrode au tungstène.

FIGURE: 4

* Abréviation du nom américain
** Procédé aussi connu sous le nom de T.I.G. (Tungsten Inert Gas Welding).

3.1 Description

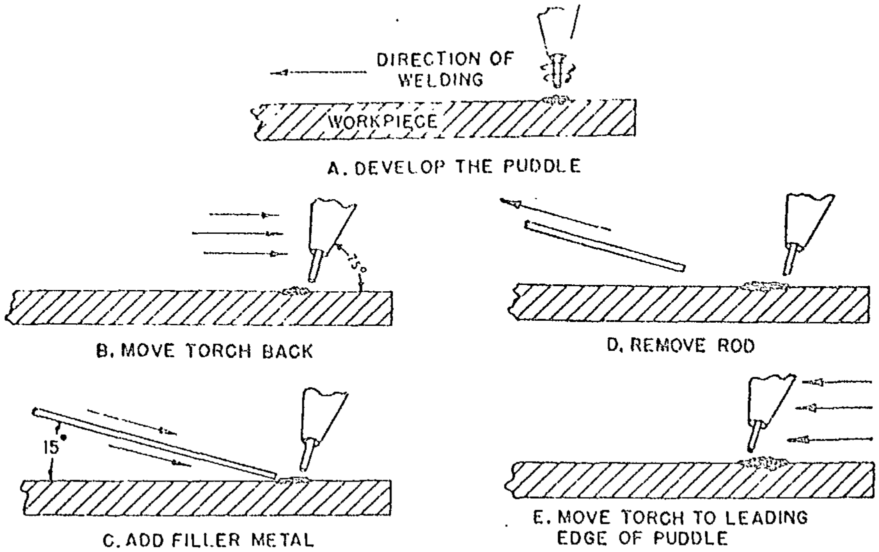
Le soudage sous flux gazeux avec électrode au tungstène consiste à faire passer un arc électrique entre une électrode de tungstène qui ne se consume pas et la pièce à souder; avec la variante que l'extrémité de l'électrode, le métal fondu et l'arc sont à l'abri de l'atmosphère ambiante, sous une couverture d'un gaz inerte conduit à travers le manche de l'électrode (voir figure 4). La soudure se forme quand l'arc fait fondre les côtés de deux surfaces métalliques adjacentes et que, par la suite, le métal se refroidit.

3.2 Principe de fonctionnement

L'arc électrique est produit par le passage du courant électrique à travers un gaz ionisé (argon ou hélium). Dans ce processus, les atomes du gaz inerte s'ionisent en perdant un électron et en gardant ainsi une charge positive. Cette charge positive va voyager du pôle positif au pôle négatif de l'arc et les électrons dans la direction inverse. L'énergie produite est donc le produit du courant par la différence de voltage.

Il est absolument nécessaire de bien nettoyer les surfaces à souder de toute huile, graisse, saleté ou autres contaminants. La première étincelle peut être obtenue en établissant un contact entre l'électrode et la pièce à souder, en augmentant temporairement le courant ou en maintenant un autre arc pilote (pilot arc) par l'intermédiaire d'un autre appareil.

L'épaisseur de la pièce à souder et la nature du joint détermineront si un métal d'apport est nécessaire. Si ceci était le cas, le métal est ajouté en plaçant un fil métallique dans la région de l'arc électrique, comme pour la soudure à l'oxyacétylène (voir figure 5).



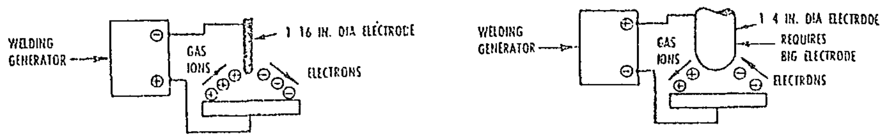
—In gas tungsten-arc welding, filler metal is fed manually in a manner similar to that used in oxyacetylene welding

Pour la soudure sous flux gazeux avec arc au tungstène, le métal d'apport est appliqué d'une manière semblable à la soudure au gaz oxyacétylène.

FIGURE: 5

3.3 Sources d'énergie

L'électrode de tungstène est reliée au pôle positif ou au pôle négatif d'un courant continu, bien qu'une électrode reliée au pôle positif doit être plus épaisse en diamètre. La direction du courant est illustrée par la figure 6.



—Electron and gas-ion flow with electrodes connected to positive and negative terminals of the power source

Illustration de la circulation des électrons et des ions gazeux, selon le branchement de la source d'énergie.

FIGURE: 6

Il est parfois avantageux d'utiliser un courant continu intermittent (plusé) et ceci, quand la pièce à souder n'est pas horizontale.

Quant au courant alternatif (C.A.), il donne les avantages d'une électrode alimentée positivement sous les limitations rencontrées avec une électrode positive en mode de courant.

La source de courant est du type "à voltage fléchissant", où le voltage baisse quand le courant augmente. Les sources de courant qui augmentent le voltage ou bien le maintiennent constant quand le courant augmente représenteraient de hauts risques de court-circuit et donc de dommages.

En règle générale, le courant alternatif est utilisé pour souder l'aluminium, le magnésium; et le courant continu est utilisé pour souder les aciers, la plupart des autres métaux et le soudage de plaques épaisses d'aluminium en mode automatique.

3.4 Applications

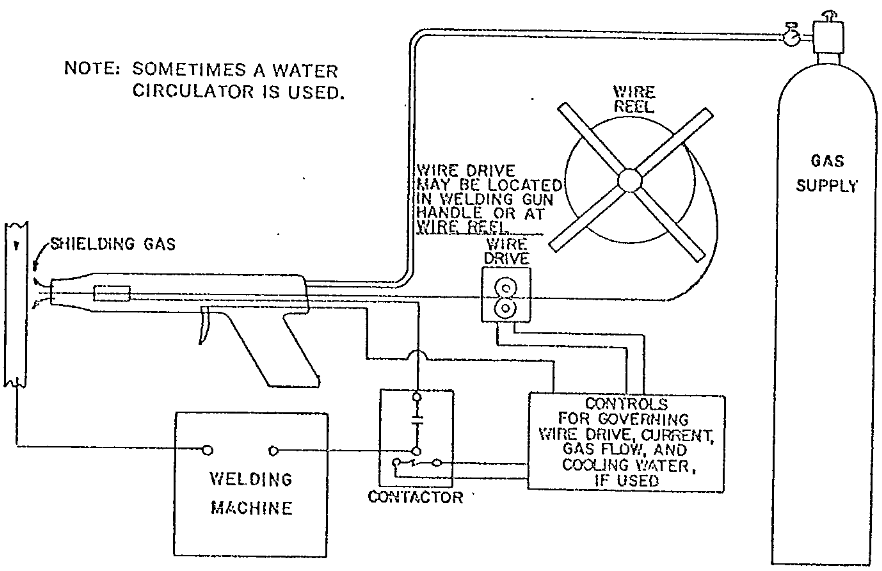
Le processus "SFGT" permet la soudure de plusieurs configurations de soudures et de pièces. Il est utilisé pour souder des feuilles métalliques, des tubes, des tuyaux et des plaques. L'épaisseur permise est de 1/16 à 3/8 de pouce et pour les tuyaux de 1 à 6 pouces de diamètre.

L'équipement consiste en une torche de soudure, une source de courant et une source de gaz inerte. Une machine à souder de 200 ampères et accessoires peut coûter environ $2,000 alors qu'une soudeuse automatique de 500 ampères coûterait environ $5,000.

En raison du coût de l'équipement original, celui du gaz inerte et du surplus d'entraînement que requiert ce processus. Cette méthode devient plus cher que les deux précédentes "SEE" et "SFG".

4. <u>SOUDAGE SOUS FLUX GAZEUX, FIL SOLIDE OU FOURRE</u>: (SFGFS & SFF)
(Gas Metal Arc Welding) et (Flux Cored Arc Welding)
(GMAW & FCAW)

Définition: Le soudage sous flux gazeux (SFGFS) et fil fourré (SFF) sont classifiés comme deux processus différents par la "American Welding Society" mais, vu qu'il existe plusieurs similarités entre eux, il serait utile de les discuter simultanément. Les deux processus utilisent un fil continu comme métal d'apport et électrode, ainsi qu'un gaz pour protection. Alors que le "SFGFS" utilise le gaz résultant de la fonte de l'électrode et ne nécessite pas une source de gaz externe.



—*Schematic diagram of gas metal-arc equipment*

Représentation d'un équipement pour soudage sous flux gazeux.

FIGURE: 7

4.1 Description

Le processus "SFGFS" utilise un fil continu, qui se consume, comme électrode et métal d'apport. Ce fil, entrant en contact avec la pièce à souder, referme un circuit électrique, produisant un arc. Une source de gaz inerte externe fournit le gaz au manche de l'électrode. Le gaz protège la soudure de l'air ambiant et affecte les caractéristiques électriques du processus.

4.2 Principe de fonctionnement

Quand ce processus fut inventé, il était considéré opérer principalement à un courant élevé, un diamètre de fil de 0.045 à 3/32 de pouce et un gaz inerte comme protecteur. Depuis lors, plusieurs détails ont changé. Ces derniers se résument à: un courant moins élevé qui transfert le métal lors d'un court-circuit; l'usage d'une pulsation du courant continu; et l'usage de gaz inertes réactifs. Les principales variantes sont décrites ci-dessous.

<u>Dépôt par pluie</u>: Le transfert de métal de l'extrémité de l'électrode à la surface à souder se fait de façon axiale. Plusieurs centaines de gouttelettes de métal par seconde se posent sur la surface à souder comme une douche "jet". Le gaz utilisé est de l'argon et le courant est continu avec le pôle po-

sitif à l'électrode. L'arc électrique que génère ce processus étant très puissant, les minces feuilles de métal et les pièces non horizontales ne peuvent être soudées de cette façon.

<u>Dépôt par globule</u>: Cette variante consiste à utiliser le bioxyde de carbone comme gaz protecteur. Ce dernier ne permet pas le transfert du métal en "jet" mais par globules. L'arc puissant enfoui dans son cratère produit des détonnations dues aux forces de l'arc et des courts-circuits non contrôlables.

<u>Arc pulsé</u>: Cette variante est une combinaison d'un courant faible continu et des pulsations d'un courant de haute amplitude. Cette combinaison produit un transfert en "jet" lors de l'intervalle entre deux pulsations consécutives. Le gaz utilisé est riche en argon.

<u>Dépôt par court-circuit</u>: Les deux variantes précédentes requièrent des courants de haute amplitude, ce qui réduit leur champ d'application. Cependant, le processus "dépôt par court-circuit" permet un courant moyen et un taux de dépôt métallique réduit en utilisant des sources d'énergie qui permettent le transfert de métal durant les intervalles de courts-circuits

Soudage avec fil fourré (SFF): ce processus utilise des électrodes recouvertes de produits minéraux et d'alliages de fer au lieu d'électrodes simples. Cette variante permet plus de protection et un meilleur contrôle de la soudure. Un gaz riche de bioxyde de carbone est aussi requis.

Souvent on utilise des électrodes qui fournissent leur propre protecteur grâce au flux fourré sans le fil, et ainsi, ne nécessitent pas une source de gaz externe.

4.3 Sources d'énergie

Toutes les variantes mentionnées ci-dessus, à quelques exceptions près, utilisent les mêmes sources d'énergie. L'équipement requis consiste en:

- un moteur à vitesse variable et un contrôle pour agencer la vitesse de l'électrode;
- un manche qui inclut un interrupteur pour contrôler l'électrode, le courant de l'arc et l'entrée du gaz; une buse qui dirige le jet de gaz vers l'arc; et un contact qui transfert l'électricité à l'électrode;
- des accessoires tels que des cables, des électrodes, des tuyaux et des connections électriques;
- des sources de gaz externe et d'eau de refroidissement, si requises;
- une source de courant.

4.4 Applications

Le "dépôt par pluie" est utilisé de façon intensive pour souder à peu près toutes sortes de métaux et leurs alliages, incluant les métaux réactifs tels que l'aluminium, le titanium et le magnésium. Son seul handicap est qu'il nécessite que la position de la pièce à souder soit horizontale.

Le "dépôt par globule" utilise le bioxyde de carbone et se limite, dans ses applications, à la soudure de l'acier en faible teneur de carbone. Sa vitesse de soudure étant rapide, il est surtout utilisé dans les chaînes de montage d'automobiles.

Le "dépôt par court-circuit" présente l'avantage de souder des pièces minces dans toutes les positions et d'être facile à manoeuvrer; cependant, il n'est pas efficace pour des épaisseurs dépassant le $\frac{1}{4}$ de pouce.

Le "soudage avec fil fourré" est utilisé pour des soudures qui nécessitent la déposition d'un grand volume de métal et dont les contours doivent être précis. Des électrodes d'un diamètre de 1/16 de pouce peuvent souder des métaux ferreux dans toutes les positions. Par contre, des électrodes de 3/32 de pouce de diamètre ne peuvent souder qu'en position horizontale.

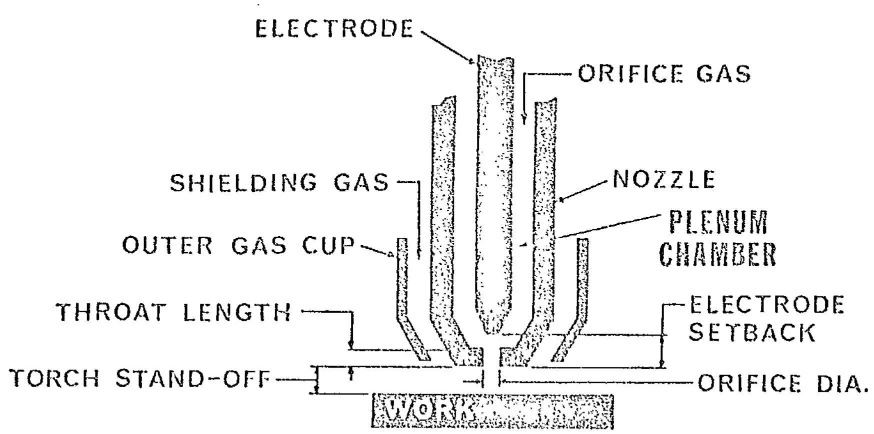
En général, les processus "sous flux gazeux et avec fil fourré" sont plus efficaces que tous les autres processus, comparativement à leur coût. Les soudeurs peuvent opérer sans interruption vu que les électrodes sont des fils continus. Pour ces raisons, ces processus ont gagné et gagnent encore de l'importance. Un équipement simple, tel que décrit plus haut, peut être acheté à raison de $1,500 à $3,000. Quant au "pulsed arc", il coûte plus de $1,500. La puissance requise varie entre 2 et 20 kilowatts.

5. SOUDAGE AVEC ARC PLASMA: (SAP)
(Plasma Arc Welding): (PAW)

5.1 Description

Le soudage avec arc plasma réfère à plusieurs processus de la même famille qui ont pour dénominateur commun la création d'un arc électrique étroit et très dense.

Le "plasma" est un gaz qui est chauffé à une température qui le rend ionisé et donc conducteur d'électricité.



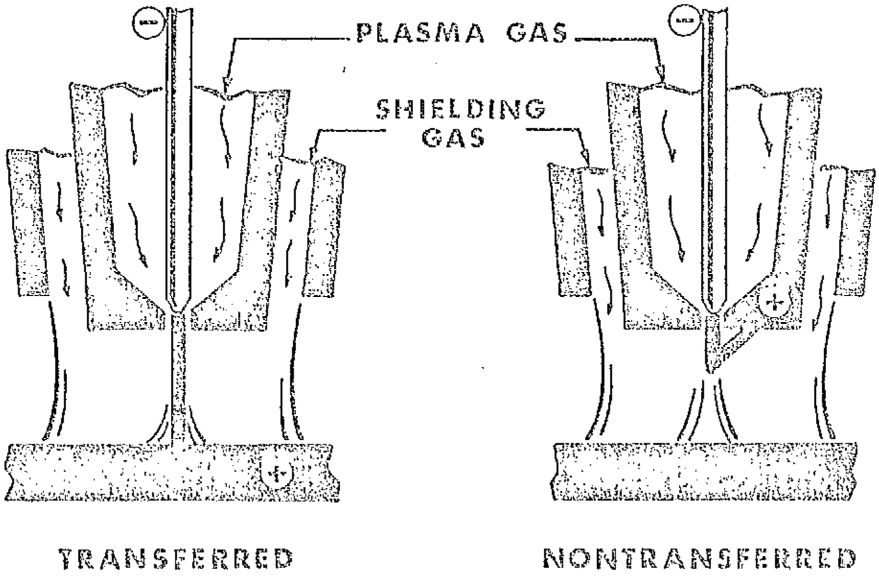
—Plasma arc torch terminology

Schéma d'une torche pour soudage avec arc plasma

FIGURE: 8

5.2 Principe de fonctionnement

Le soudage avec arc plasma est un processus de soudure électrique où la chaleur provient d'un arc électrique condensé entre une électrode et la pièce à souder (arc transféré) ou bien entre l'électrode et la buse de la torche (arc non transféré). Voir figures 9 et 10.



—*Transferred and nontransferred arcs*

Différence entre arc transféré et non-transféré

FIGURE: 9

La protection est obtenue grâce au gaz chaud et ionisé qui sort de l'orifice de la torche. Comme compléments à ce processus, un autre gaz protecteur peut être ajouté, une pression peut être appliquée et un métal d'apport peut être utilisé.

L'arc est guidé et condensé par une buse qui est généralement refroidi à l'eau. L'arc condensé représente les avantages suivants, comparativement aux autres processus:

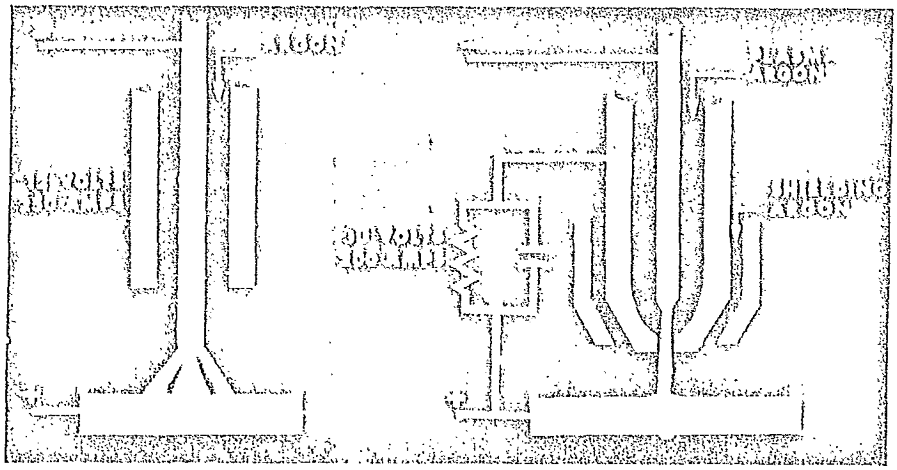
- une plus grande concentration d'énergie;
- une stabilité accrue;
- une énergie accrue;
- un meilleur contrôle de la vitesse du plasma;

- une rapidité de soudure accrue;

- une diminution de distortion;

- une machinerie moins compliquée que le processus précédent, soudage sous flux gazeux avec électrode tungstène.

Les différences majeures entre l'arc plasma et le processus avec électrode tungstène sont que le premier inclut un arc pilote qui démarre le processus et le maintien et une buse de cuivre qui concentre l'arc électrique. Voir figure 10.



—Schematic comparison of gas tungsten-arc and plasma arc welding torches

Comparaison entre l'arc plasma (SAP) et avec l'électrode au tungstène (SFGT).

FIGURE: 10

5.3 Sources d'énergie

Le processus "arc plasma" mécanisé utilise un électrode non consommable à arc transféré. Le courant de soudure est continu et varie de 100 à 400 ampères. La source est du type "voltage et ampérage tombant" dont le voltage en circuit ouvert est de 65 à 80 volts.

Le processus "SAP" manuel peut souder de minces couches de métal grâce à un courant très bas de 0.1 ampère. Le courant maximum est de 100 ampères pour souder une épaisseur maximale de 1/8 de pouce.

L'équipement de soudure "SAP" mécanisé consiste en une source de courant type "redresseur" unité de contrôle, torche, pompe à eau, générateur à haute fréquence, source de gaz protecteur et accessoires. L'équipement manuel comprend les mêmes items mais diffère dans les accessoires. Le coût de l'équipement varie de $2,000 à $3,000.

5.4 Applications

Le processus "SAP" procure une source de chaleur très stable et concentrée. Il peut souder la majorité des métaux d'épaisseur allant de 0.001 à 0.25 pouce. Dépendant du courant utilisé, on peut distinguer trois variations majeures, qui sont les suivantes:

- "Arc à faible intensité": 15 ampères, 115 volts, c.a., 60 Hz, est utilisé pour souder des métaux minces (0.001 à 0.062 pouce).
- "Arc sans déforcement": 60 ampères, 208/230 volts, c.a., 60 Hz ou 30 ampères, 460 volts, c.a., 60 Hz, est utilisé pour souder des épaisseurs de 1/32 à 1/8 de pouce.
- "Arc avec déforcement": même spécifications que le mode précédent et pouvant atteindre 275 ampères, est utilisé pour des épaisseurs allant de 3/32 à 1/4 de pouce.

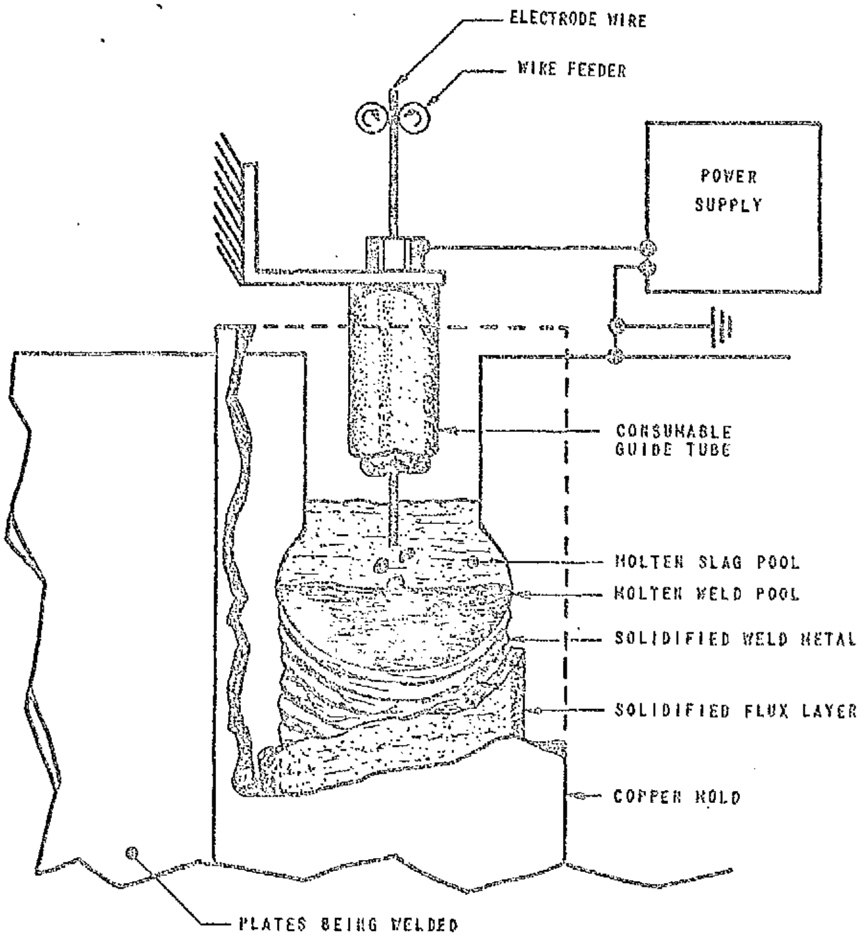
6. SOUDAGE SOUS LAITIER GRANULE OU GAZEUX
(Electrogas & Electroslag Welding)

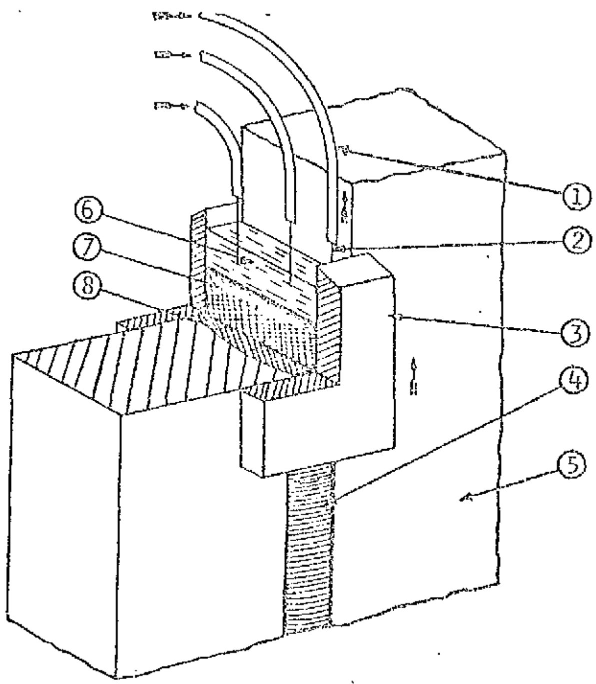
Le soudage sous laitier avec ou sans gaz sont deux processus ayant en commun le fait qu'ils opèrent seulement en position verticale et qu'ils déposent du métal fondu dans une cavité séparant les deux pièces à souder*, comme protecteur de la soudure. Vu que ces deux processus ont plusieurs caractéristiques similaires, il serait avantageux de les discuter simultanément, comme nous l'avions fait avec le "SFGFS" et le "SFF".

6.1 Description

Le soudage sous laitier est un processus de soudure qui utilise la chaleur d'un laitier fondu pour faire fondre le métal d'apport et les parois de la pièce à souder. En plus de produire la chaleur, le laitier protège aussi la soudure de l'air ambiant. Le laitier gagne sa chaleur en interférant comme une résistance à un courant électrique allant d'une électrode à la pièce à souder. La figure 11 démontre ce processus.

* Le soudage sous laitier utilise un laitier granulaire ou gazeux.





–Schematic view of conventional wire method of electroslag welding: (1)—Curved wire-guides, (2) Electrode wires, (3)—Cooled shoes, (4)—Weld surface, (5)—Plates being welded, (6)—Molten slag pool, (7)—Liquid metal pool, (8)—Solidified weld metal

Schéma d'un équipement conventionnel de soudage sous laitier.

FIGURE: 11

6.2 Principe de fonctionnement

A) Soudage sous laitier

Le processus est amorcé de la même façon que le soudage sous flux granulé en débutant un arc électrique immergé dans un "flux" granulaire. Ce "flux", en fondant, forme le laitier qui, grâce à sa résistance au courant électrique, n'a plus besoin de l'arc pour gagner sa chaleur. A partir de ce moment, le processus est vraiment du soudage sous laitier.

Dans la cavité qui sépare les deux pièces à souder, qui est de 1 à 1½ pouce de largeur, baigne un mélange de "filler", de métal de la pièce à souder et de "slag", à 3500°F. Ce mélange de métal liquide, en refroidissant, forme la soudure.

Une ou plusieurs électrodes sont utilisées, dépendant de la largeur de la cavité. La figure 12 démontre un processus utilisant trois électrodes. Afin de soutenir le métal fondu aux extrémités de la pièce à souder, des gabarits, refroidis à l'eau, sont généralement utilisés.

B) Soudage sous laitier gazeux

Le soudage sous laitier gazeux fournit un arc électrique continu, vu que l'électrode n'est pas enfouie dans un laitier mais entourée d'un gaz protecteur (un mélange de bioxyde de carbone et d'argon ou bien d'hélium). Cette méthode est classifiée par l'"American Welding Society" comme une variation du "Soudage sous flux gazeux avec fil solide" et désignée comme "GMAW-EG"* ou "FCAW-EG"* (si l'électrode fournit son propre gaz). Voir figure 12).

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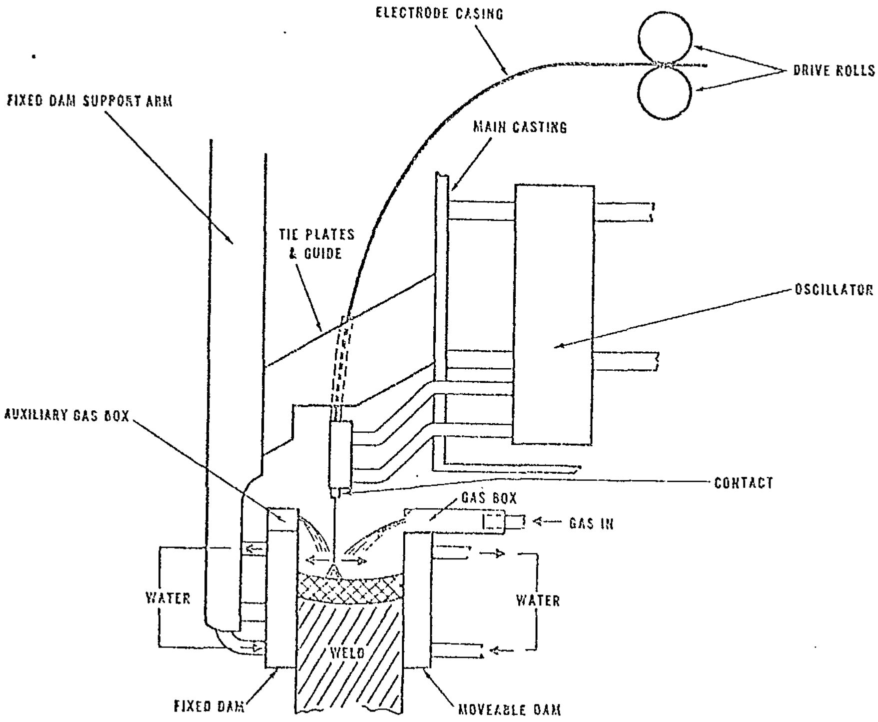
* EG pour électrogas; GMAW et FCAW abréviations américaines pour SFGFS et SFF.



—Schematic of typical electrogas equipment in weld area

Schéma d'un équipement de soudure sous laitier gazeux
FIGURE: 12

6.3 Sources d'énergie

Le courant de soudure est relatif au taux de consommation de l'électrode. En augmentant celui-ci, on augmente le déploiement du fil de l'électrode et, donc, la quantité de métal déposé. La moyenne des courants utilisés varie de 550 à 650 ampères pour une électrode de 1/8 de pouce de diamètre.

Quant au voltage, il affecte la profondeur de fusion et la stabilisation du processus. En augmentant le voltage, on augmente aussi la largeur et la profondeur de la soudure ainsi que les chances de craquelures. C'est pour ces raisons que le voltage est maintenu entre 40 et 55 volts.

La source de courant est, d'habitude, de courant continu (c.c.), bien que le courant alternatif (c.a.) peut aussi être utilisé. La puissance varie de 20 kilowatts (c.c.) à plusieurs centaines de kilowatts (c.c.).

6.4 Applications

Le soudage sous laitier est utilisé pour souder des structures en acier, des réservoirs à haute pression ou des plaques métalliques allant de 2 à 36 pouces d'épaisseur. Le processus trouve ses applications surtout dans la construction, la construction marine, la fabrication des réservoirs et les aciéries.

Les machines à soudage sous laitier granulé ou gazeux en grandeur de 75 lbs à des dimensions massives nécessitant l'usage de grues mécaniques pour leur déplacement. Elles sont, pour la plupart, automatisées et peuvent contenir plusieurs électrodes. Quant aux prix de l'équipement, ils commencent à partir de $5,000 pour une machine portative et excèdent $50,000 pour des machines hautement automatisées.

LES SOURCES D'ENERGIE

POUR LA SOUDURE A ARC ELECTRIQUE

"ARC WELDING"

CATEGORIE I

(sous-section)

Plusieurs sources d'énergie sont disponibles pour les diverses catégories de soudeuse à arc électrique. En règle générale, des facteurs d'ordre économique sont à la base de la sélection de ces sources de courant. Ces dernières sont classifiées d'après les besoins du processus de soudure. Exemple: Voltage constant ou courant constant ou bien d'après l'équipement dont il est fait usage ex: transformateur, moteur-générateur, etc. Il est donc désirable de décrire une machine à souder d'après le genre de courant qu'elle utilise et d'après l'équipement électrique qu'elle contient. Par exemple: "Transformateur, courant constant, c.c./c.a.". Ensuite, il s'agit de décrire les caractéristiques du courant, le "duty cycle", le voltage et la fréquence de la source.

Le tableau suivant relate les types de machines à souder et leurs besoins, en termes de courant électrique.

Type of Welding Machine	Requirements of Process Selected					
	Volt-Ampere Characteristics		Type of Welding Voltage			
	Constant-Voltage	Constant-Current	AC Only	AC or DC	DC Only	AC and DC Pulse
Rotating electric motor generator	X	X			X	
Transformer	X	X	X			
Transformer-rectifier	X	X		X	X	X
Type of Power						
Power line to motor generator	X	X			X	
Power line to transformer	X	X	X	X		X
Engine to generator	X	X	X	X	X	

En règle générale, le courant distribué par les compagnies d'électricité détient un voltage trop élevé (220 volts ou plus) pour que l'électrode puisse en faire usage. Il est donc commun de réduire ce voltage (20 à 80 volts), en incorporant un transformateur ou un moteur connecté à un générateur. Ces derniers, en baissant le voltage, augmentent en même temps l'intensité du courant intrant (10 à 100 ampères) aux alentours de 50 à 500 ampères. Le diagramme suivant schématise le circuit électrique utilisé par les soudeuses à arc électrique.

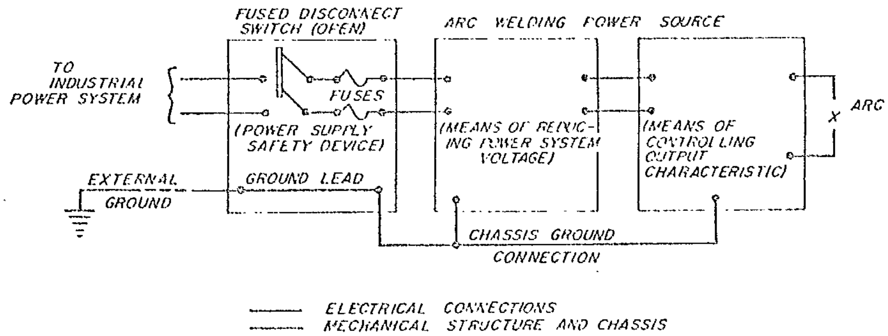


Fig. 25.1.—Elements of an arc welding power source, shown connected to power lines

Il serait bien trop compliqué de discuter chaque variation décrite dans le tableau précédent, en détail, dans ce texte. Mais, vus l'importance du sujet, le lecteur pourra se référer aux titres qui l'intéressent en annexe. Les sujets suivants y sont traités:

SOURCES D'ENERGIE: Sujets traités en annexe

Ces numéros de page correspondent aux numéros de page du "Welding Handbook", publié par l'American Welding Society, Volume 2, dont nous avons reproduit le chapitre à l'annexe I.

SOUDURE PAR RESISTANCE AU COURANT ELECTRIQUE

"RESISTANCE WELDING"

CATEGORIE II

SOUDURE PAR RESISTANCE AU COURANT ELECTRIQUE - ("Resistance Welding")

La soudure par résistance au courant électrique des matériaux à souder, tout comme la soudure à arc électrique, est une catégorie qui inclut plusieurs procédés de soudure qui ont pour dénominateur commun de générer la chaleur requise grâce à la résistance des pièces à souder au courant électrique. Cette catégorie de soudure est surtout utilisée pour souder des feuilles de métal superposées, grâce à des électrodes qui, en plus de conduire le courant électrique, servent à appliquer une forte pression au centre de la jointure.

Les variables importantes à considérer dans cette catégorie de soudure sont l'amplitude du courant, le temps de soudure requis, la pression appliquée par l'électrode et les caractéristiques de l'électrode. En général, l'amplitude du courant utilisé par cette catégorie est de dix à cent fois plus élevée que la soudure à arc électrique. Par exemple, une soudure par point requiert un courant de 19,000 ampères et une demie seconde pour souder deux feuilles d'acier de 1/8 de pouce d'épaisseur.

La catégorie "soudure par résistance" comprend trois procédés majeurs qui sont discutés conjointement dans les pages qui suivent. Ces derniers sont:

7. Soudure par point: (SPP)
   (Résistance Spot Welding): (RSW)
8. Soudure par joint continu: (SJC)
   (Resistance Seam Welding): (RSEW)
9. Soudure par bossage: (SPP)
   (Projection Welding): (RPW)

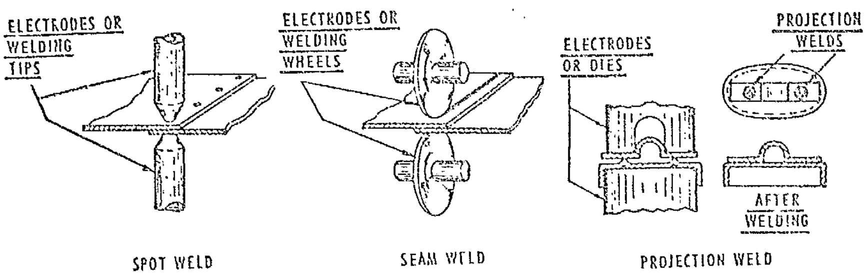
.1 Description

7.1 Soudure par point: Une soudure à forme presque circulaire de deux feuilles de métal superposées. Après chaque soudure, les électrodes sont rétractées.

8.1 Soudure par joint continu: Une soudure continue de deux feuilles de métal superposées. La soudure peut être un sillon continu ou bien une série de points superposés.

9.1 Soudure par bossage: Une soudure obtenue grâce à la chaleur que dégage la résistance au courant électrique de deux pièces tenues ensemble par la pression de deux électrodes. Les soudures sont localisées à des points prédéterminés, lors de la conception des pièces à souder.

La figure 13 reflète la différence entre les trois procédés.



—Comparison of spot, seam and projection welding

Comparaison entre les trois procédés.

FIGURE: 13

.2 Principe de fonctionnement

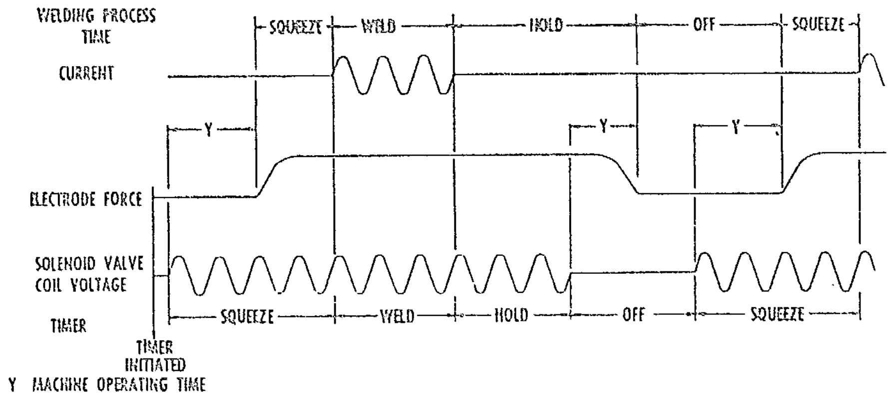
Les trois procédés suivent un cycle identique de soudure (voir figure 14). Ce cycle consiste en quatre étapes distinctes qui sont les suivantes:

a) Temps d'accostage: le laps de temps entre l'application initiale de l'électrode sur la pièce et l'application du courant électrique.

b) Temps de soudage: le laps de temps que dure l'application du courant électrique.

c) Temps de maintien: le laps de temps durant lequel la pression est appliquée après la cessation du courant électrique.

d) Temps d'ouverture: le laps de temps durant lequel les électrodes sont rétractées. Ce terme est employé pour les soudures répétitives et non continues.



—Graphical representation of simple resistance welding cycle; simulates functions of NEMA type N2 control

Représentation graphique du cycle de soudage.

FIGURE: 14

Le principe de fonctionnement des trois procédés implique l'application coordonnée d'un courant électrique d'une certaine amplitude, pour un certain laps de temps. Ce courant est le produit d'un court-circuit contrôlé grâce à la pression appliquée par les électrodes. La chaleur dégagée par le processus doit être assez élevée afin de fondre un volume suffisant de métal qui, une fois refroidi sous pression, se solidifie et soude les deux pièces. Les températures atteintes lors de ce procédé ne doivent pas être élevées au point de fondre trop de métal, sinon les électrodes, sous pression, passeraient à travers les pièces à souder. Les temps de réchauffement et de refroidissement doivent être courts afin de rendre la vitesse de soudure commercialement viable.

.3 Sources d'énergie

Un circuit électrique type du procédé "Resistance Welding" est représenté par la figure 15. Il consiste en une source de courant, un transformateur et deux électrodes. Les sources de courant peuvent être du type alternatif (c.a.), continu (c.c.) ou à énergie électrique emmagasinée.

La majorité des machines à résistance, aux Etats-Unis et au Canada, utilisent le courant alternatif à phase unique dont la fréquence est de 60 Hz. Un transformateur réduit le voltage entrant à un niveau variant de 1 à 25 volts et augmente l'amplitude du courant à 1,000 ou 100,000 ampères, dépendant des types de pièces à souder et de leur épaisseur.

D'autres systèmes de courant alternatif moins usités réduisent la fréquence du courant grâce à un changeur de fréquence trois-phases ou bien l' augmentent à des fréquences pouvant atteindre 450,000 Hz.

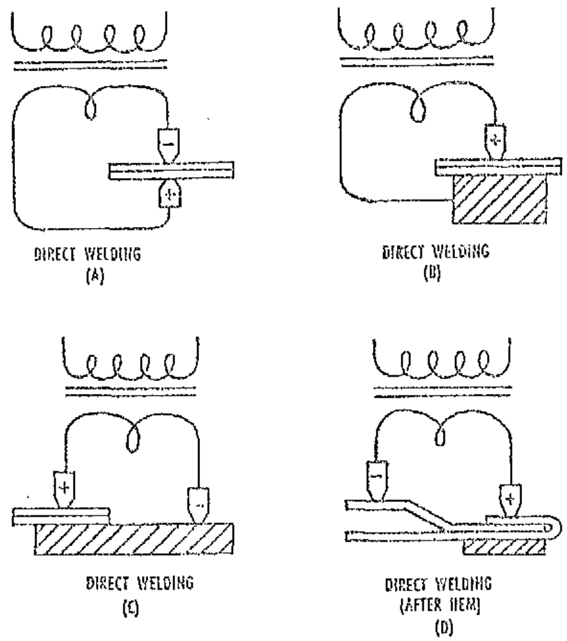
Les systèmes à courant continu transmettent le courant de la source et du redresseur de courant directement au transformateur. Les redresseurs les plus usités sont du type à trois phases, à diodes de silicone et refroidis à l'eau.

Finalement, les systèmes à énergie emmagasinée sont, pour la plupart, dépassés sauf le type à condensateur qui est encore utilisé par certaines petites industries de pièces électroniques.

.4 Applications

7.4 La soudure par point est utilisée pour souder des feuilles de métal dont l'épaisseur peut varier de

0.001 à 1 pouce, bien que la majorité des pièces soudées grâce à cette technique ont moins d'un quart de pouce d'épaisseur. La figure suivante démontre quatre types d'application.

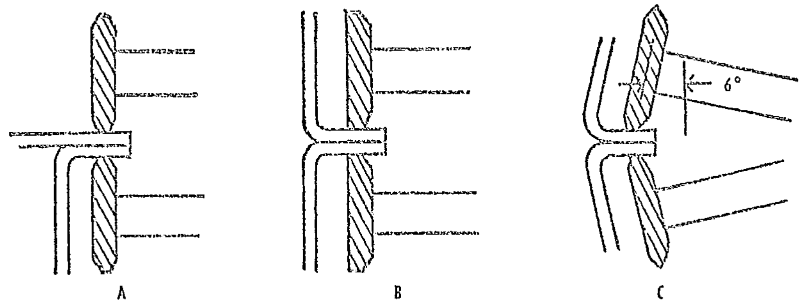


—Types of single spot welds

Diverses techniques de soudure par point.

FIGURE: 15

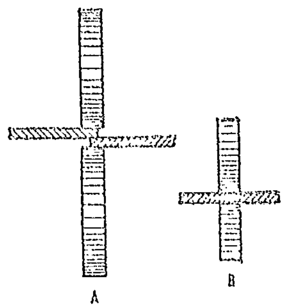
8.4 La soudure par joint continu est le plus souvent appliquée pour souder des pièces dont l'épaisseur ne dépasse pas le quart de pouce. Les figures suivantes donnent une idée des maintes applications de ce processus.



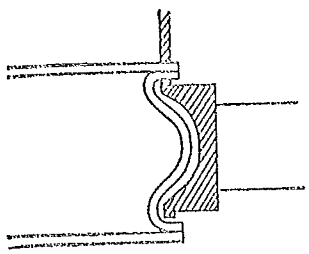
—Common types of seam-welded flanged joints

Variétés communes de joints

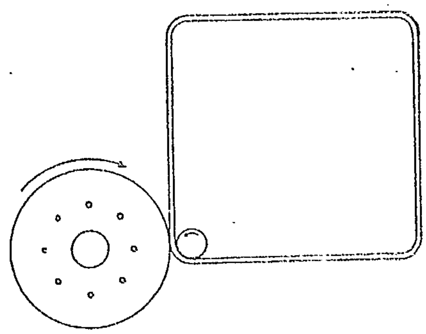
FIGURE: 16



—Mash seam weld



—Special electrode for seam welding dished heads

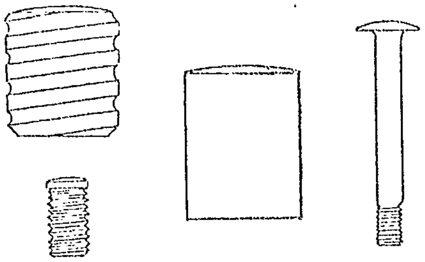


—Use of small diameter electrode for seam welding corner joints

Méthodes de soudure par joint continu

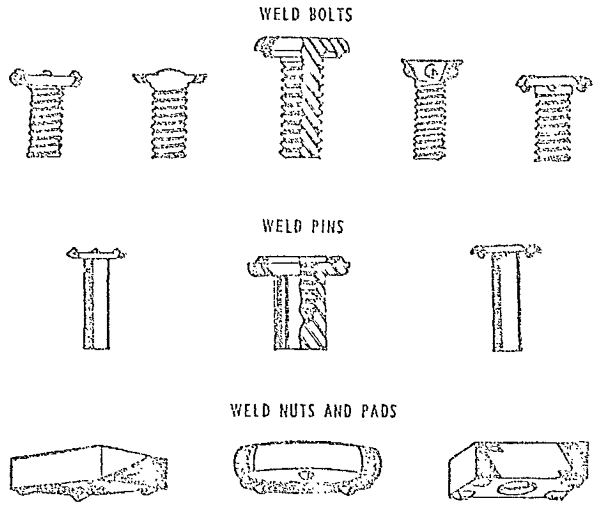
FIGURE: 17 FIGURE: 18 FIGURE: 19

9.4 La soudure par bossage peut souder des pièces dont l'épaisseur dépasse 0.02 pouce. Les figures qui suivent décrivent certaines applications de ce processus.



—Typical screw and stud parts suitable for projection welding

FIGURE: 20



—Parts available with welding projections

Exemple d'application de soudure par bossage

FIGURE: 21

Les coûts des machines à souder à résistance électrique varient largement, dépendamment du type et de l'épaisseur du matériel à souder. Par exemple, une machine à phase unique et de faible puissance (mesurée en KVA) coûte approximativement $1,000; par contre, une machine de 100 KVA coûte $7,000. En règle générale, une machine à trois phases coûte deux fois et demie le prix d'une machine à phase unique de la même puissance. Malgré les coûts élevés des machines, ce processus est plus ou moins économique, vu qu'il ne consomme pas autant d'électrodes que le processus à arc électrique et qu'il ne requiert pas de métal d'apport ni de gaz protecteur.

"LA SOUDURE PAR ETINCELLAGE"

"FLASH WELDING"

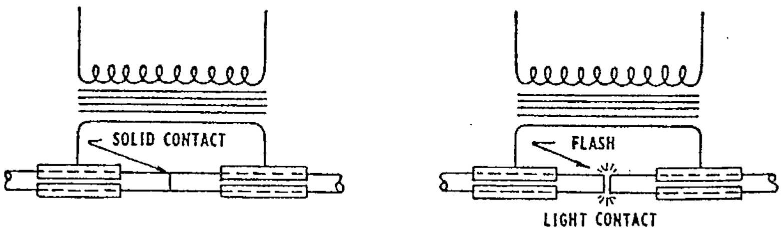
CATEGORIE III

10. SOUDURE PAR ETINCELAGE (Flash Welding)

10.1 Description

La soudure par étincelage **est** un processus qui utilise la résistance des pièces à souder au courant électrique pour faire fondre les surfaces où se fait le contact. Une forte pression est alors appliquée, mélangeant ainsi le métal fondu. Ce dernier, en refroidissant, forme la soudure.

10.2 Principe de fonctionnement



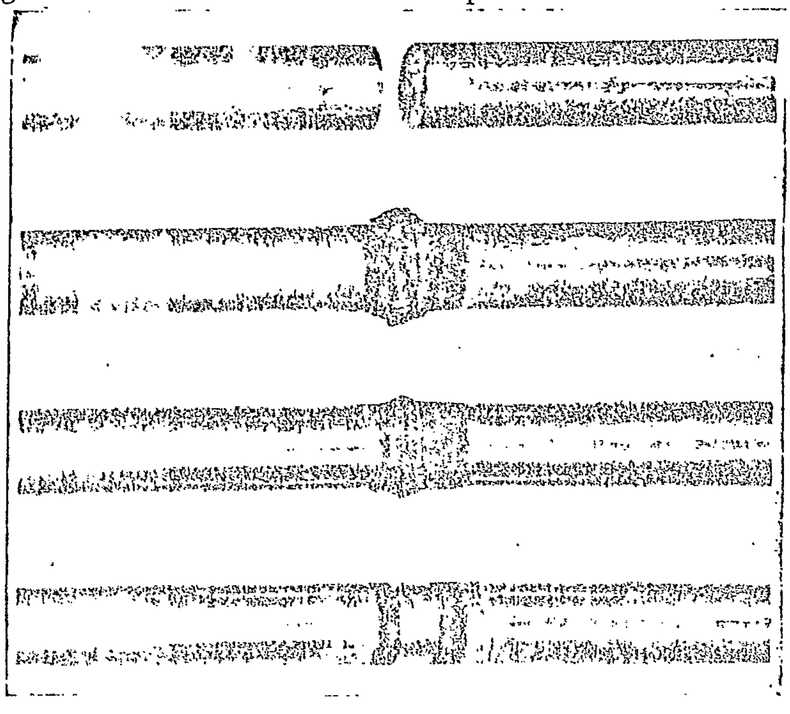
—Relationship of parts for flash welding

Positions des pièces à souder pour ce procédé
FIGURE: 22

Deux pièces de métal sont placées l'une en face de l'autre. Un courant électrique passe à travers les pièces et donne lieu à une étincelle aux extrémités adjacentes. L'étincelle dégage une chaleur qui fait fondre le métal des surfaces opposées. Une forte pression soude le métal ainsi fondu. (Voir figure 22)

Le laps de temps que dure l'étincelle est critique. S'il est trop court, la chaleur est insuffisante pour terminer la soudure; par contre, s'il est trop long, une grande quantité de métal fond et il est difficile d'appliquer la bonne pression pour faire une belle soudure.

La pression est appliquée pour deux raisons fondamentales. La première est évidente: elle unit le métal en fusion. La seconde est de ressortir le laitier et les particules oxydées vers la surface de la soudure. Ceux-ci sont enlevés par la suite. La phase lors de laquelle la pression est appliquée est nommée "écrasement". Durant cette phase, le courant électrique est toujours en vigueur pour maintenir les extrémités du métal dans un état plastique. La figure suivante relate le processus.



–Flash welding two solid rods. From top to bottom: before welding, after welding, after flash removal and after upset metal removal

Cycle de soudure par étincelage
FIGURE: 23

10.3 Sources d'énergie

La plupart des machines à soudure qui utilisent ce processus sont semi-automatiques ou automatiques. Le courant et le voltage varient largement dépendamment du type de métal, de son épaisseur et du "Upsetting time". Il n'est donc pas possible de généraliser à ce sujet. Une source d'énergie de 4,800 volts accomode une machine dont la puissance peut varier de 200 à 500 KVA.

10.4 Applications

Le processus d'étincelage est très pratique pour souder des fils, des tubes et même des feuilles métalliques. Les industries automobiles, aéronautiques et d'appareils de cuisine utilisent ce processus pour souder des feuilles de 0.01 à 1 pouce d'épaisseur et des tubes de 0.05 à 2 pouces de diamètre. Le coût des machines varie de $5,000 pour une puissance de 10 KVA à $600,000 pour une soudeuse de feuilles d'acier automatique de 1,500 KVA.

"SOUDURE PAR PHYSIQUE DE L'ETAT SOLIDE"

"SOUDAGE PAR BOSSAGE ET COMPRESSION"

"SOLID STATE WELDING"

"DIFFUSION WELDING"

CATEGORIE IV

11. SOUDAGE PAR PHYSIQUE DE L'ETAT SOLIDE.- SOUDAGE PAR BOSSAGE ET COMPRESSION
(Solid State - Diffusion Welding)

11.1 Description

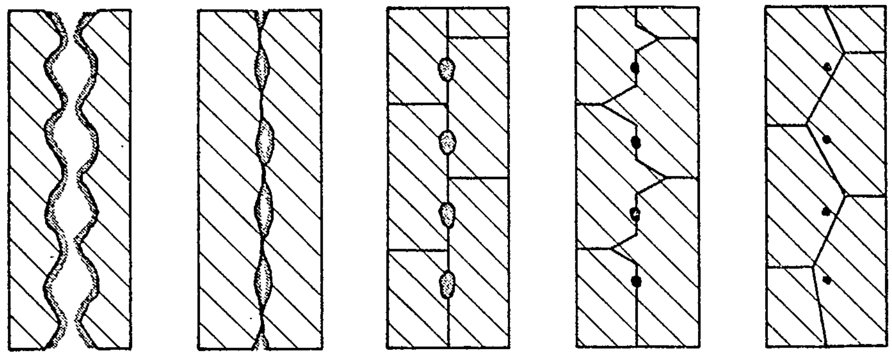
Bien que les principes du soudage par bossage et compression aient été connus depuis plus de mille ans, l'intérêt qu'ils ont suscité est tout récent. Ce type de soudure offre des solutions à plusieurs problèmes, tels que la réduction de la corrosion (ex: titanium et zirconium), l'amélioration de la résistance du titanium à la fracture, l'évitement de dommages métallurgiques des métaux réfractaires et l'amélioration de la soudure de métaux différents.

Cette technique de soudage est définie comme un processus où la chaleur des surfaces juxtaposées est générée sous pression et à des températures élevées. La soudure se fait sans déformations macroscopiques ni mouvement relatif des pièces. Le métal d'apport est optionnel.

11.2 Principe de fonctionnement

Le processus de soudure par bossage et compression inclut deux étapes fondamentales. La première consiste à amener un contact mécanique intime entre les deux pièces à souder. La seconde est de joindre les deux pièces le long de la surface de contact.
Quand une forte pression est appliquée sur les deux pièces à souder, une certaine déformation microsco-

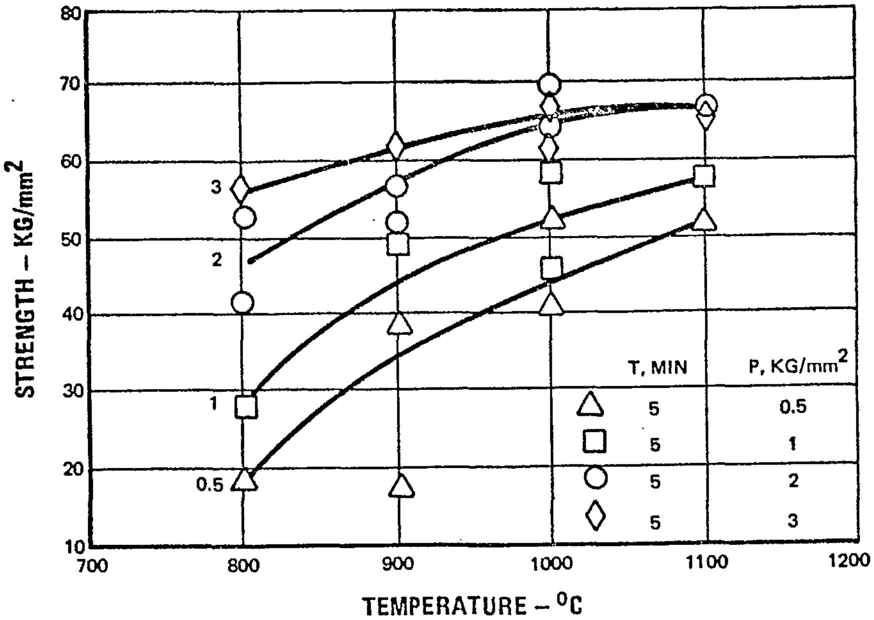
pique commence aux parties les plus proches des pièces (voir figure 24). Cette dernière se généralise graduellement à la totalité de la surface, créant ainsi un contact intime de métal à métal. C'est alors qu'une force d'attraction surgit entre les atomes et joint les deux pièces.



—Overall two step diffusion welding process. (Steps expanded in sequential form for clarity.)

Etape de la soudure par bossage et compression
FIGURE: 24

Les trois variables les plus importantes sont la température, la pression et le temps. Le degré de température absolu est généralement plus élevé que 0.5 Tm (Tm est la température à laquelle le métal fond) et dépend de la pression appliquée et du temps d'application. Le temps est un paramètre relatif à la température et à la pression appliquée. Il varie de quelques secondes à plusieurs heures, dépendamment des circonstances. Quant à la pression, elle représente la variable la plus importante vu que, pour un temps/température donné, plus de pression signifie meilleure soudure. La figure suivante résume la relation qui existe entre les trois variables temps/température/pression.



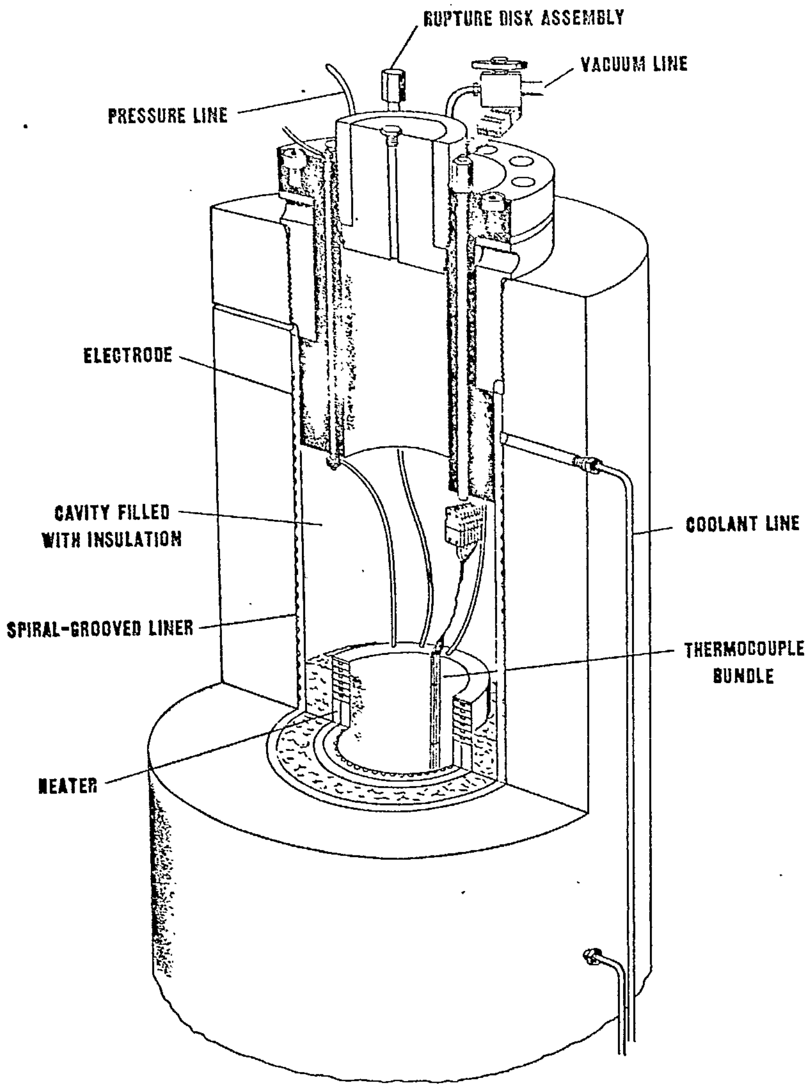
—Effect of temperature and pressure on strength of 0.45%C steel diffusion welds

Effet de la température et de la pression quant à la qualité de la soudure.

FIGURE: 25

11.3 L'équipement

Plusieurs sortes d'équipement sont disponibles pour réaliser de telle soudure. Cette technique a l'avantage de souder des géométries fort complexes. Un exemple de machine à soudure par bossage et compression est représenté par la figure suivante.



—High-temperature cold-wall autoclave

Exemple d'un équipement de soudure par bossage et compression.

FIGURE: 26

11.4 Applications

Les principales applications de ce type de soudure se retrouvent principalement dans l'industrie atomique et aéronautique. Vu les coûts élevés qu'entraîne ce procédé, il n'est utilisé que pour obtenir des soudures de haute performance sans pour cela changer les dimensions ou caractéristiques des éléments soudés.

Le coût d'un équipement à soudure par bossage et compression varie, dépendamment de la surface à souder. Il se situe entre $1,000 et $2,000 par pouce carré de surface à souder. Vu son coût exorbitant, cette technique n'est économique que pour des soudures nécessitant une haute précision.

SOUDURE PAR FAISCEAU D'ELECTRONS

"ELECTRON BEAM WELDING"

CATEGORIE V

12. SOUDURE PAR FAISCEAU D'ELECTRONS
("Electron Beam Welding")

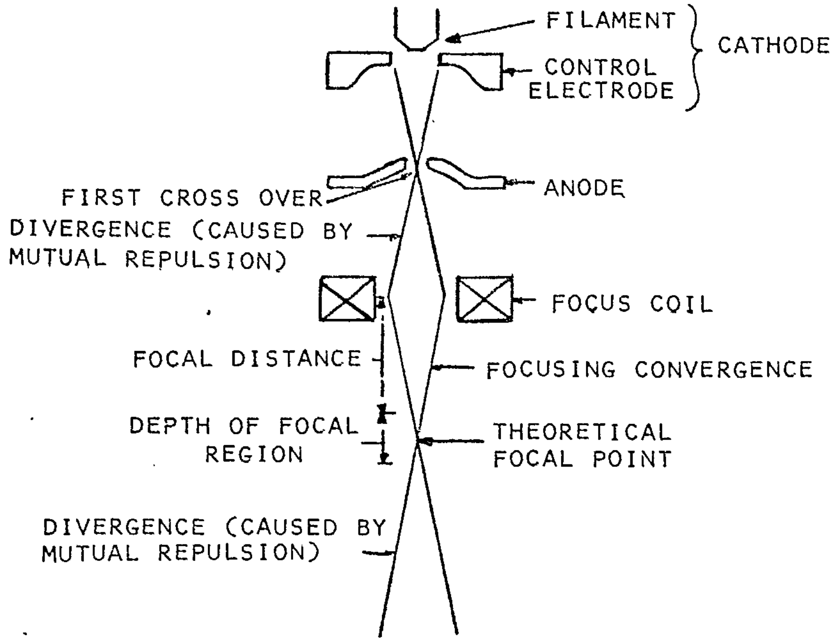
12.1 Description

La soudure par faisceau d'électrons, comme son nom l'indique, consiste à chauffer les pièces à souder par l'entremise d'un faisceau d'électrons (d'infimes particules à charge négative). Autrefois, le processus se faisait à l'intérieur d'une chambre à vide où l'appareil et les pièces étaient inclus. L'avantage, bien sûr, était d'obtenir une soudure très pure. Aujourd'hui, cette soudure est pratiquée dans un vide partiel et dans des conditions de pression atmosphérique normale. Néanmoins, le faisceau d'électrons est toujours généré dans un vide presque total.

Le fait d'utiliser un faisceau d'électrons permet d'obtenir une source de chaleur très condensée pouvant faire une soudure d'une épaisseur de 0.06 pouce.

12.2 Principe de fonctionnement

Un faisceau d'électrons convergents, accéléré à une vitesse de 30,000 à 120,000 milles par seconde, passe par un orifice à l'intérieur de l'anode et se dirige vers la pièce à souder. Ces électrons sont tellement rapides qu'ils traversent la pièce à souder et perforent un trou très étroit. Le métal du trou fond et coule vers la surface inférieure de la pièce où il se solidifie, formant ainsi la soudure. Le schéma de la figure 27 représente le processus.



—Geometry of electron beam in unobstructed space

Géométrie d'un faisceau d'électron dans un espace libre.

FIGURE: 27

12.3 Sources d'énergie

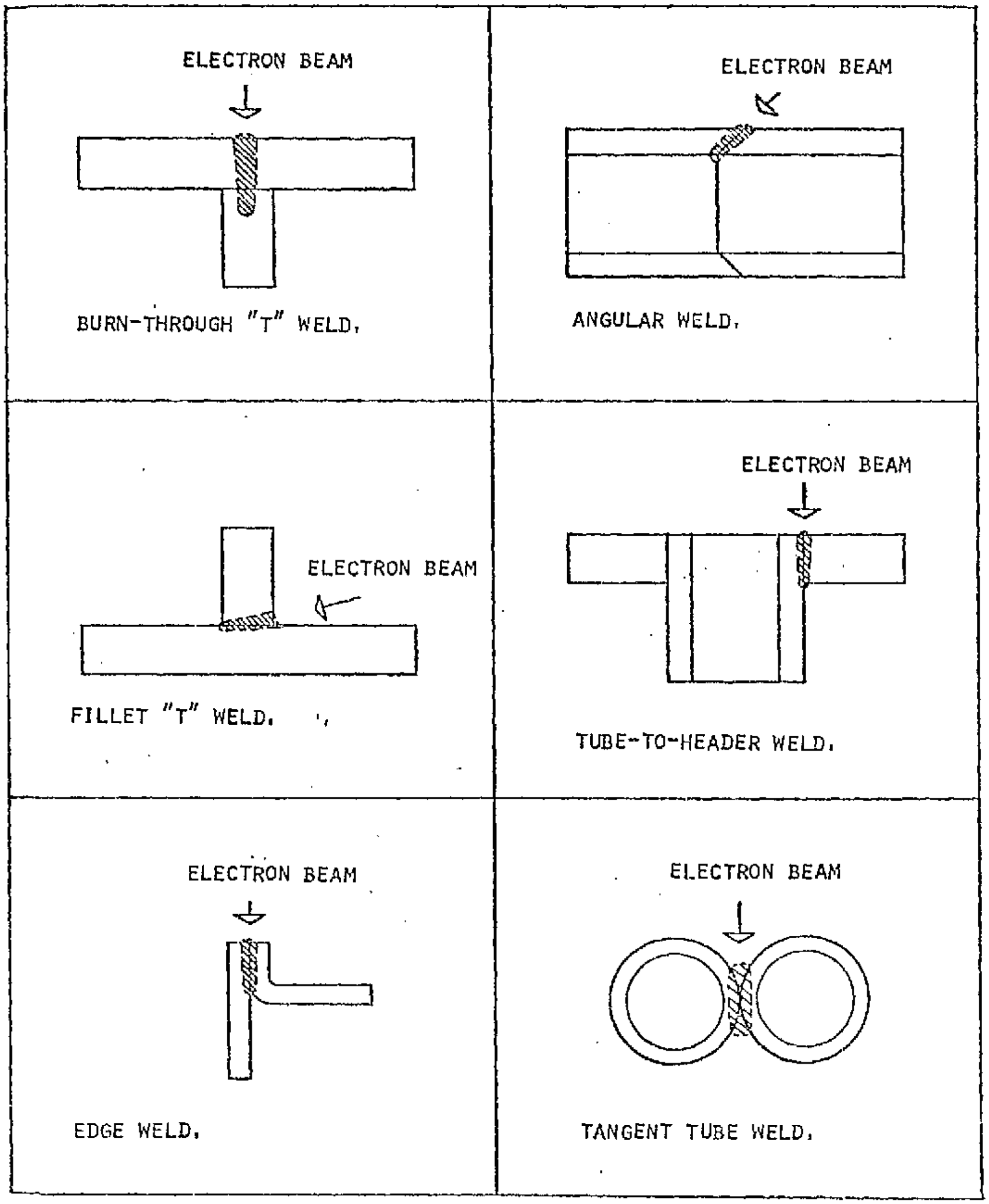
La capacité d'une soudeuse à faisceau d'électrons est déterminée par la densité du faisceau à la surface de la pièce à souder. A son tour, cette densité dépend du paramètre du canon d'électrons et surtout du produit du courant par le voltage.
La densité du faisceau d'électrons peut atteindre 10^8 watts/cm^2 (plus que le double de la chaleur atteinte par la soudure à arc électrique).

Il existe deux types de système. Celui qui ne dépasse pas le voltage de 60 KV et dont la capacité du faisceau atteint 50 KW, et celui qui opère à un haut voltage, dépassant les 60 KV et atteignant 150 KV et dont la puissance du faisceau atteint 30 KW.

12.4 Applications

La soudure à faisceau d'électrons est surtout utilisée de nos jours dans l'industrie aéronautique et atomique. Toutefois, ce procédé est utilisé dans la fabrication d'automobiles, de camions et de tracteurs.

L'équipement inclut une chambre à vide, un canon d'électrons de 30 à 175 KV et 50 à 1,000 mA, une source de courant trois-phases 60 Hz, 440/480 volts, des instruments optiques et des accessoires.
Les prix varient de $75,000 à $1,500,000. Par contre, une machine à vide très poussé peut souder de l'aluminium. Des exemples de soudures possibles sont illustrés à la page suivante.



Exemple de soudure par faisceau d'électrons

FIGURE: 28

SOUDURE AU LASER

"LASER BEAM WELDING"

CATEGORIE VI

13. SOUDURE AU LASER
("Laser Beam Welding")

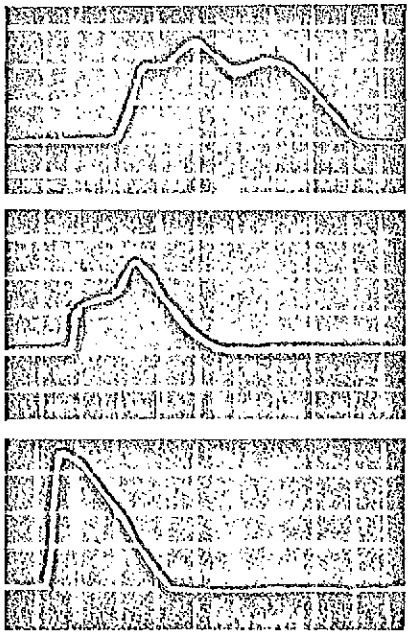
13.1 Description

Le laser est un appareil optique qui amplifie des rayons de lumière et les concentre à un point donné. Cette concentration de rayons lumineux dégage une chaleur intense qui sert, dans le présent cas, à souder des pièces de métal.

Certains types de laser (matière à l'état solide) utilisent des cristaux d'oxyde d'aluminium et de chrome. Cet alliage est appelé "rubis". Quand ce dernier est exposé aux radiations lumineuses de lampes au xénon, il dégage des rayons lumineux rouges qui sont concentrés par un jeu de prismes. Cette énergie lumineuse est transformée en énergie calorifique au contact de la pièce à souder.

13.2 Principe de fonctionnement

La chaleur intense dégagée par le rayon lumineux vaporise la surface du métal et fait fondre une colonne cylindrique à travers le métal. Le ratio de pénétration à la largeur est de 4 à 1. C'est pour cette raison que les lasers à rubis sont utilisés pour souder des pièces microélectriques ou d'autres qui nécessitent une grande précision de soudure. La chaleur du laser se dégage sous forme d'impulsion. Le taux d'impulsion par seconde varie d'après le genre de laser utilisé. La figure 29 illustre des impulsions de différente durée.



—Typical energy-time distributions

Exemple de cycle énergétique.

FIGURE: 29

13.3 Applications

La soudure au laser a prouvé son utilité pour souder des métaux différents, tels que le cuivre, le titanium, l'acier inoxydable, le dumet, le kovar, l'aluminium, le tungsten, le titanium, etc. Les soudures sont généralement fil à fil, feuille à feuille, fil à feuille et tube à feuille. Elle est surtout bien adaptée pour les soudures infiniment petites et précises, dans des métaux relativement lourds.

La soudure au laser offre plusieurs avantages comparativement à la soudure au faisceau d'électrons. Ceux-ci se résument comme suit:

a) Le laser n'a pas besoin de chambre à vide.

b) Le faisceau de lumière ne génère pas de radiations.

c) Les faisceaux du laser sont plus facilement contrôlables par des appareils optiques, facilitant ainsi l'automatisation;

d) La densité de chaleur du faisceau laser étant plus faible que le faisceau à électrons, il en résulte moins de détonnations, une meilleure fusion et porosité du métal.

Un laser à bioxyde de carbone de 5 KW peut atteindre une vitesse de soudure de 200 pouces à la minute, dans une épaisseur de 0.1 pouce. La puissance maximale atteinte, obtenu à ce jour dans les soudeuses au laser est de 25 KW. Les coûts n'en demeurent pas moins exorbitants et varient de $40,000 à $750,000.

ETAMAGE

"SOLDERING"

CATEGORIE VII

14. ETAMAGE
(Soldering)

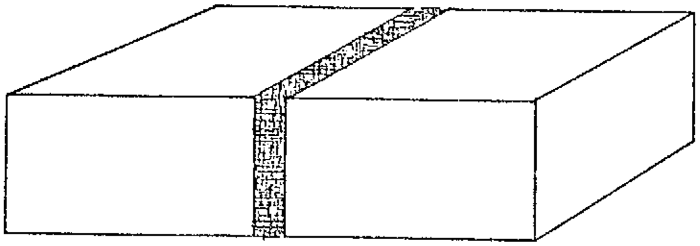
14.1 Description

L'étamage est défini comme une catégorie de soudure qui regroupe plusieurs procédés qui ont en commun le fait de chauffer les pièces à souder et d'utiliser un métal de remplissage dont le point de fusion est plus bas que le métal qu'il soude et n'excède pas 800^{o}F ou 427^{o}F.

14.2 Principe de fonctionnement

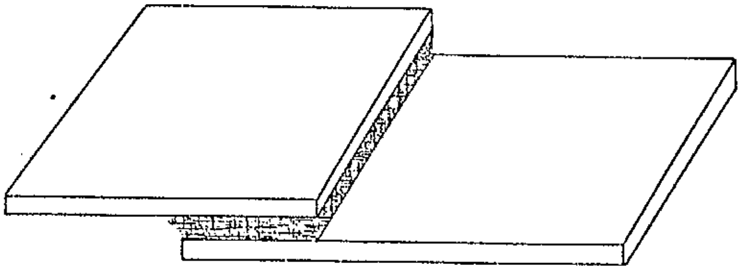
Un métal est ajouté entre les deux pièces à souder. Le tout est chauffé (par plusieurs moyens discutés plus loin) à une température qui fait fondre le métal d'apport qui rougit les pièces à souder. C'est alors que le métal d'apport se dissout sur la surface qui lui est adjacente et forme avec elle un composé métallique. Ce dernier, en refroidissant, durcit et joint les deux pièces. Le rôle du solvent est primordial dans ce procédé. La soudure est meilleure à mesure que l'action du solvent est plus efficace.

Les sondures réalisées par cette technique sont généralement plus faibles que les métaux qu'elles joignent. C'est pour cette raison qu'il est suggéré d'utiliser ce procédé pour les applications dont les pièces soudées ne seront pas soumises à des forces importantes et que la soudure du type à joints superposés (voir figure 30) est à conseiller.



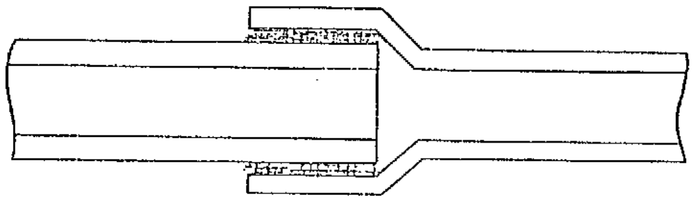
BUTT JOINT

Joint en bout



LAP JOINT

Joint superposé



PIPE JOINT

Joint tubulaire

—Typical joint design used for soldering

Exemple de joint pour le soudage par étamage.

FIGURE: 30

14.3 Sources d'énergie

La source d'énergie ou de chaleur est choisie de façon à atteindre la bonne température, un taux de réchauffement et de refroidissement adéquats et, finalement, en fonction des métaux à souder. Plusieurs méthodes sont pratiquées. Elles sont brièvement discutées dans les pages suivantes.

A- FER A SOUDER
(Soldering Iron)

La méthode du fer à souder est la plus traditionnelle. Elle consiste à utiliser un métal d'apport d'étain, de cuivre et chauffé, soit électriquement, soit à l'huile, au charbon ou au gaz.

B- TORCHE A SOUDER
(Torch Soldering)

Cette méthode consiste à utiliser une torche à gaz comme source d'énergie. Dépendamment de la grandeur des pièces à souder, de leur poids et géométrie, par conséquent, le type de torche à utiliser varie selon la sorte de flamme désirable.

C- SOUDAGE PAR PLONGE
(Dip Soldering)

Cette méthode consiste à plonger des unités entières à souder dans un bassin où se trouve le métal d'apport, dans un état liquide et chaud. Ce dernier remplit les ouvertures à souder et y demeure jusqu'à refroidissement.

Cette méthode est très économique. Elle ne s'applique, toutefois, qu'aux pièces qu'on peut plonger sans déplacer les espaces à souder.

D- SOUDURE AU FOUR
(Oven Soldering)

Bien que cette méthode n'est pas couramment utilisée, elle est très efficace dans les circonstances suivantes:

- quand des pièces entières peuvent être chauffées sans pour cela détériorer leurs composantes et leurs propriétés;

- quand la production est telle qu'il soit économique de mécaniser le processus d'entrée et de sortie des pièces du four;

- quand les pièces sont si complexes que les autres méthodes ne sont plus pratiques.

E- SOUDURE PAR PISTOLET A JET
(Spray Gun Soldering)

Quand l'endroit de la soudure se présente de façon à ce qu'il est difficile de placer le métal d'apport à la main, il est préférable d'utiliser des pistolets à jet. Ces derniers sont chauffés au gaz ou à l'électricité et sont conçus pour déposer un jet de soudure sur les pièces à souder. Ce jet est à 90% liquéfié par la chaleur du pistolet et reçoit la balance de chaleur requise de la pièce à souder.

F- <u>SOUDURE PAR RESISTANCE</u>
(Resistance Soldering)

La pièce à souder est reliée soit à la terre et à une électrode mouvante ou bien à deux électrodes mouvantes pour refermer un circuit électrique. De par la résistance du métal et de l'électrode au courant électrique, une intense chaleur se dégage et produit la soudure. Plusieurs variétés d'électrodes peuvent être utilisées, dépendamment de la vitesse de soudure, de la chaleur et de l'énergie requise.

G- <u>SOUDURE PAR INDUCTION</u>
(Induction Soldering)

Tout matériel qui soit bon conducteur de l'électricité peut être soudé par cette technique. La chaleur dégagée et sa distribution dépendent de la fréquence du courant. Les hautes fréquences concentrent la chaleur à la surface. Trois types d'équipement sont, à l'heure actuelle, disponibles sur le marché. Ils sont l'oscillateur à lampe, le résonnateur à cavité et l'unité moteur-générateur.

H- <u>SOUDAGE PAR VAGUE</u>
(Wave Soldering)

Une variante du soudage par plongé, consiste à pomper le métal d'apport à l'intérieur du bain où baigne la pièce à souder. Le métal d'apport pompé produit des vagues d'où le nom "soudage par vague".

I- SOUDAGE PAR ULTRASON
(Ultrasonic Soldering)

Cette méthode est rarement utilisée. Elle consiste à créer des vibrations à hautes fréquences afin de briser les films d'oxyde tenaces qui se trouvent sur la surface des métaux à souder et, en particulier, sur l'aluminium.

NOTE: D'autres méthodes d'étamage moins connues sont le soudage par infra-rayons - infra-rouge, le soudage par gaz chaud, le soudage par abrasion.

14.4 Applications

Le processus d'étamage est utilisé pour souder une grande gamme de métaux de diverses épaisseurs et largeurs. Les vitesses de soudure de l'équipement automatisé sont très élevées, vu le nombre de soudures possibles en une seule plongée dans un bain de métal d'apport. Les circuits imprimés électroniques utilisent cette méthode économique. Les coûts de l'équipement sont très variés. Une machine manuelle peut coûter une centaine de dollars alors qu'un équipement automatique atteint $50,000.

TABLEAUX SYNTHESES

MATERIAUX - PROCEDES

Overview of Joining Processes*

Material	Thickness	SMAW	SAW	GMAW				FCAW	GTAW	PAW	ESW	EGW	RW	FW	OFW	DFW	FRW	EBW	LBW	B							S
				ST	B	P	S													TB	FB	IB	RB	DB	IRB	DFB	
Carbon Steel	S	X	X			X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X	X	X	X				X	X	X		X	X	X	X	X	X	X	X		X	X
	M	X	X	X	X	X		X					X	X	X		X	X	X	X	X	X				X	
	T	X	X	X	X	X		X			X	X		X	X		X	X			X					X	
Low Alloy Steel	S	X	X			X	X		X				X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X	X	X				X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X		X		X						X		X	X	X	X	X	X	X				X	
	T	X	X	X		X		X			X			X		X	X	X			X					X	
Stainless Steel	S	X	X			X	X		X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X	X	X	X			X	X		X	X	X	X,	X	X	X				X	X
	M	X	X	X		X		X		X				X		X	X	X	X	X	X	X				X	
	T	X	X	X		X		X			X			X		X	X	X			X					X	
Cast Iron	I	X													X					X	X	X				X	X
	M	X	X	X				X							X					X	X	X				X	X
	T	X	X	X				X							X						X					X	
Nickel and Alloys	S	X				X	X		X	X			X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X		X	X			X	X			X	X	X	X	X	X				X	X
	M	X	X	X		X				X				X			X	X	X	X	X					X	
	T	X		X		X					X			X			X	X			X					X	
Aluminum and Alloys	S			X		X			X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	I			X		X			X				X	X		X	X	X	X	X	X			X		X	X
	M			X					X					X			X	X		X	X			X		X	
	T			X							X	X		X				X			X					X	
Titanium and Alloys	S.					X			X	X			X	X		X		X	X		X	X			X	X	
	I			X		X			X	X				X		X	X	X	X		X					X	
	M			X		X			X	X				X		X	X	X	X		X					X	
	T			X		X								X		X		X			X					X	
Copper and Alloys	S					X			X	X				X				X		X	X	X	X			X	X
	I			X		X				X				X			X	X		X	X		X			X	X
	M			X										X			X	X		X	X					X	
	T			X										X				X			X					X	
Magnesium and Alloys	S					X			X				X					X	X	X	X			X		X	
	I			X		X			X				X	X			X	X	X	X	X			X		X	
	M			X		X								X			X	X	X		X					X	
	T			X		X								X				X									
Refractory Alloys	S					X			X	X			X	X				X		X	X	X	X		X	X	
	I			X		X				X				X				X		X	X					X	
	M													X													
	T																										

*This table is presented as a general survey only. In selecting processes to be used with specific alloys, the reader should refer to other appropriate sources of information.

LEGEND FOR TABLE

Process Code

SMAW–Shielded Metal Arc Welding
SAW–Submerged Arc Welding
GMAW–Gas Metal Arc Welding
- **ST–Spray Transfer
- **B –Buried Arc
- **P –Pulsed Arc
- **S –Short Circuiting Arc

FCAW–Flux Cored Arc Welding
GTAW–Gas Tungsten Arc Welding
PAW–Plasma Arc Welding
ESW–Electroslag Welding
†EGW–Electrogas Welding
RW–Resistance Welding
FW–Flash Welding
OFW–Oxyfuel Gas Welding
DFW–Diffusion Welding
FRW–Friction Welding
EBW–Electron Beam Welding
LBW–Laser Beam Welding
B–Brazing
- TB–Torch Brazing
- FB–Furnace Brazing
- IB–Induction Brazing
- RB–Resistance Brazing
- DB–Dip Brazing
- IRB–Infrared Brazing
- DFB–Diffusion Brazing

S–Soldering

Thickness

S –Sheet: up to 3 mm (1/8 in.)
I –Intermediate: 3 to 6 mm (1/8 to 1/4 in.)
M–Medium: 6 to 19 mm (1/4 to 3/4 in.)
T–Thick: 19 mm (3/4 in.) and up
X–Recommended

**Not standard AWS letter designations. Pulsed arc and short circuiting arc are officially designated GMAW-P and GMAW-S respectively, but for brevity, the designations are given here as P and S. There are no official designations for spray transfer and buried arc.

†Not standard AWS letter designation. Electrogas welding is a process variation of GMAW and FCAW and should be designated as either GMAW-EG or FCAW-EG. (See discussion of electrogas welding on p.12.) For brevity, however, electrogas welding is designated as EGW here.

Source: American Welding Handbook, Volume 1

Applicability of Cutting Processes to Materials*

Material	Cutting Processes			
	OC	PAC	AAC	LBC
Carbon Steel	X	X	X	X
Stainless Steel	X′	X	X	X
Cast Iron	X′	X	X	X
Aluminum and Alloys		X	X	X
Titanium and Alloys	X′	X	X	X
Copper and Alloys		X	X	X
Refractory Metals and Alloys		X	X	X

*This table is limited in content and scope and should be regarded as only a very general guide to process applicability. For processes to be used with specific alloys, appropriate sources should be referenced.

LEGEND

Process Code

OC — Oxygen Cutting
PAC — Plasma Arc Cutting
AAC — Air Carbon Arc Cutting
LBC — Laser Beam Cutting

X — Process may be applied.
X′ — Process applicable with special techniques.

Source: American Welding Handbook, Volume 1.

A N N E X E I

LES SOURCES D'ENERGIE POUR LA SOUDURE A ARC ELECTRIQUE "ARC WELDING"

CONSTANT-CURRENT AND CONSTANT-VOLTAGE POWER SOURCES

Arc welding power sources are commonly classified as constant current and constant voltage. Paragraph EW1-1.18 of the Electric Arc-Welding Apparatus Standard (EW1-1968) of the National Electrical Manufacturers Association (NEMA) states: "A constant-current arc-welding power supply (arc welder) is one which has characteristically drooping volt-ampere curves producing relatively constant current with limited change in load voltage. This type of supply is conventionally used in connection with manual-stick-electrode or tungsten-inert-gas arc welding."

The characteristics of this type of supply are such that if the arc length varies because of external influences, and slight changes in arc voltage result, the welding current remains substantially constant. Generally, manual operations where variations in arc length are almost inevitably owing to the human element employ this type of power source.

Although each current setting of the supply yields a separate and individual volt-ampere curve when tested under steady conditions, the curves are not usually parallel. In the vicinity of the operating point, it should be expected that the static volt-ampere curve will be more vertical than horizontal (see Fig. 25.14 on page 25.24).

The no-load voltage is considerably higher than the arc voltage under load in the constant-current type of arc welding power supply.

Constant-current power supplies are not used exclusively for manual shielded metal-arc welding processes; they are also applicable to semiautomatic or automatic processes in which a constant arc length is maintained by automatic changes in the feed rate of the consumable electrode. This type of supply is suitable for automatically controlled processes for which a reasonably constant current is required.

In the NEMA standard quoted above, the constant-voltage system is defined as follows: "A constant-voltage arc-welding power supply (arc welder) is one which has characteristically flat volt-ampere curves producing relatively constant voltage with a change in load current. This type of power supply is conventionally used in connection with welding processes involving consumable electrodes fed at a constant rate" (Paragraph EW1-1.19).

A welding arc fed by a constant-voltage supply, and utilizing consumable electrodes and a constant-speed wire feed, is essentially a self-regulating system. It tends to stabilize itself despite momentary changes such as friction in the wire feed, fluctuations in the power supply, etc. The arc length and weld current are interrelated in such a way as to correct for sudden changes. For example, arc length variation is fundamentally determined by the differences between melting rate and feed rate; arc voltage is directly related to arc length; for any one wire size, melting rate is governed to a major extent by current.

Thus, if the power supply is capable of providing large current variations while still maintaining nearly constant voltage, a constant-speed system for wire feed can be used to good advantage. The wire-feed rate will be found to be proportional to arc current for all wire sizes.

PRINCIPLES OF OPERATION

The voltage-reducing element in Fig. 25.1 may be an electric generator driven by an electric motor, or it may be a transformer. If an electric generator is used, it is usually a d-c generator. The arc welding power supply is then used for d-c welding only. In this case, the electromagnetic means of controlling the volt-ampere characteristic of the arc welding power source is an integral part of the generator; it is not a separate element as shown in Fig. 25.1.

Various d-c generator configurations are employed. The d-c generator may use a separate exciter and current control for determination of the desired volt-ampere characteristics. Another type uses a separate exciter and differential or cumulative compounding for selection of volt-ampere characteristics.

Figure 25.2 shows the basic elements of a transformer. For a transformer, the significant relations among turns ratio, and input and output voltages and currents, are as follows:

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1}$$

where N_1 is the number of turns on the primary winding of the transformer, N_2 is the number of turns on the secondary winding, E_1 is the input voltage, E_2 is the output voltage, I_1 is the input current and I_2 is the output (load) current. The element that determines the volt-ampere characteristics is not shown in Fig. 25.2.

Taps in the transformer secondary winding may also be furnished as shown in Fig. 25.3 to control the no-load output voltage. In this case, the tapped transformer permits the adjustment or control of the number of turns, N_2, in the secondary winding of the transformer. Fewer turns used on the secondary means less output voltage, since a smaller proportion of the transformer secondary windings is then in use. The tap selection, therefore, controls the no-load voltage.

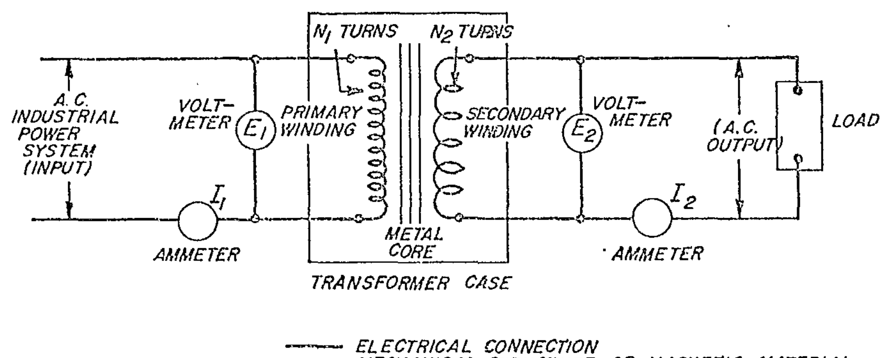


Fig. 25.2.—Principal electrical elements of a welding transformer, shown connected to power supply and load

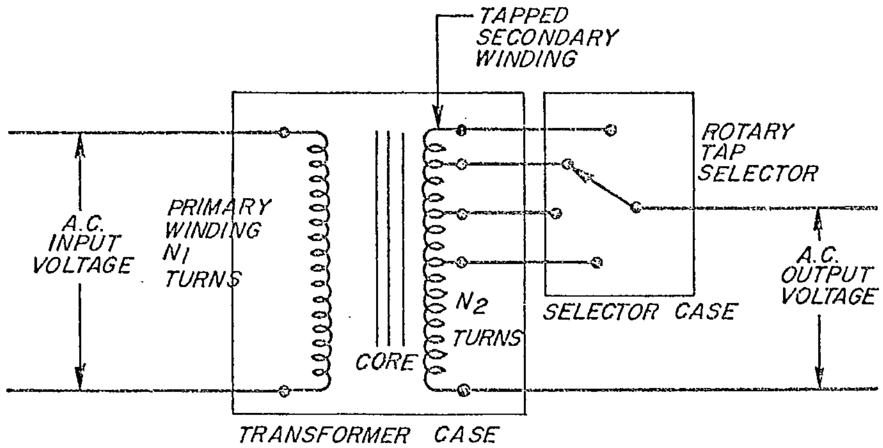


Fig. 25.3.—Welding transformer with tapped secondary winding to control no-load output voltage

In constant-voltage systems (Fig. 25.4), there may be an adjustable (saturable or tapped) reactor connected electrically to the transformer secondary winding. The reactor adjustment determines the slope of the static volt-ampere characteristics and the tap selection controls the no-load voltage. A later section entitled Manual Control explains these adjustments for both generator and transformer or transformer-rectifier power supplies.

In constant-current arc welding power sources that use a transformer, the adjustable reactor is usually located in the secondary circuit in series with the arc circuit. Here again, taps in the transformer secondary can offer control of the no-load voltage, but this is not usually done.

The type of circuit shown in Fig. 25.4 is typical of the constant-current type as well as many constant-voltage type arc welding power supplies. In constant-current power supplies, the voltage drop, E_X, across the reactor increases greatly as the load current, I_2, is increased. The increase in load current causes a large reduction in the level of the load voltage, E_2. Adjustments in the value of

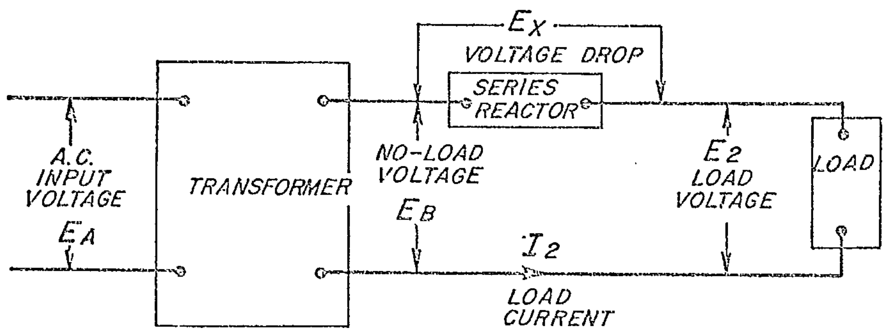


Fig. 25.4.—Typical circuit for constant-current and many constant-voltage type arc welding power supplies using a reactor to control output

reactance in the series reactor control the relation of load current to load voltage. This is called current-range control. Voltage E_B equals the no-load (open-circuit) voltage of the power supply.

In constant-voltage power supplies, the voltage drop, E_X, across the reactor increases only slightly as the load current increases; the drop in the level of the load voltage is small. Adjustments in the value of reactance in the series reactor control the relation of load current to load voltage. This is known as slope control with simple reactors, and voltage control with saturable reactors.

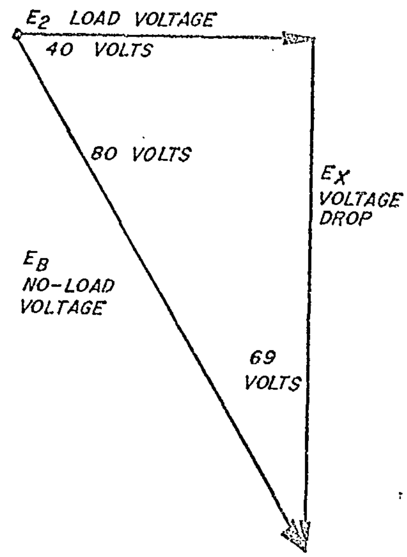


Fig. 25.5.—Typical vector relationship of the a-c voltages in the secondary circuit of a welding transformer as shown in Fig. 25.4

Figure 25.5 shows a typical vector relationship of the a-c voltages for the circuit of Fig. 25.4. The voltage drop across the reactor plus the load voltage equals the no-load voltage only as a vectorial addition. In the example pictured, the output voltage of the transformer is 80 volts, the voltage drop across the reactor is 69 volts and the load (equivalent to a resistor) voltage is 40 volts. The vectorial addition shown is analogous to the addition of 69 miles west and 40 miles north to make a total of 80 miles northwest.

In those welding power sources having both a transformer and a rectifier (for a-c or d-c welding), the rectifiers are located in the arc-circuit side. In other words, the control system is not located in the d-c circuit since it is an a-c system including reactors and transformer taps. The transformer-rectifier type of arc welding power supply usually incorporates a stabilizing inductance or choke located in the d-c arc circuit to improve arc stability.

STATIC VERSUS DYNAMIC CHARACTERISTICS

A power source, either of the generator or transformer type, has two kinds of operating characteristics, each of which affects its welding performance in different ways. These are its dynamic characteristics and its static characteristics.

Only the static characteristics can be readily measured by conventional test procedures. A set of voltage-current characteristic curves (E-I curves, or volt-ampere curves) describes the static characteristics.

In contrast, the dynamic characteristic of the arc welding power source is determined by the characteristic variations in output voltage that appear in as little as 0.001 second after a change in arc current. Dynamic characteristics describe the instantaneous variations or those variations that occur over very short intervals of time. Static characteristics are measured over longer periods of time (seconds or minutes).

Arc stability is primarily determined by the dynamic characteristics of the arc welding power supply. It is also true that improper selection of a volt-ampere characteristic for a given electrode and material might result in difficulty in maintaining an arc; however, circuit elements that add to arc stability will be effective to some extent regardless of other variables.

The inherently transient characteristic of all welding arcs is the principal reason for the great importance of the dynamic characteristic of an arc welding power source. The arc is, of course, in a continuous transient condition but, in particular, transients occur (1) during striking and extinction of arcs in short-circuiting metal transfer (with either globular transfer or short-circuiting transfer), (2) in spray transfer and (3) during arc extinction and reignition during each half-cycle of a-c welding. Other causes of transients include variations in arc length, variations in arc column temperatures and variations in cathode spot emission characteristics.

Each of these arc transients can appear and disappear in a time interval comparable to the interval during which a significant change in ionization of the arc column can occur (0.001 second). However, this time interval is too short for the static characteristics of the welding power supply to react correctively. Therefore, steady state or static volt-ampere characteristics (defined by constant load current tests) have little significance in determining dynamic characteristics of an arc welding power source.

Among the arc welding power supply characteristics that do have an effect on arc stability are those that provide: (1) local transient energy storage, such as a d-c series inductance; (2) feedback controls in automatically regulated systems and (3) modifications of wave form or a-c frequencies in the welding current. An improvement in arc stability is typically the goal of such modifications; beneficial results include: (1) easier control of the amount and direction of metal transfer, (2) reduction in spatter and (3) improvement in the efficiency of metal transfer.

MANUAL CONTROL OF VOLT-AMPERE CHARACTERISTICS

As described under "Principles of Operation," manual adjustments are used to control the load-voltage versus load-current characteristic (E-I curve). A description of how to select the characteristics best suited to various welding conditions is included in the section above entitled "Constant Current and Constant Voltage."

The no-load voltage control of a d-c generator used as an arc welding power supply adjusts the relatively small current in the main field winding; this control is sometimes described as a vernier control. The current-range control adjusts the d-c generator series or bucking field winding that carries the arc current. The reversing switch controls the voltage polarity by changing the interconnection between the exciter and the main field. In general no separate inductor need be added to the welding circuit to improve arc stability in this type of welding equipment; the several turns of series winding on the field poles of the rotating generator represent more than enough inductance to ensure satisfactory arc stability. This unit is described in more detail in later sections of this chapter.

Variable reactance or variable mutual inductance may be used to control the E-I characteristics in typical transformer or transformer rectifier arc welding power sources. The variable reactance or mutual inductance is, of course, located in the a-c electrical circuit of the welding machine, in series with the secondary circuit of the transformer as shown in Fig. 25.4. The basic transformer and its principal electrical modification, a tapped transformer, were shown in Figs. 25.2 and 25.3.

As previously mentioned and as shown in Fig. 25.5, the voltage drop across a series reactance in an a-c circuit may be added vectorially to the load voltage to equal the transformer secondary voltage. By varying the voltage drop across the reactor, the load voltage may be changed. This peculiar characteristic (vectorial addition) of reactor voltages in a-c circuits is related directly to the reason reactors are used in place of series resistances for producing a drooping-voltage characteristic. An advantage is that the reactor consumes little or no power, despite the fact that a current flows through it and a voltage can be measured across it. Were a resistor used in its place, the power loss and the temperature rise would be much increased. In this case, the voltage drop across the resistor could be added arithmetically to that of the load voltage to equal the output voltage of the transformer.

Another major advantage of reactance over resistance is that the phase shift produced in the current by the reactance increases arc stability for a given open-circuit voltage to be discussed below under Electrical Characteristics.

The reactor can be varied by any of several means; it can be built with taps similar to a resistor; it can be varied by many other mechanical and electrical means, some of which are described in later sections.

Varying the inductance and, therefore, the reactance value will vary the voltage drop across the reactance for any one load current. The reactance value controls the shape of the volt-ampere characteristic of the arc welding power source.

In addition to the adjustment of reactance (self-inductance), it is also possible to adjust the mutual inductance of a pair of coils. This may be done by moving the coils in relation to one another, or by combining the concept of a movable shunt with the concept of a saturable reactor, to produce a transformer with an electrically adjustable mutual inductance.

SERVICE CLASSIFICATION

Since some welding loads are not as demanding as others in time of operation, a power source that supplies a given current for a short time need not be as large and rugged as one required to supply the same current continuously. Duty cycle is one of the most important rating points of a welding power supply that takes into consideration this difference in load. Unlike many other electrical devices or machines that, once turned on, must deliver their rated output until shut off, a welding power supply is called on to deliver output during limited periods only, unless it is used on automatic processes. Because the welder must stop welding to change electrodes, and to adjust his work and his position, a welding power supply is allowed to be idle during part of its operating time.

Duty cycle expresses as a percentage the portion of the time that the power supply must deliver its rated output in each of a number of successive 10 minute intervals. Thus a 60% duty cycle (the standard industrial rating) means that the power supply can deliver its rated load output for 6 minutes out of every 10 minutes. (Operation at rated load steadily for 36 minutes out of one hour is not a 60% duty cycle. The rating is based on successive 10 minute intervals.) A 100% duty cycle power supply can produce its rated output continuously without exceeding the established temperature limits.

Duty cycle is the main determining factor regarding the type of service for which a power supply is designed. Industrial units for manual welding are rated at 60% duty cycle. For automatic and semiautomatic processes, the rating usually is at 100% duty cycle. NEMA rates limited service power supplies at 20% duty cycle. Individual manufacturers have sometimes rated power supplies at duty-cycle values other than those above; but the rating method using 10 minute intervals is standard.

In any duty-cycle rating, the maximum allowable temperature of the components in the unit is the determining factor. These maximum temperatures are specified by various organizations and agencies whose interest lies in the field of insulation standards.

An important point is that the duty cycle of a power supply is based on the output current and not on the kva or kw rating. Two useful and approximate formulas are given below for determining a new duty cycle at other than rated output, or for determining another than rated output at a new specified duty cycle.

$$Ta = \left(\frac{I}{Ia}\right)^2 T$$

$$Ia = I\sqrt{\frac{T}{Ta}}$$

where T is given duty cycle in percent; Ta is required duty cycle in percent; I is rated current at given duty cycle and Ia is current at required duty cycle.

Example.—At what duty cycle can a 200 ampere industrial-type NEMA-rated welding transformer (60% duty cycle) be operated at 250 ampere output?

$$Ta = \left(\frac{200}{250}\right)^2 \times 60\%$$

$$= (0.80)^2 \times 60\% = (0.64) \times 60\%$$

$$Ta = 38\% \text{ (approximately)}$$

Therefore, this unit must not be operated more than 3.8 minutes out of each 10 minute period at 250 amperes.

Example.—The aforementioned transformer is to be operated continuously (100% duty cycle). What current must not be exceeded?

$$Ia = I\sqrt{\frac{T}{Ta}}$$

$$= 200\sqrt{\frac{60\%}{100\%}} = 200\sqrt{0.6} = 200 \times 0.775$$

$$Ia = 155 \text{ amperes (approximately)}$$

If this transformer is operated continuously, no more than 155 amperes output should be used.

For very high current output power supplies (750 amperes and higher), another duty-cycle rating is usually used. This is identified as the one-hour duty rating. These power supplies are designed for service in semiautomatic or automatic welding systems. In determining the rated output of these machines, they are loaded for one hour at rated output and then tested. Then the output is reduced immediately to 75% of the rated current value, and operation is continued for an additional three hours; at this time the test period is terminated. Temperatures are measured at the end of the first one-hour period and at the conclusion of the test. These temperatures must be within established allowable limits.

MAINTENANCE

Welding power sources demand very little attention in normal service. However, trouble-free operation cannot be achieved without proper care and maintenance. Periodic checks provide for the correction of minor troubles and prevent greater ones.

Servicing and maintenance schedules have been established by the manufacturers of welding power sources. Maintenance schedules and the related instructions are listed in instruction manuals for the various power sources. Maximum service life and performance result from following recommended maintenance schedules.

SAFETY

Safe practices for the installation and operation of welding machines are discussed in Chapter 9 of Section 1 of the 6th Edition of the *Handbook*. Most of the precautions that should be taken are obvious, but they bear repeating.

A welding machine should be treated with the same regard for safety that would be exercised with any electrical device. The nameplates of all devices should be checked carefully and compared to the line power available. When a considerable number of single-phase units are being installed, unbalanced line loads can be minimized by connecting them to different phases. When a-c welding machines are used, welders should avoid physical contact with one another when they are working on a single large weldment, since a voltage may exist between electrode holders. When adapting a unit for a specific voltage, the instruction manual for the specified power supply should be consulted to make sure that all changeovers for the specific line voltage have been completed. Installation of the power supply should be done by a licensed electrician. Part of the installation should be a fusible safety switch, mounted on the wall near the power supply. The case of the unit should always be grounded. Special care should always be taken to assure tight connections on the output side of the power supply.

Care should be taken in the selection of arc welding power supplies to ensure that the current rating chosen is adequate to handle the job. Welding machines should not be operated above their current ratings and corresponding rated duty cycles listed in the standards, or above the limits specified by the manufacturer. Welding cables should be of the extra-flexible type designed especially for welding and of size adequate for current and duty cycles reasonably expected. The insulation on the cables should be in good condition. It is essential from the standpoints of good quality and safety that proper equipment be used. The selection and the condition of equipment, such as electrode holders, cables, connections and clamps are equally important. Electrode holders should not be used if the insulation is damaged.

Avoidance of electric shock is largely within the control of the welder. Therefore, it is especially important that he be thoroughly instructed how to avoid shock. Voltages required for arc welding are low and normally will not cause injury or severe shock, although the fact that they are low may, and does, lead to carelessness. These voltages are nevertheless high enough to endanger life under certain circumstances. Severity of shock is determined largely by the amount of current flowing through the body, and this is determined by voltage and contact resistance of the area of skin involved.

Welding power sources are no more hazardous than any other piece of properly used industrial equipment. Because all manual arc welding processes are based on an exposed electrode, a welder may touch the electrode and receive a mild to severe shock, depending on the local conditions.

A point is often made that alternating current is more dangerous than direct current. This generalization is usually made on the basis that a-c rms (root-mean-square) voltages given are actually only 71% of the peak value. In addition, the physiological effect of alternating current is somewhat different from that of direct current. The NEMA maximum open-circuit voltage for a-c welding power sources is approximately 35% lower than the normal voltage in homes, but this is no reason to abandon caution. Electricity must be treated with respect no matter where it is encountered.

Voltage reducers, designed either to remove or substantially reduce the open-circuit voltage of a-c power sources during idling periods, are available as an auxiliary device that may be incorporated into the circuitry of most industrial a-c power sources. The use of these devices is normally specified in hazardous locations where the usual precautions are not deemed sufficient.

If alternating current is applied to the body at the normally used 50 or 60 cycles, the muscles will react and tighten. This explains why a person cannot release an electrically charged conductor on his own volition. The electrical impulses sent out from the human brain are literally overpowered by the higher a-c voltage of the power line.

ALTERNATING-CURRENT POWER SOURCES—CONSTANT CURRENT

Single-operator, alternating-current power sources are normally single-phase transformers that take the commercial a-c power from plant power lines and transform the voltage and amperage to values suitable for welding. The transformer also serves to isolate the welding circuit from the plant power lines.

Another source of a-c welding power is a generator (more properly called an alternator), which converts mechanical energy into electrical power suitable for arc welding. The mechanical power may be obtained from various sources, such as an internal combustion engine or an electric motor.

Alternator design normally places the magnetic field coils on the rotor and the armature coils in the stator. This configuration precludes the necessity of the commutator and the brushes used with d-c output generators. The frequency of the output welding current is controlled by the speed of rotation of the rotor assembly, and by the number of poles in the alternator design. A two-pole alternator must operate at 3600 rpm to produce 60 cycle current, whereas a four-pole alternator design will operate at 1800 rpm to produce 60 cycle current.

TRANSFORMER ALTERNATING-CURRENT POWER SOURCES

To discuss the types of transformer alternating-current power sources is to define their methods of adjustment of the volt-ampere output characteristic. For many years, the welding industry has considered that current is set on a "constant-current" power source. This is misleading. It is the volt-ampere output curve characteristic that is set on any power source, regardless of make, model or type. This concept is explained in detail in the following paragraphs.

Movable-Coil Control

A movable-coil transformer consists essentially of an elongated core on which are located primary and secondary coils. Either the primary coil or the secondary coil may be movable, the other one is fixed in position. Most a-c transformers of this design have a fixed position secondary coil. The primary coil is normally attached to a lead screw and, as the screw is turned, it moves closer to, or farther from, the secondary coil.

The varying distance between the two coils regulates the inductive coupling of the magnetic lines of force between them. The farther the two coils are apart, the more vertical the volt-ampere curve and the less the maximum short-circuit current value. Conversely, the closer the two coils are together, the higher the maximum short-circuit current and the less slope in the volt-ampere output curve.

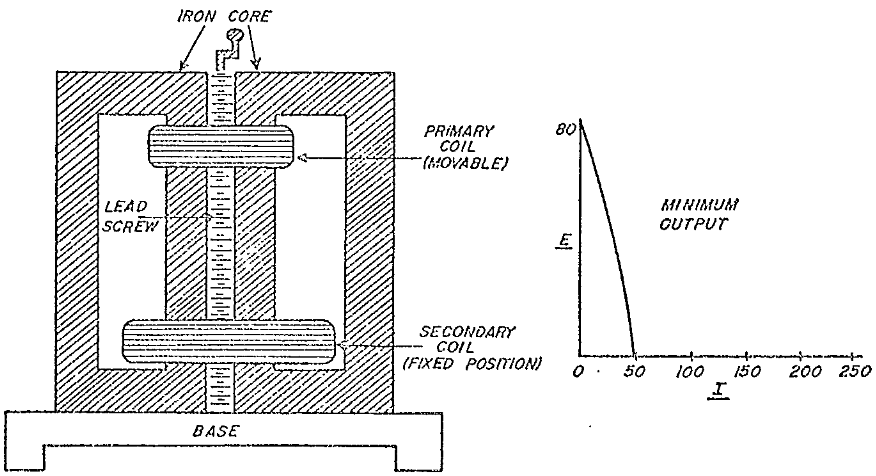


Fig. 25.6.—Movable coil a-c power source with coil spread set for minimum output

Figure 25.6 shows the movable coil machine with the coils far apart, and the steep shape of the volt-ampere curve. Figure 25.7 shows the coils as close together as possible. The volt-ampere curve is indicated at maximum output.

Movable-Shunt Control

The movable-shunt method of control is used with a-c transformers and may be used with ac/dc power sources also. In this design concept, both the

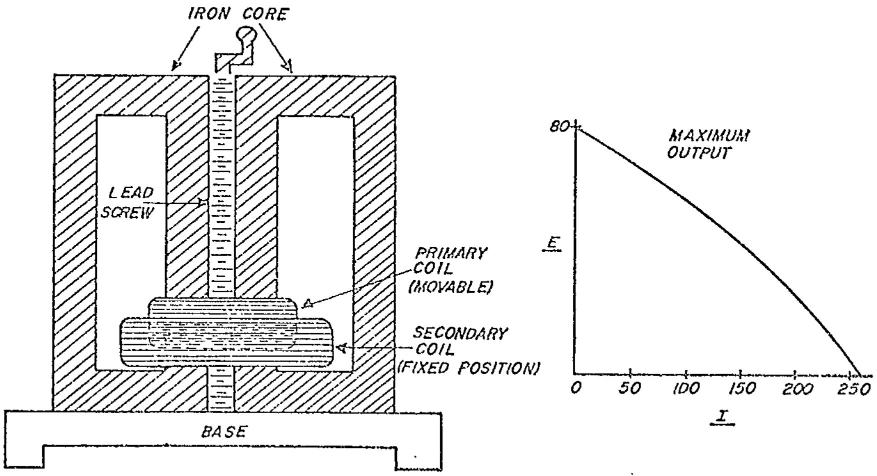


Fig. 25.7.—Movable coil a-c power source with coils set for maximum output

primary coils and secondary coils are fixed in position. A laminated iron core shunt, fixed within a containing mechanism, is moved between the primary and secondary coils. The iron material is the same as that used for the transformer cores and is insulated on both sides of each lamination. The shunt acts as a magnetic "flux" diverter. (The term flux means the same as magnetic lines of force in this usage.) The following sections provide details about the other types of controls used with welding transformers.

As illustrated in Fig. 25.8, the movement of the magnetic lines of force, or magnetic flux, is unobstructed when the iron shunt is not between the primary and secondary coils. As the shunt is moved between the primary-secondary coil

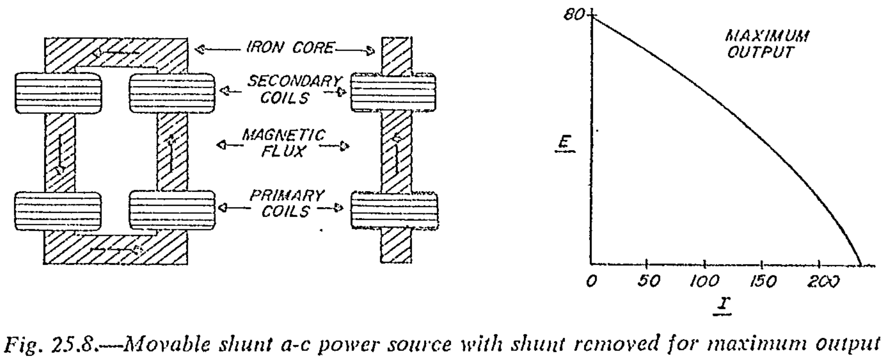


Fig. 25.8.—Movable shunt a-c power source with shunt removed for maximum output

arrangement, as shown in Fig. 25.9, the magnetic lines of force are diverted into the iron shunt rather than to the secondary coil.

The output volt-ampere curve is adjusted from minimum to maximum within the amperage range of the welding power source. When the shunt is not between the primary-secondary coils, the output volt-ampere curve is at maxi-

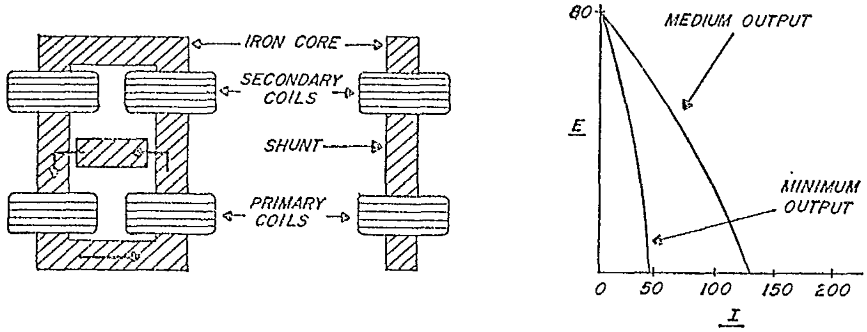


Fig. 25.9.—Movable shunt a-c power source with shunt between power coils

mum. As the iron shunt moves in between the primary and secondary coils, the volt-ampere curve is positioned more vertically and the maximum short-circuit current is decreased.

Moving Core Reactor

The moving core reactor type of a-c welding machine consists of a constant-voltage transformer, plus a reactor whose inductance is varied by moving a section of its iron core (Fig. 25.10). The moving core is shown in a withdrawn position, forcing the magnetic lines of flux (magnetic field) to cross an air space, making for low inductance, which, in turn, permits a large welding current to flow. When the moving core is inserted into the stationary core as

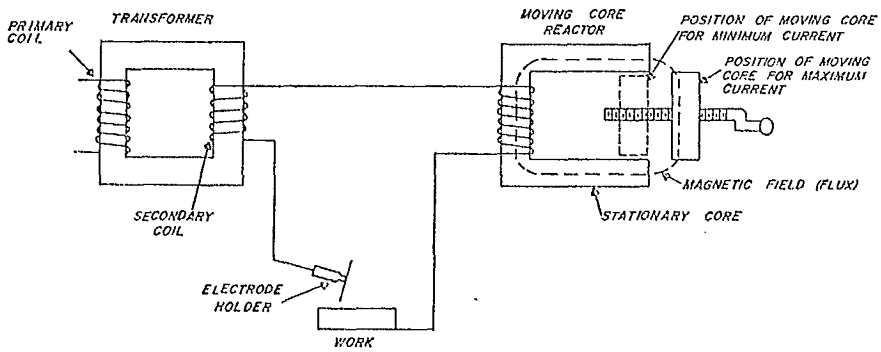


Fig. 25.10.—Moving core reactor type a-c power source

shown in dotted lines in Fig. 25.10, inductance of the reactor is increased, reducing welding current.

Tapped Secondary Coil Control

A tapped secondary coil may be used for control of the volt-ampere output of a transformer. This method of adjustment is used with limited service power sources. Basic construction is somewhat similar to the moving shunt type (Fig. 25.9) except that the shunt is permanently located inside the main core and the secondary coils are tapped to permit adjustment of the number of turns. Decreasing secondary turns reduces open-circuit voltage, but also decreases inductance of the transformer, causing welding current to increase.

Saturable Reactor Control

A saturable reactor control is called an electrical control because it employs an isolated low-voltage and low-amperage d-c circuit to change the effective magnetic characteristics of the reactor cores. The principal advantage of this type of control circuit is that it makes remote control of output from the power source relatively easy.

In this design concept, the main transformer has no moving parts. As such, there would be only one output volt-ampere characteristic and that is *maximum*. By adding a reactor to the secondary a-c circuit, it is possible to achieve the *minimum* volt-ampere curve characteristic.

By adding a d-c control circuit to the reactor system, it is possible to adjust the output volt-ampere curve from minimum to maximum. The saturable reactor uses d-c power for control purposes. It is possible to control a large amount of alternating current by a small amount of direct current.

Saturable Diverter Path Transformer

The saturable diverter path transformer is a cross between the moving shunt and the saturable reactor type controls. A shunt (known as the diverter path) is permanently fixed in position between the primary and secondary coils of a transformer. A control coil is wound on this diverter path. When a direct current (known as control current) is passed through the control coil, a d-c magnetic field is set up in the paths, as shown in Fig. 25.11. This d-c magnetic field interacts with the normal a-c magnetic field to cause the welding current to increase when control current is increased.

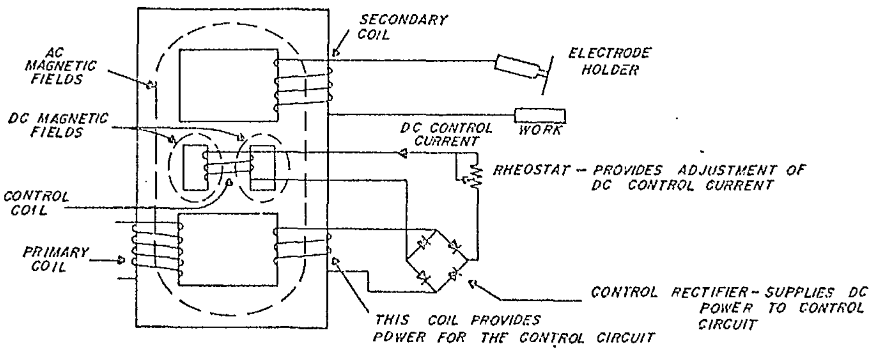


Fig. 25.11.—Saturable diverter path type a-c power source

OPEN-CIRCUIT VOLTAGE (OCV)

Open-circuit voltage is the voltage apparent at the output terminals of a welding machine when it is energized under no-load conditions. Open-circuit voltage is one of the design factors influencing the performance of a single-phase a-c welding machine, along with transient-voltage recovery characteristics of the machine, drop transfer and degree of ionization of the arc stream of the electrode.

Open-circuit voltage is a function of the primary input voltage and the ratio of primary-to-secondary coils of the main transformer. This fact naturally affects the physical size of the welding power source.

Although a high open-circuit voltage may be desirable from the standpoint of arc stability, the factors of safety and cost preclude excessively high values. Alternating-current arc welding power supplies of the transformer type are usually made in ratings that have been standardized by NEMA.

The NEMA standards require that no-load (open-circuit) voltage does not exceed 80 volts for manual welding and 100 volts for automatic and semi-automatic welding operations. Lower open-circuit voltages are sometimes used on a-c power sources. No-load voltages of 65 and 75 volts are common for a-c power sources of industrial sizes, with 80 volts favored where low-hydrogen electrodes are to be used. In some of the smaller a-c power sources such as the limited-service class, open-circuit voltages may be as low as 40 volts. Most a-c electrodes may be used with a 75 to 80 volt power source. Power sources with lower open-circuit voltage may require the selection of specific grades and types of electrodes for successful operation.

Power sources classed as industrial models normally have one open-circuit voltage at, or close to, the maximum allowed by NEMA. Limited-service class a-c power sources frequently have two or more open-circuit voltages. One arrangement is to have a high and low range of amperage output from the power source. The low range normally has approximately 80 volts open circuit. Another arrangement is the tapped secondary coil method, described earlier, in which at each current setting, the open-circuit voltage changes about 2 to 4 volts.

Alternating current (60 cycle) reverses direction of flow each 1/120 second. Plotting the direction and strength of the current through a complete cycle of alternations produces a sine wave form. Figure 25.12 shows typical a-c two-range power source sine wave forms, with open-circuit voltages of 80 volts and 55 volts. A key fact is that each sine wave form shown goes through a complete cycle in 1/60 second.

Since the current must change direction after each half-cycle, it is apparent that, for an instant, at the point at which the current wave form crosses the zero line, the current must be zero. At that time, the electrons and ions, which constitute the current flow in the arc, cease to flow. An instant later, the electrons and ions should reverse their respective directions of flow. However, during the period in which current is decreasing and reaches zero, the arc cools, reducing the thermal energy level, which helps maintain ionization of the arc. In order for the current to begin flowing in the opposite direction, ionization of the material in the arc must either be maintained or reinitiated by the voltage across the arc gap. This voltage is shown in Fig. 25.12 as the recovery voltage. The greater this recovery voltage, the shorter the period during which the arc is extinct.

Figure 25.12 also shows the phase relations among voltage and the same current for two different open-circuit voltages, assuming the same arc voltage (not shown) in each case. As can be seen in the figure, recovery voltage is greater with 80 volts open-circuit voltage because of the higher source voltage and because the greater phase shift of the current causes zero current at a time when recovery voltage is near the peak of the open-circuit voltage wave form. If resistance, rather than reactance, were used to regulate welding current, the power source voltage and current would be in phase, and the recovery voltage would be zero, causing a less stable arc.

Factors that permit use of low open-circuit voltages include the ingredients in some electrode coatings, which help to maintain ionization, and favorable drop transfer characteristics in some electrodes, which prevent sudden gross increases in arc length.

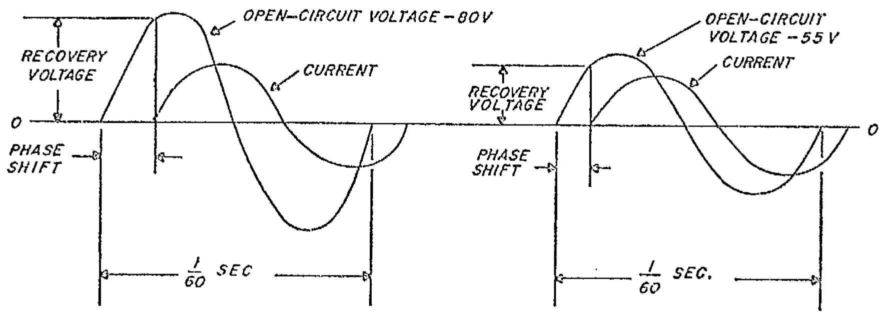


Fig. 25.12.—Typical sine waves of two-range a-c power source

ELECTRICAL RATING

The NEMA ratings for transformer-type arc welding power sources are shown in Table 25.2. The welding transformers having high current ratings (1 hour duty ratings) of 750 amperes or more are used mainly for automatic or machine welding.

ELECTRICAL CHARACTERISTICS

The electrical characteristics of any static, single-phase a-c welding power source normally appear in the form of plotted curves. For example, the input energy, the electrical efficiency, the power factor and the output energy are capable of being plotted. In Fig. 25.13 (p. 25.20) all these curves appear in a graph. The graph represents a typical 300 ampere a-c, single-operator welding transformer. As indicated in the illustration, the electrical efficiency is quite high for this type of power source.

Before discussing power factor, some of the terms used must be defined. *Primary kva power* (kilo-volt-amperes) is the apparent power drawn from plant power lines. *Primary kw power* is the actual power used by the welding machine to produce its rated load. *Secondary kw power* is the product of the output voltage (amperes) multiplied by the current when the power source is connected to a purely resistive load.

The ratio of primary kw to primary kva is called input power factor. Dividing the primary kw by the primary kva will give the power factor percentage of an a-c welding machine. Power factor may be improved by the addition of capacitors to the primary power circuit of the welding power source. The addition of capacitors to an inductive circuit, such as a transformer-type a-c power source, improves power factor by demanding less primary current from the plant power lines while welding is being performed.

Table 25.2—NEMA ratings of transformer a-c welding power sources

Industrial Service A-C Transformer Type					
Output Ratings—60% Duty Cycle at Rated Output					
Rated		Minimum		Maximum (at 35% Duty Cycle)	
Amperes at	Load Volts*	Amperes at	Load Volts*	Amperes at	Load Volts*
200	28	40	22	250	30
300	32	60	22	375	35
400	36	80	23	500	40
500	40	100	24	625	44
600	44	120	25	750	44
High Current Ratings—(One-hour Duty Ratings)					
750	44	187	28	925	44
1000	44	250	30	1250	44
1500	44	450	38	1875	44
Limited Service Arc Welding Machines (AC, DC, AC/DC)					
Output Ratings—20% Duty Cycle at Rated Output					
Rated		Minimum		Maximum	
Amperes at	Load Volts	Amperes at	Load Volts	Amperes at	Load Volts
180–230	25	30–40	20	180–230	25
235–295	30	40–50	22	235–295	30

*Voltages are based on the formula $E = 20 + 0.04\,I$, where E is the load voltage and I is the load current. For currents above 600 amperes, the voltage shall remain constant at 44 volts.

Alternating-current transformer power sources are normally equipped with capacitors for power factor correction to approximately 75% at rated load. At lower than rated load current settings, the power factor may have a leading characteristic. When the a-c transformer is operating at no load or very light loads, the capacitors are drawing their full corrective kva, thus contributing power factor correction to the remainder of the load on the total electrical system. For this reason, too much power factor correction may be undesirable.

When a number of transformer-type a-c welding power sources are connected to a primary supply line, consideration should be given to the possibility that the combined power factor correction capacitance will not upset the voltage stability of the line when all units are operating at light loads. If three-phase primary power is used, the load on each phase of the primary system should be balanced for best performance. Power factor correction, under normal conditions, has no bearing on welding performance except for any effect that may be attributed to high primary current.

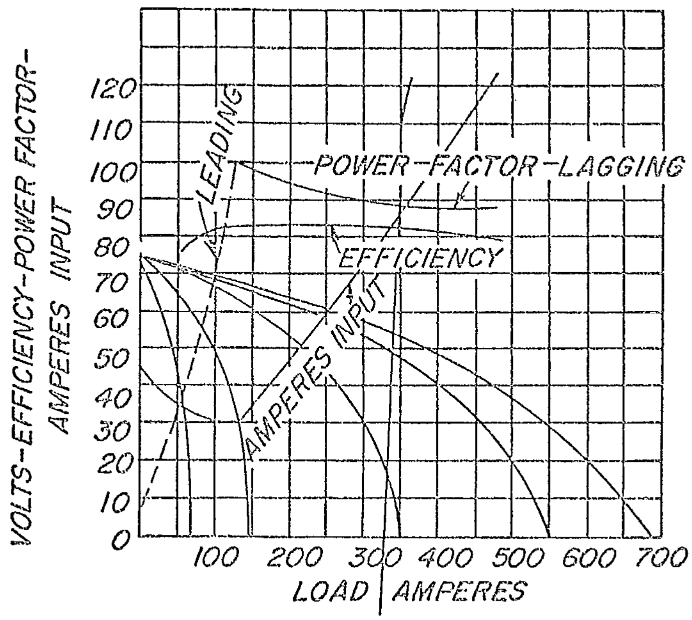


Fig. 25.13.—Typical characteristic curves of a 300 ampere welding transformer

CONTROL DEVICES

Differences in transformer welding machines exist mainly in the auxiliary equipment used. Auxiliary equipment is incorporated in transformer welding machines either to adapt the unit specifically for use with a given process or to make it more convenient to operate.

Primary contactors, or manually operated power switches, are usually included in industrial a-c power sources to turn the welding machine on and off. Most industrial units are furnished with a terminal board or other means of reconnecting for various rated primary line voltages. Input supply cords are not normally supplied with industrial welding power sources. The smaller, limited-service power sources are generally equipped with a manually operated primary switch and are usually furnished with an input supply cord.

Some a-c power sources incorporate a system of relays for supplying a higher-than-normal current to the arc for a fraction of a second at the start of a weld. This "hot start" device is intended to provide starting surge characteristics similar to those of motor-generator sets and to assist in initiating the arc, particularly at current levels under 100 amperes.

Alternating-current power sources in industrial sizes may be provided with means for remote adjustment of output energy. This may consist of a motor-driven, geared device for use with crank-adjusted units, or a rheostat at the work station when an electrically adjusted reactor control is being used. When a weldment requires frequent changes of amperage or when welding must be accomplished in an inconvenient location, time studies have shown that use of remote control adjustment can save money for the user. The use of foot-operated remote controls permits a gradual build-up and reduction of welding current, which is of great assistance in crater filling to prevent crater cracking. The use of these devices on a-c industrial welding power sources has proved to be economical and sound engineering practice since greater safety and more satisfactory operations result.

Voltage reducers are available to reduce the no-load voltage of a-c arc welding power sources. With these units, voltage at the electrode holder during no-load times is reduced to about 30 volts. Voltage reducers consist of relays and contactors that either reconnect the secondary winding of the main transformer for a lower voltage, or disconnect the welding load from the main transformer and connect it to an auxiliary transformer of a lower voltage.

Units designed for the gas tungsten-arc welding process usually incorporate electrically operated valves and timers to control the shielding gas and coolant flows for the electrode holder.

ELECTRICAL RATING

The electrical rating of transformer-type welding power sources should be shown on the nameplate of the machine. The normal procedure is to show the primary voltage and current requirements, the number of phases used, frequency used, primary kva and primary kw. The listing of secondary output data includes rated output voltage and current, duty cycle, maximum open-circuit voltage, the minimum-maximum current range and the maximum allowable temperature rise of the power source components.

Prior to 1962, all industrial class welding power sources were usually rated at 40 load volts. For example a 300 ampere NEMA-rated power source could deliver 300 amperes into a 40 volt load, although it would seldom be required to do so. The 40 volt load rating had its origin during the early 1930's when it appeared that arc voltages would tend to higher values with the new mineral electrode coverings. This trend did not materialize however, and so the 40 volt load rating is unrealistic when considered from a practical standpoint. Individual power source manufacturers generally use their own curve of load volts versus amperes, based on an average electrode characteristic, when they place the ampere markings on the "current control" device.

The present NEMA ratings (1968) are based on a load voltage given by the formula cited in the footnote to Table 25.2: $E = 20 + 0.04\ I$, where E is the load voltage and I is the output current in amperes. An upper load limit of 44 volts is applied for current output of 600 amperes or more. This formula follows very closely the various international standards and also provides a realistic compromise with actual welding conditions.

SERVICE CLASSIFICATIONS

The service classifications of welding power sources are usually based on rated current output, rated load voltage and duty cycle. All three factors must be considered in order to properly determine power source capability. The two general classifications of service for constant-current transformer power sources are limited service and industrial.

Limited Service.—This class of power source is normally considered as a semi-industrial unit. Limited service units are designed for less rigorous applications than industrial power sources, and are usually rated at less than 300 amperes at 50% or less duty cycle.

Industrial.—Any welding power source having 60% duty cycle or more is considered an industrial model. This class of power source is specifically designed to withstand the heavy-duty service required in industrial environments.

The current rating of a power source is not necessarily a true indication of its size or capacity. Therefore, the user must use discretion in the choice of a power source, in order to make sure that the equipment is compatible with the job requirements.

APPLICATIONS

Alternating-current transformer welding power sources have many uses in industry or wherever arc welding is being done. Whereas this section of the text does not cover all possible applications, it is designed to provide a basis from which to determine usefulness of specific a-c transformer units.

Shielded Metal-Arc Welding

Alternating-current transformer welding power sources are designed specifically for this welding process. Industrial class units provide the necessary open-circuit voltage and output current for most welding applications. Electrodes designed for a-c welding should be used.

Gas Tungsten-Arc Welding

Alternating-current transformers are normally employed for welding aluminum and magnesium with the gas tungsten-arc welding process. Although standard industrial class units are sometimes used, with a separate high-frequency system added to the welding power circuit, it is more common to use a-c power sources that are specifically designed for the process. This type of power source normally has built-in high frequency, gas and water valves and solenoids, timers for postflow control of gas and water, etc. Such units may also be used for shielded metal-arc welding.

Submerged Arc Welding

Alternating current transformers are used with the submerged arc welding process where heavy plate thicknesses are being joined. The a-c power sources designed for the process are normally rated at 750 amperes or higher. In most cases, the appropriate contactor and other circuitry necessary to supply power to the process equipment are built into the power source.

Carbon-Arc Cutting and Gouging

Almost any industrial a-c power source may be used for carbon-arc cutting and gouging if the electrode size is compatible with the power source rating. Carbon electrodes recently introduced are designed specifically for use with a-c power sources and they permit the use of alternating current on some applications heretofore restricted to d-c welding power.

DIRECT-CURRENT WELDING GENERATORS—CONSTANT CURRENT

TYPES

The motor-generator welding power source converts the alternating current of the power line or the energy output of an internal combustion engine into mechanical rotation and then into d-c power of suitable voltage and current. The first arc welding generator of this type was introduced in 1907. This welding power source was a constant-current design. Today there exist three types of direct-current welding generators. They are the constant-current welding generator, the constant-voltage welding generator and a combination generator that permits selecting either the constant-voltage or constant-current performance characteristics or any variation in between. Although these power sources vary considerably in performance, they are all specifically designed to have electrical characteristics suitable for welding.

The typical direct-current generator power source is driven by a line-operated, three-phase electric motor. If convenient or necessary, the motor can be replaced with a gasoline or diesel engine or some other source of mechanical energy to drive the generator. The electric motor or engine has no effect on the welding performance characteristics or power output of the generator provided it is of sufficient size. and operation is at the proper speed.

A direct-current welding generator has three primary parts: the field coils, the armature and the commutator. Like all electrical generators, it operates on a principle of inducing a voltage in a coil that is mechanically moved with relation to a magnetic field. Usually the magnetic field is produced by field coils energized by direct current.

The generator armature consists of numerous coils that are connected to a copper bar commutator. Alternating-current welding power is generated as the armature is rotated by the motor or engine in the magnetic field. This a-c power is picked up by carbon brushes that ride on the surface of the commutator and convert the alternating current into direct current. Heavy electrical cables are fastened to the brush holders that hold the brushes on the commutator. These cables, which are inside the welding machine, carry the d-c power from the brushes to the output terminals or "studs" where the welding cables are connected.

The variations in electrical design of the currently available generator power sources primarily relate to differences in the system of excitation used to energize the magnetic field. The source of this d-c field current classifies the generator as to self- or separate excitation. In the separately excited generator, a small self-excited generator called the exciter is mechanically coupled to the main generator and generates the proper excitation current. In the self-excited generator, part of the actual output current is used to energize the field coils. Another separately excited generator makes use of a small control transformer and diode bridge to provide excitation current. This system is used with electric motor driven models. Both principles are sound in design and provide satisfactory performance.

OPEN-CIRCUIT VOLTAGE

A constant-current welding generator (often called a variable-voltage weld-

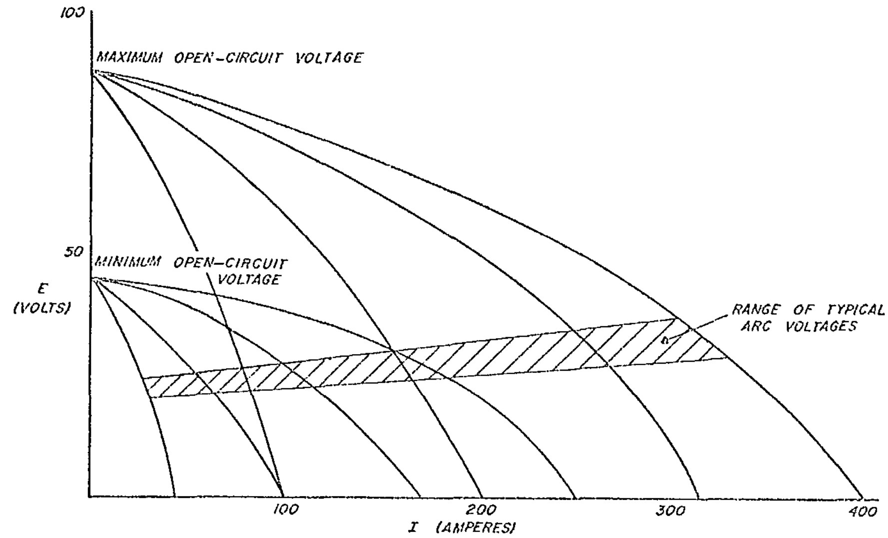


Fig. 25.14.—Volt-ampere curves for the maximum and minimum open-circuit voltage settings of a constant-current motor generator; the drooping characteristic of this type of power source is illustrated

ing generator) can be described as one whose current output varies only slightly with variations in arc voltage as compared to the alternate constant-voltage welding generator designs. The volt-ampere curves for a constant-current welding generator are found in Fig. 25.14. Because of the shape of these curves, the constant-current welding generator is occasionally described as having a "drooping-voltage" output, and called a "drooper" type of power source. When the arc is struck, the voltage automatically falls from the preset open-circuit voltage (which can be anywhere between the minimum and maximum open-circuit voltage settings on the machine) to the arc voltage. These static volt-ampere characteristic curves suggest the possible voltage-current combinations that can be supplied by a generator for steady-state load conditions and by a fixed setting of the generator controls. The instantaneous relation of voltage and current for transient load conditions is not indicated by these characteristics.

ELECTRICAL CHARACTERISTICS

The performance characteristics of the constant-current welding generator are controlled by the volt-ampere curve for a given generator setting and the welding arc voltage as indicated in Fig. 25.15. The arc voltage is a function of load conditions such as arc length, current density, electrode feed rate and composition of the arc atmosphere. If these load conditions change, the arc voltage changes as does the welding current. The degree of current change with voltage change is controlled by the amount of droop or "slope" of the volt-ampere curve. This is graphically illustrated by the current variation resulting from the short arc—lower voltage—and the long arc—higher voltage—intersection with the two extreme volt-ampere curves.

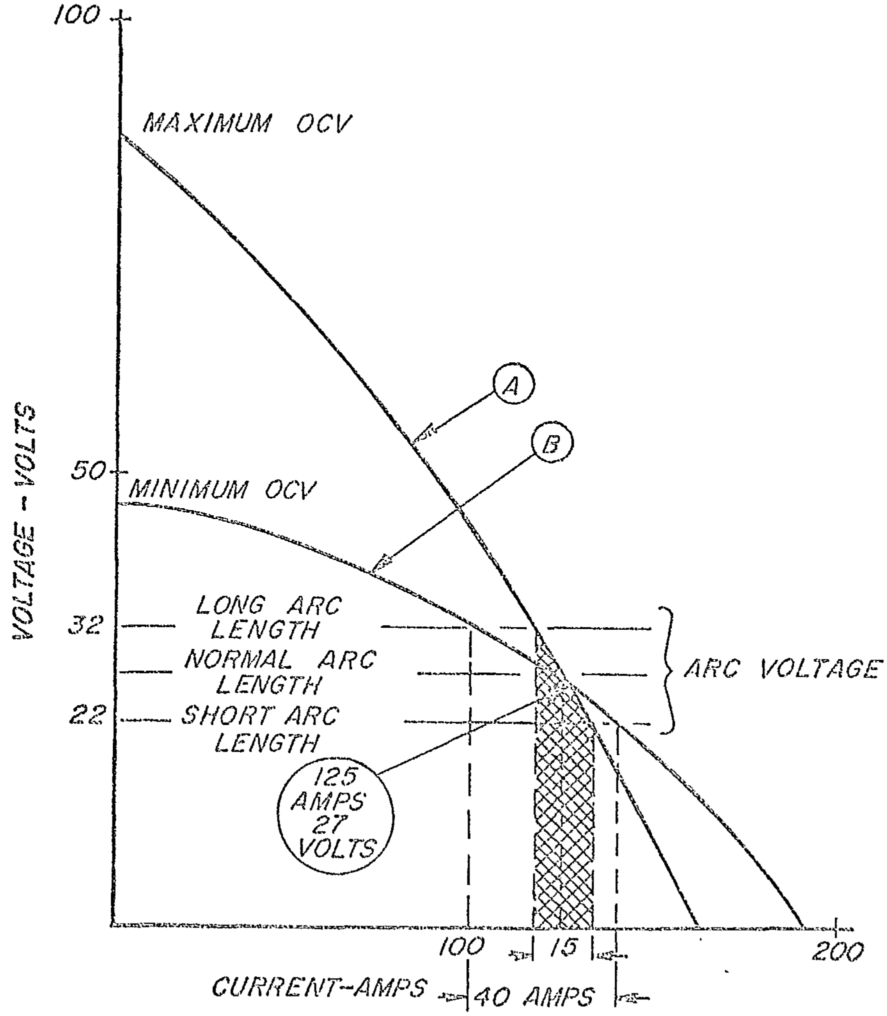


Fig. 25.15.—Changing the open-circuit voltage setting of a constant-current generator welding machine changes the slope

The short-to-long arc length variation occurring in manual arc welding produces little change in current if the shape of the curve is that of (A) in Fig. 25.15. The electrode melting rate and heat input, therefore, would remain fairly constant, despite the welder's inability to hold a perfectly steady arc length. A constant welding current is desired when welding thin materials. The high open-circuit voltage and steep slope of curve (A) give relatively little current variation with change in arc length. When automatic equipment is used, the steeper volt-ampere characteristic promotes constant current, thereby assuring uniform appearance and penetration of the weld bead.

The alternate curve (B) shown in Fig. 25.15 would be particularly helpful for manual welding in the vertical and overhead positions. The low open-circuit voltage and flatter slope of curve (B) give more current variation with change in arc length. Thus, the welder has the opportunity to substantially vary the current with changes in arc length. This enables him to vary the current input by lengthening or shortening the arc, and thus helps control the volume of molten metal in the weld puddle. This is essential for out-of-position welding.

A welding generator is also characterized by its response to transient load conditions. Conditions in manual arc welding operations may change rapidly because of short circuits between the electrode and the work caused by transfer of metal from the electrode. The generator must be capable of providing extremely rapid changes in its output voltage and current in response to these continually changing arc conditions; yet it must provide a steady current output during the welding operation at each current setting. For example, the surge of current during a short circuit causes an increase in weld metal spatter. Inversely an appreciable decrease in the arc current, during re-establishment of the arc after a short circuit, may result in extinction of the arc. The voltage and current output from the generator must change rapidly enough to meet

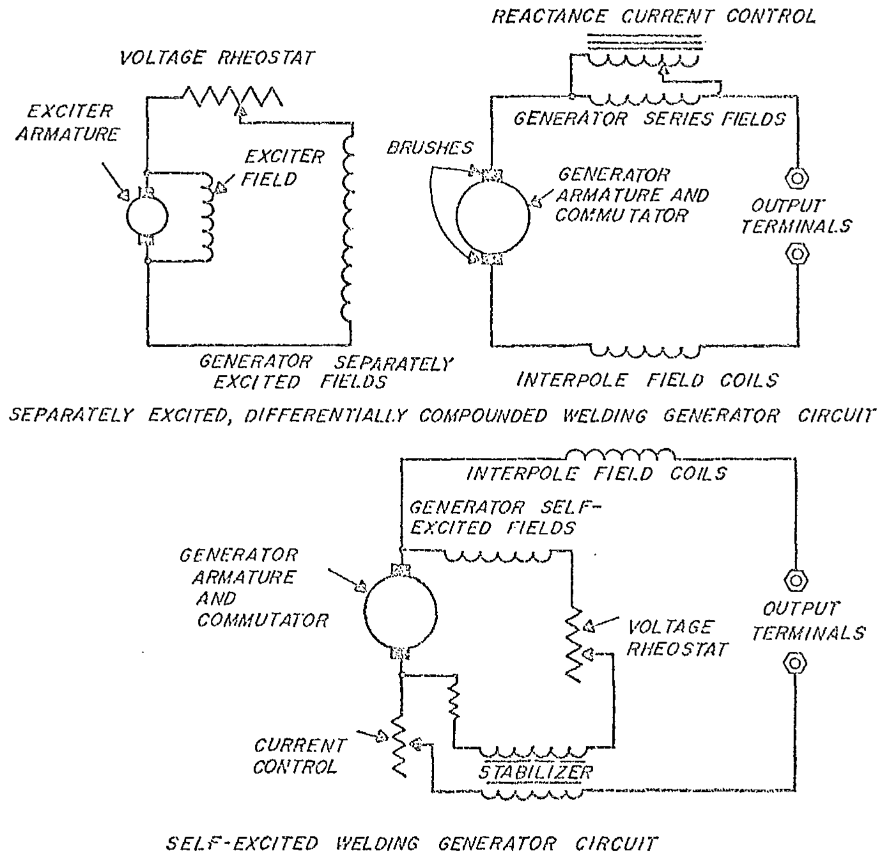


Fig. 25.16.—Typical generator circuits

the demands of the arc load at all times. The generator response to these transient load conditions cannot be observed with the standard meters for reading voltage and current. Laboratory equipment is needed to detect this type of response.

GENERATOR DESIGN

The static and dynamic volt-ampere characteristics are determined by the electrical design of the generator. Direct-current arc welding generators have been developed in a large number of designs. They differ primarily with respect to the method of generating and controlling the welding current. One of the earliest designs still manufactured employs a generator with separate excitation, differential compounding and an external stabilizer. Elimination of the stabilizer or external reactor is accomplished in later designs of this type by incorporating sufficient inductance in the generator. The circuit for such a generator is shown in the top sketch in Fig. 25.16. In order to achieve a wide welding current range, adjustment of the differential series field is usually provided, either by means of an adjustable shunt across the series field or by tapping its windings. The former approach provides for continuous current control throughout the entire range of the machine, whereas the latter offers specific fixed settings between the maximum and minimum output of the generator. The circuit for a self-excited version of this basic design is found in the bottom sketch in Fig. 25.16.

The present constant-current welding generator designs incorporate two methods of controlling outputs. Compound-wound d-c generators have a series control, a shunt field control, or both. Changing the shunt field control raises or lowers the open-circuit voltage and results in a group of essentially parallel volt-ampere curves (Fig. 25.17A p. 25.28). Changes in the series field control do not affect the open-circuit voltage but result in a group of volt-ampere curves having various slopes, all of which have the same open-circuit voltage (Fig. 25.17B p. 25.29).

CONTROL DEVICES

Devices that make possible remote control of the welding current are sometimes used with constant-current welding generators. Good practice frequently requires that a different current be used for welding in the overhead, vertical and flat positions, and for different thicknesses of metal. A remote control device may be desirable under these conditions when the work is some distance from the welding units.

One simple method involves either attaching a portable foot control rheostat in parallel with, or actually removing the rheostat from, the generator that is used to adjust the welding current. In either case, the portable control is placed at the welding position. A cable the size of a lamp cord is used to connect the rheostat to the welding generator. This portable control permits the welder to adjust the welding current over a limited range without returning to the generator.

Another remote control scheme uses a small motor and gear reduction arrangement to operate the continuous-current control of the unit. The welder is given a push-button wired to the motor to allow the raising and lowering

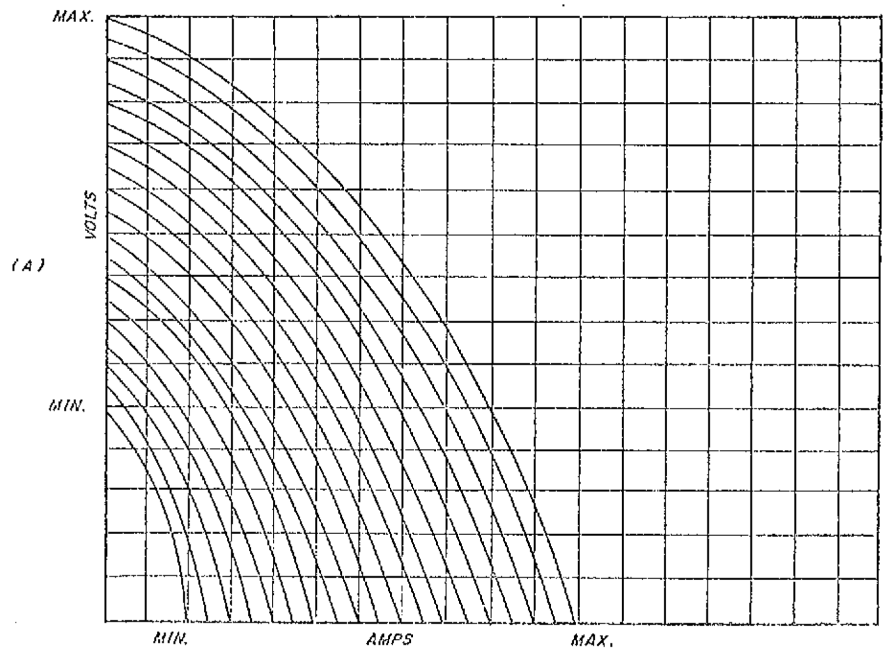


Fig. 25.17A.—Volt-ampere curves for a constant-current welding generator which result when voltage control is changed, the current control remaining constant

of the welding current setting without moving from the welding position. This arrangement provides greater range of adjustment of the welding current, but it is usually more expensive to install than the devices mentioned previously.

ELECTRICAL RATING

Minimum ratings of constant-current welding generators have been stand-

Table 25.3—NEMA ratings of constant-current d-c welding generators

Output Ratings—60% Duty Cycle at Rated Output					
Rated		Minimum		Maximum	
Amperes at Load	Volts*	Amperes at Load	Volts*	Amperes at Load	Volts*
150	26	20	20	185	27
200	28	30	21	250	30
250	30	40	22	310	32
300	32	60	22	375	35
400	36	80	23	500	40
500	40	100	24	625	44
600	44	120	25	750	44

*The above load voltages are based on the formula $E = 20 + 0.04\,I$, where E is the load voltage and I is the load current. For currents above 600 amperes, the voltage shall remain constant at 44 volts.

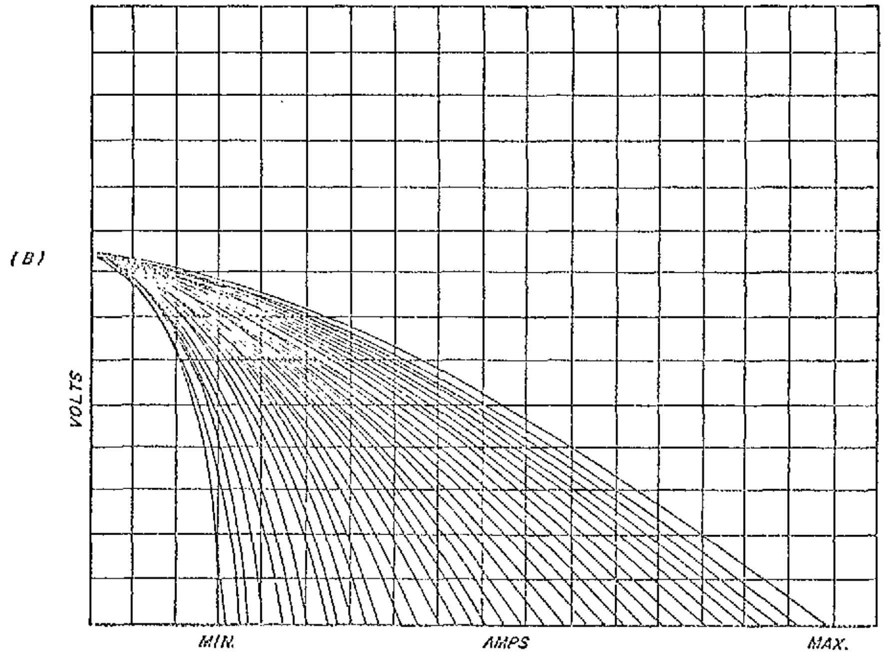


Fig. 25.17B.—Volt-ampere curves for a constant-current welding generator which result when the current control is changed, the voltage control remaining constant

ardized by the National Electrical Manufacturers Association as shown in Table 25.3. A rating is expressed in terms of arc voltage, current and duty cycle.

PARALLEL OPERATION

Although increased current capacity can be obtained by connecting generators in parallel, parallel connection is not advised unless the manufacturer's specific instructions are followed; even then, parallel connection should not be attempted by an inexperienced person. Such caution is necessary because successful paralleling depends upon matching the output voltage, output setting and polarity of each machine. In the case of self-excited generators, the problem is further complicated by the necessity to equalize the excitation between the generators.

SOURCE OF MECHANICAL POWER

Constant-current d-c generators are available with alternating-current driving motors of several voltage and frequency ratings, and also with direct-current motors. The constant-current welding generators are usually single units with the electric motor or engine and generator assembled on the same shaft.

Induction motor driven welding generators are normally available for 200, 230, 460 and 575 volts, three-phase, 60 Hz input. Other standard input requirements are 220, 380 and 440, 50 Hz. Few are made with single-phase motors, since transformer or rectifier-type welding power supplies usually fill the need for single-phase operation. The most commonly used driving motor is the 230/460 volt, three-phase, 60 Hz induction motor.

Typical curves for over-all efficiency, power factor and current input of a 230/460 volt, three-phase, 60 Hz induction motor-generator set are shown in Fig. 25.18.

The motors of d-c welding generators usually have a good power factor (80 to 90%) when under load and from 30 to 40% lagging power factor at no load. No-load power input ranges between 2 and 5 kw, depending upon the rating of the motor-generator set. The power factor of induction motor driven welding generators may be improved by the use of static capacitors similar to those used on a-c welding transformers. Welding generators have been built with synchronous motor drives in order to correct the low line power factor.

When no electric power is available, gasoline, liquefied petroleum gas and diesel engines are commonly used to drive welding generators. The engine should be selected with care and with consideration for the overload capacity inherent in welding generator design. A 300 ampere welding unit, for example, has a rated output of 9.6 kw. When the overload capacity and efficiency of the generator are taken into account, a 20 horsepower electric motor is needed to drive the generator to assure full-capacity, trouble-free performance. The engine, however, is usually rated at its maximum possible output. General practice is to publish horsepower ratings that include the power required by the fan, water pump and other engine accessories. This accessory load reduces the power available at the output shaft. The gasoline engine for this same welding generator

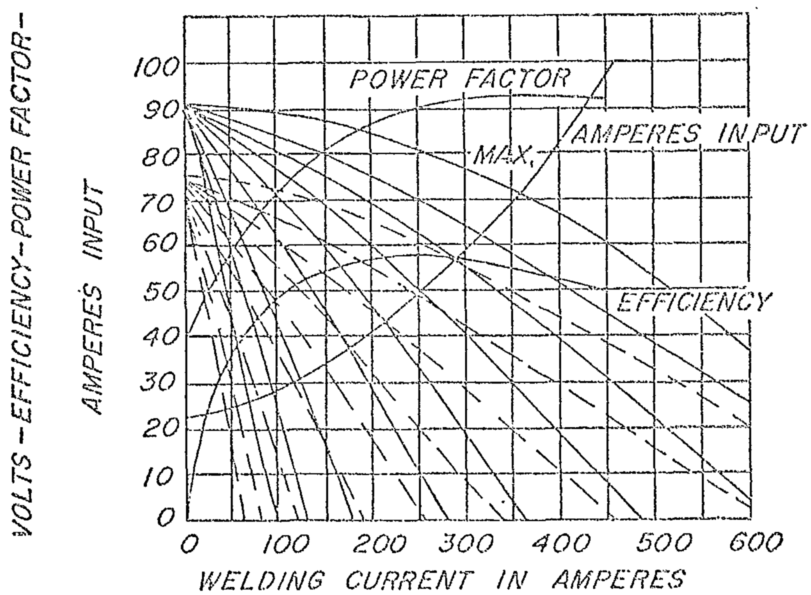


Fig. 25.18.—Typical characteristic curves of a 300 ampere single-operator d-c motor generator

would be rated in the 50 horsepower area at generator operating speed. A diesel engine with a lower nominal horsepower rating can normally produce the same output, because accessories are usually included in the engine rating.

In order to provide for engine accessory load, generator losses and the overall capacity of the generator, the use of about 70 cu. in. of piston displacement per 100 amperes of generator rating is a good rule of thumb. This is based on an engine speed of between 1500 and 2000 rpm. At higher engine speeds, the cubic inch displacement per 100 amperes drops at about the same rate that the speed increases.

Constant-current welding generators can be obtained without electric motor or engine. These usually come equipped with a shaft extension for belt or direct connection to any suitable source of mechanical power.

SERVICE CLASSIFICATIONS

Ratings of constant-current d-c welding generators were shown in Table 25.3. The duty cycle of the generators is normally 60%, but manufacturers supply welding generators of the constant-current type with duty cycles other than 60 percent. Such ratings may vary from 30 to 100%, depending on the design and application.

APPLICATIONS

The response of the power source to the transient load conditions of the arc determines whether the power source is suitable for use with the various welding processes. Transient load conditions concern current density, composition of the arc atmosphere and mode of weld metal transfer, as opposed to the static load conditions that involve open-circuit voltage, arc voltage, short-circuit current and welding current. The dynamic response of the constant-current welding generator makes it capable of handling the wide variety of arc transfer characteristics of the various types and kinds of manual electrodes and, therefore, suitable for use with the shielded metal-arc welding process. In addition, the units continue to experience wide use with submerged arc welding and gas tungsten-arc welding.

The versatility and portability of constant-current equipment, plus its reputation for rugged, trouble-free performance make such units particularly appropriate for maintenance welding activities both in shop and field; it can also be used for stud welding and arc-air gouging, but is not necessarily the best power source selection for these types of jobs. The constant-current welding generator can be used as a power source for mechanized welding with one of the various gas shielded or self-shielded open-arc welding processes; however, this type of application is not recommended. The constant-voltage welding generator has performance characteristics better suited for these processes.

RECTIFIER-TYPE POWER SOURCES—CONSTANT CURRENT

A feature common to all arc welding power sources in this category is that the output is direct current obtained from rectifiers and the input to the rectifiers is alternating current. The source of the alternating current varies with the type of machine.

TYPES

Single Phase

A single-phase transformer is used to change the a-c voltage of the incoming power line to a suitable lower voltage. An example would be a transformer wound for a 460 volt primary and an 89 volt secondary.

Multiphase

A multiphase, or polyphase transformer is almost always a three-phase system. There are two-phase systems, but they are rare. A three-phase transformer is used to change the high primary voltage to a lower secondary voltage. An example would be a 460 volt primary and a 55 volt secondary.

Engine-Driven Generator

An engine-driven generator has a generator that may be either single-phase ac or three-phase ac in its output. The a-c output is then fed into the rectifiers the same way as that from single-phase and three-phase transformers. The engines commonly used are gasoline or diesel fueled.

Electric Motor Driven Generator

It is also possible to drive an a-c generator by an electric motor. However, this type of drive is not commonly used. A single-phase or multiphase transformer would be preferred.

Transformer-Rectifier AC/DC Constant-Current Machine

This type of machine is a variation of the single-phase type referred to above. A switch is provided so that the rectifier can be connected to, or removed from, the secondary circuit to furnish either a-c or d-c current at the output terminals. These machines involve some engineering compromises, but they are very useful and have wide acceptance because of their versatility.

Constant-Current—Constant-Voltage

Constant-current—constant-voltage machines are built to allow the user to choose either type characteristic. This is done by internal taps or switching that must be changed by the user when going from one type of characteristic to the other.

OPEN-CIRCUIT VOLTAGE

Open-circuit voltage for constant-current rectifier-type machines depends on the intended welding application and can range from 50 to 80 volts. Industrial machines are usually in the 70 to 80 volt range.

ELECTRICAL CHARACTERISTICS

An important electrical characteristic is the relation of the output current to the output voltage. There is a static (steady-state) relationship and a transient (dynamic) relationship that are of interest. The first relationship is easily measured and shown by volt-ampere curves (Fig. 25.19), usually representing

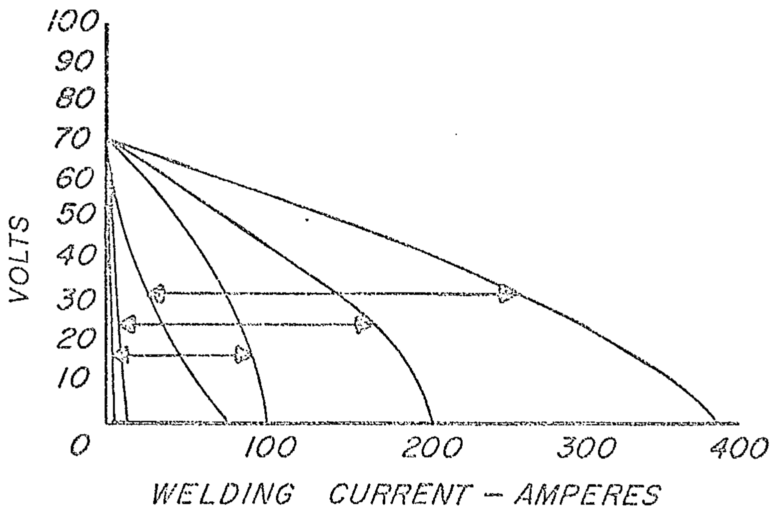


Fig. 25.19.—Static volt-ampere curves of constant-current rectifier machine

the maximum and minimum curves for each current range setting as the load current is increased from zero to the short-circuit value. The dynamic relationship is seldom published, since it is difficult to define and measure for all load conditions. The dynamic characteristic determines the stability of the arc under actual welding conditions.

GENERAL DESIGN

Transformers are designed so that the primary can be connected to the incoming supply line. In the United States, the usual voltages of the a-c supply mains are 200, 230, 460 and 575 volts with a frequency of 60 Hz. With 50 Hz input, voltages are 220, 380 and 440 volts. Transformers are seldom designed to work on all the above voltages, although a choice of two or three of those voltages is often provided for in a single machine. This is done by arranging the primary coils in sections and with taps so that the leads from each section can be connected in series or parallel with other sections to suitably match the incoming line voltage. On three-phase machines, the primary can be connected in delta or Wye and the secondary is frequently connected in delta because a delta connection makes it easier to use for low voltages and high current from the standpoint of wire size. There are exceptions to this, and transformers can use the Scott Tee connections as well as the Vee or open delta. The latter two methods are convenient in machines that use the moving coil type of current control.

The method of varying the current is usually in the a-c section of the machine before the rectifiers. The control of the current uses the principle of variable inductance or impedance. The methods of varying the impedance for current controls are: (1) moving coil, (2) moving shunt, (3) saturable reactor or magnetic amplifiers, (4) tapped reactor and (5) moving reactor core. In addition to these five systems is a type that employs resistors in series with the d-c portion of the circuit. Methods (1), (2) and (5) are classed as mechanical

Table 25.4—Methods of current control for constant-current rectifier-type power sources

	Transformer With Three-Phase Input Line	Transformer With One-Phase Input Line	Three-Phase Alternator (Alternator- or Engine-Driven)	One-Phase Alternator (Motor- or Engine-Driven)
Moving Coil	Seldom used	Used often	Cannot be used	Cannot be used
Moving Shunt	Seldom used	Used often	Cannot be used	Cannot be used
Saturable Reactor	Used often	Used often	Can be used	Can be used
Tapped Reactor	Seldom used	Suitable	Can be used	Can be used
Moving Core	Suitable	Can be used	Can be used	Can be used
Resistor	Suitable	Can be used	Can be used	Can be used

controls; method (3) as an electric control; method (4) as the resistor type of tap control. These are the same methods used in control of a-c transformer constant-current machines. On constant-current rectifier-type machines, the suitability of these methods varies as shown in Table 25.4.

Rectifiers are used to convert the alternating current to direct current. The rectifiers are in the class of semiconductors and are made of selenium or silicon, selenium rapidly being replaced by silicon. Silicon diodes are smaller than those of selenium and are mounted on a suitable fin for cooling. Selenium cells have lower voltage capability than silicon. Two or three selenium cells may be required in each leg of a rectifier stack where a single silicon cell would suffice. Silicon is vulnerable to transient voltages and currents. Manufacturers design transient protection into the equipment. Selenium has protection inherent in the cell or diode construction. Both require forced air cooling for optimum economic designs. Theoretically, silicon has greater rectification efficiency than two or three selenium diodes per leg; however, the rectifier losses are small compared to over-all losses in constant-current machines, and are not of great economic significance. Recent advances in both selenium and silicon rectifiers are such that the choice of rectifier type is largely a matter of manufacturing economics—both units perform well. Thermal sensing elements are often placed in the rectifier stack to avoid current overload and damage to the rectifiers. When actuated, these thermal sensors can either remove power to the machine or reduce the current to a lower level until the rectifier temperature drops.

Figure 25.20 shows typical single-phase and three-phase rectifier circuits.

A stabilizer is used in the d-c circuit to minimize excessive current surges in load current. These surges have two sources: some arc loads produce surges, and there is also the inherent ripple in rectifying alternating current into direct

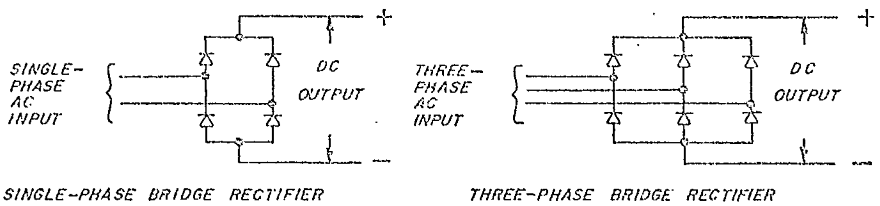


Fig. 25.20.—Bridge rectifier circuitry

current. A three-phase rectifier has relatively little ripple so that the size of the stabilizer (often called reactor) is determined by the need to reduce arc load surges. On single-phase rectifiers, the ripple is quite high because the voltage goes to zero twice each cycle, or 120 times per second on 60 Hz power. Therefore, the stabilizer on single-phase i ›ut machines will be larger than on three-phase input machines. The stabilizer is required to smooth the ripple produced by the arc as well as the ripple in the rectifier output. Machines of this type often have a switch in the d-c output so that the polarity of the voltage at the machine terminals can be reversed.

CONTROL DEVICES

Control devices are those used by the operator in the normal operation of the machine such as power on-off switches, range switches and current controls. Frequently, transformer-rectifier machines have the total current range broken into segments or steps. This is similar to coarse adjustment. The range selector is similar to a knife switch. In general, the wider the machine range, the more switch positions necessary. As many as five ranges is common. The current control is that device used by the operator to vary the current within a given range.

Mechanically controlled machines can use a hand wheel rotating an adjusting screw to transmit motion to the controlling element. In electric control, a rheostat, potentiometer or variable transformer is used to vary the control current to a saturable reactor. Electric control machines are easily adjusted from a remote location. Mechanical controls require the addition of a motor drive for remote current control and, in some types, the current cannot be adjusted while there is a load on the machine. In resistor-controlled machines, switches on the control panel change the magnitude of resistance in series with the d-c portion of the welding machine circuit.

ELECTRICAL RATING

Electrical ratings are given to the input and output. The input or primary ratings that are of interest are the primary input voltage, current for each voltage at rated output load and power factor. The output rating is the d-c load current at a specified load voltage at the machine terminals. Duty cycle and current range are specified. Output ratings established by NEMA standards for industrial machines are shown in Table 25.5. (See Table 25.2 for ratings for limited service type d-c and ac/dc arc welding machines.)

SERVICE CLASSIFICATION

Service classifications for these welding machines fall into industrial and limited service types as identified under NEMA specifications. (See Table 25.2 for data on limited service d-c and ac/dc arc welding machines.)

APPLICATIONS

Applications of machines of the industrial transformer-rectifier type include shielded metal-arc welding, gas tungsten-arc welding, carbon-arc gouging, submerged arc welding, plasma arc welding and stud welding processes.

Table 25.5—NEMA ratings of industrial transformer-rectifier d-c arc welding machines

Output Ratings—60% Duty Cycle at Rated Output					
Rated		Minimum		Maximum (at 35% Duty Cycle)	
Amperes at	Load Volts*	Amperes at	Load Volts*	Amperes at	Load Volts*
200	28	40	22	250	30
300	32	60	22	375	35
400	36	80	23	500	40
500	40	100	24	625	44
600	44	120	25	750	44
800	44	160	26	1000	44

*Voltages are based on the formula $E = 20 + 0.04\ I$, where E is the load voltage and I is the load current. For currents above 600 amperes, the voltage shall remain constant at 44 volts.

DIRECT-CURRENT WELDING GENERATORS—CONSTANT VOLTAGE

A constant-voltage welding generator can be defined as an arc welding power source that will maintain a relatively constant arc voltage throughout the entire current range of the machine. A few typical volt-ampere curves for a constant-voltage welding generator appear in Fig. 25.21. Since this type of power source offers continuous voltage control, similar output curves for any desired arc

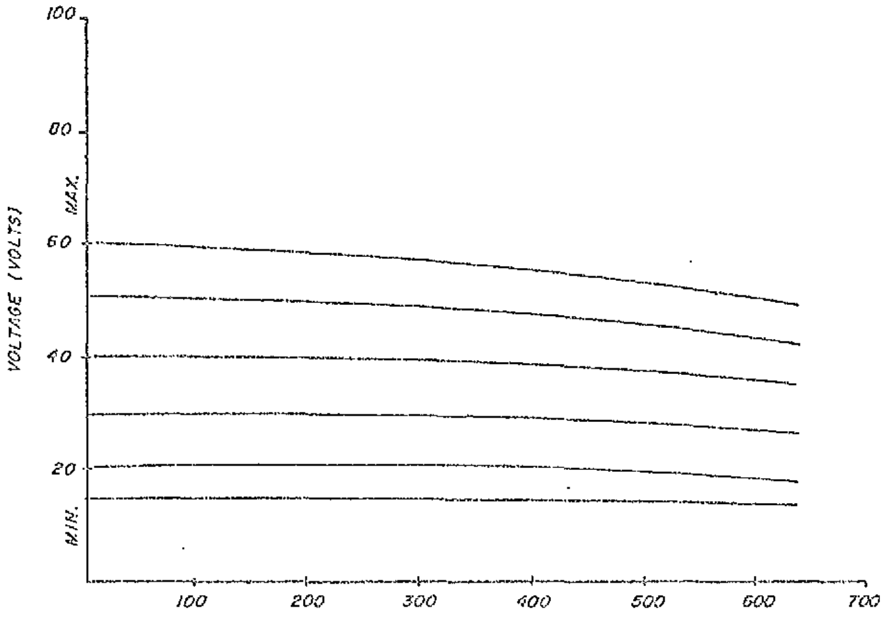


Fig. 25.21.—Typical volt-ampere curves of constant-voltage generator

voltage between the maximum and minimum voltage settings of the machine may be obtained.

ELECTRICAL CHARACTERISTICS

The open-circuit voltage and arc voltage of a constant-voltage welding generator are almost identical. Although the curves in Fig. 25.21 demonstrate a slightly drooping characteristic, some constant-voltage welding generators have a perfectly flat characteristic; others have a slightly rising characteristic, while still others offer limited slope control.

Since the arc voltage of the constant-voltage type of power source remains almost constant throughout the entire current range of the machine, variations in arc conditions produce a substantial, instantaneous change in welding current. This instantaneous current-voltage response relationship differs significantly from that of the constant-current welding generator. The current response to a change in arc conditions for the curves, (1), (2) and (3), illustrated in Fig. 25.22 provides an example. The welding current for a specific wire-feed speed has stabilized at 200 amperes. Any change in wire-feed speed will produce a compensating change in welding current. If the wire-feed speed is increased, the wire, entering the arc at a higher speed, tend to reduce the arc length, thus causing a lower arc voltage. However, the design characteristics

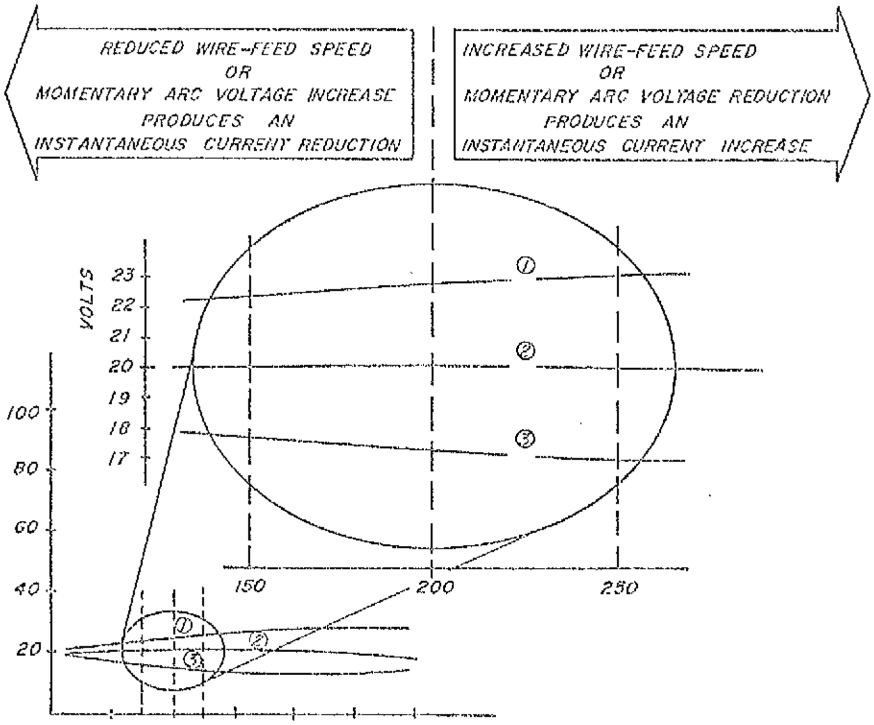


Fig. 25.22.—Curves showing current changes with wire-feed speed changes

of the constant-voltage welding generator will not permit a reduction in arc voltage, and the welding current changes automatically to raise the energy input at the arc, thus increasing the melting rate of the wire electrode. If the increased wire-feed speed is maintained, the generator output stabilizes at the higher current level. The same response occurs, but in a reverse manner, when the wire-feed speed is reduced.

The same generator response is produced by momentary variations in arc conditions, which continually occur as the droplets of molten metal cross an arc, or are caused by the welding operator's inability to maintain a constant distance between his welding gun and the surface of the weld puddle. But in such cases, the wire-feed speed has not been permanently changed and, after answering the need for more or less arc energy, the welder returns to the 200 ampere welding current output. If the generator output is observed with meters while a weld is being made, the voltage reading will remain steady, whereas the current will be continually changing to compensate for the varying arc conditions.

As Fig. 25.22 shows, the direction of the current change will be the same regardless of the slope of the volt-ampere curve. This response characteristic of the constant-voltage generator is clearly contrary to what has already been stated concerning the volt-ampere response of the constant-current welding generator. The slope of the curve of a constant-voltage welding generator does, however, affect the rate of response to varying arc conditions during welding. It also affects the arc starting characteristics as welding commences. A drooping curve will have a definite short-circuit current value and this will have less tendency to generate a lower starting current. Thus, there will be less likelihood of blasting the tip off the electrode when establishing the arc.

GENERATOR DESIGN

The constant-voltage welding generator is of the separately excited, compound-wound design with interpoles. The generator field windings are cumulatively compounded as compared to the differential compounding in the constant-current design. Cumulative compounding develops the flat volt-ampere output curves characteristic of the constant-voltage welding generator.

A constant-voltage welding generator has a single rheostat control for changing generator output. Adjustment of this control varies the strength of the generator's shunt fields, thereby raising or lowering the open-circuit voltage and the arc voltage of the machine. The control cannot change either the slope of the volt-ampere curves or the current output.

Limited slope change can be accomplished on some constant-voltage welding generators by reconnecting the electrode cable to an alternate output terminal, internally connected to a different point in the series field of the generator (Fig. 25.23). This change is made when the normal volt-ampere performance of the generator does not meet the requirements of the welding process being used. Addition of a small resistance in series with the generator is another method of slope control.

Current control is accomplished by varying the wire-feed speed. This forces the constant-voltage generator to automatically change the welding current to provide sufficient energy to the arc to melt the electrode at a rate that maintains the preselected arc voltage.

Comparison of the schematic diagrams in Fig. 25.23 with those appearing at the top of Fig. 25.16 shows the similarity of the two designs.

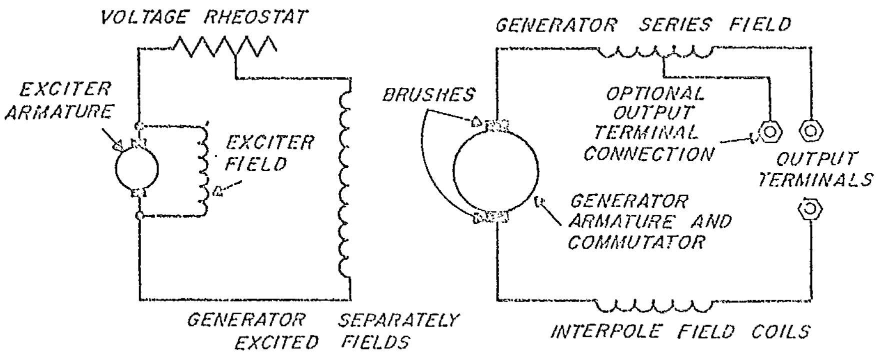


Fig. 25.23.—Separately excited, cumulatively compounded welding generator circuit

An electric motor is used to provide the mechanical energy needed to drive the constant-voltage welding generator. Gasoline engine driven models are also available but experience limited use, since an engine drive suggests portable use of the generator for maintenance or some type of field welding. These applications normally call for the use of manual shielded metal-arc welding as well as a mechanized welding process and would require constant-current performance as well as in the constant-voltage category. A combination constant-voltage—constant-current engine-driven welding generator would be preferred as the better power source selection for this type of work and would thus eliminate the need for an engine-driven constant-voltage welding generator.

CONTROL DEVICES

The output of the constant-voltage welding generator may be completely controlled by a small shunt field rheostat or a solid state control device. In either case, it is a simple matter to provide for remote control. One type of remote control is usually a second rheostat attached to the voltage knob in the control panel of the wire feeder. It is usually wired in series with the rheostat at the generator and provides limited adjustment of the welding generator at the welding station. If total range control is required, however, it is usually necessary to return to the control box on the welding generator. Solid state controls using a small potentiometer mounted at the wire feeder provide full voltage control if desired.

ELECTRICAL RATINGS AND SERVICE CLASSIFICATION

Constant-voltage generators are normally rated at 100% duty cycle owing to their use for mechanized welding involving either semiautomatic or fully automatic wire feeders. Consequently, this power source is usually providing more current for a greater time period than its constant-current counterpart. For this reason, it is important to consider both the welding procedure and operating factor when specifying size.

APPLICATIONS

The performance characteristics of the constant-voltage welding generator make it particularly suited for the various open arc welding processes being used for semiautomatic and fully automatic welding. These include both the gas shielded-arc and self-shielded arc processes using solid or flux cored wire electrodes. Such generators also work well for small wire submerged arc welding where the wire electrode diameter is 1/16 in. or smaller.

The constant-voltage welding generator is not a suitable power source for manual shielded metal-arc welding or submerged arc welding with the larger electrode diameters. These processes call for the performance characteristics of the constant-current design.

CONSTANT-CURRENT—CONSTANT-VOLTAGE WELDING GENERATOR

The expanding industrial acceptance of the various arc welding processes suited to mechanized welding and the continued use of manual shielded metal-arc welding has created a need for a combination power source capable of both constant-current and constant-voltage performance. This type of power source can be used for all existing arc welding processes—manual shielded m. tal-arc

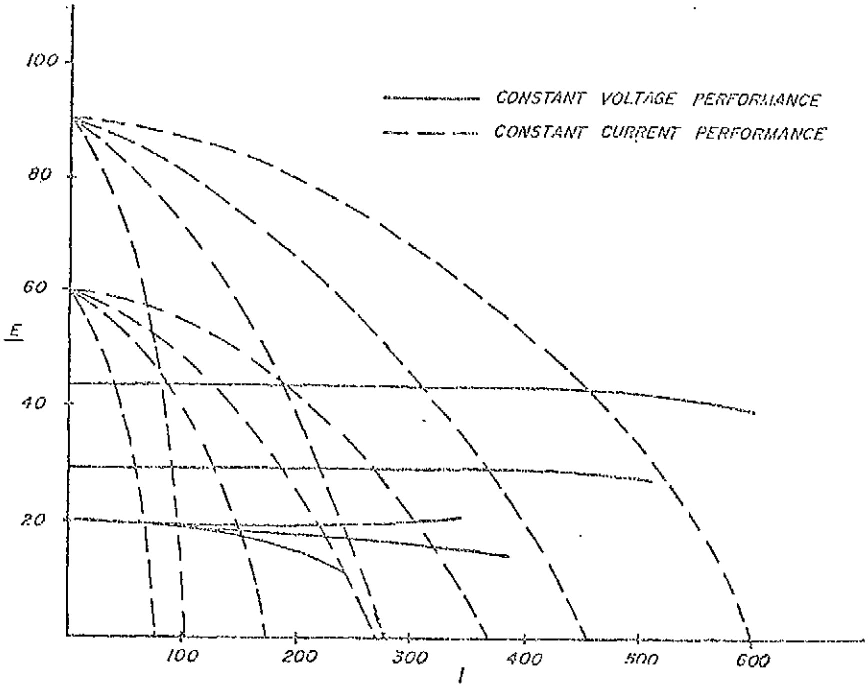


Fig. 25.24.—Typical volt-ampere curves for a constant-current—constant-voltage generator

or the mechanized gas shielded-arc, self-shielded arc and submerged arc processes. The typical applications for this power source are such that relatively low generator capacity (300 or 400 amperes) is adequate.

GENERATOR DESIGN

The volt-ampere curves for various control settings shown in Fig. 25.24 demonstrate the performance range of the constant-current—constant-voltage type of machine. This combination power source, like the constant-current and constant-voltage units, is a separately excited, modified compound-wound generator with interpoles. Solid state components are used in the excitation circuit to achieve optimum performance. The same schematic diagrams appearing in Figs. 25.16 and 25.23 present the arrangement of the major electrical components. The generator is differentially compounded when performing as a constant-current power source and cumulatively compounded for constant voltage.

The presence of solid state regulation of shunt field excitation simplifies remote control. A small control box can be carried to the welding site to provide voltage and limited current adjustment for either mechanized or manual shielded metal-arc welding.

Electrical Rating

The combination welding generator carries the same NEMA ratings as the constant-voltage and constant-current machines. The generator can be driven by an electric motor or by a gasoline or diesel engine. Since its use invariably involves welding mechanization, the decision on welding generator size should involve consideration of the application, the process or processes to be used and the anticipated operating factor.

Applications

The combination constant-current—constant-voltage power source has potential use in respect to the existing arc welding processes within the current capacity of the welding generator.

RECTIFIER-TYPE POWER SOURCES—CONSTANT VOLTAGE

Rectifier constant-voltage welding power sources are the newest family of welding power supplies and have undergone considerable evolution since their introduction. This evolution, the result of advances and new techniques in consumable electrode gas shielded metal-arc welding, may have reached a leveling-off point with the present state of the art. The first machines in this classification had a relatively flat output curve of about 1 volt drop per hundred amperes. Some machines have a rising volt-ampere curve designed to match the arc-length—arc-voltage characteristic of the arc and were adjustable from 0 to 6 volts rise per hundred amperes. The actual steady state load that was present at the terminal of the power source by the arc was also within the range of constant-current machines. For some welding processes, easier arc starting and better arc stability could be obtained with this rising-voltage type. The most recent step has been the inclusion of a variable inductance (or stabilizer) to improve the welding with low-voltage arcs.

TYPES

All high-current machines of this type are designed for three-phase input. Low-current machines are designed for three-phase input and in some cases for single-phase input.

An important variation is the amount of inductance (stabilizer) built into the machine and whether it is located electrically in the a-c or d-c part of the circuit. Machines with a large range of adjustment in the inductance in the a-c part of the circuit are often referred to as constant-voltage variable-slope welding machines.

ELECTRICAL CHARACTERISTICS

The volt-ampere curve of this class of machine ranges from relatively flat to a slope that approaches that of a constant-current machine. The machines that do not have a variable inductance have a constant slope of 1 or 2 volts per hundred amperes of load current. In the machines with variable-slope inductances, a change in the slope inductance affects the static volt-ampere and the dynamic characteristics.

GENERAL DESIGN

There are several popular approaches to the design of constant-voltage power sources. In the versions using a variable inductance, the power transformer secondaries (three-phase) have an adjustable voltage taken off the secondary by contacts (brushes) moving along the secondary windings or by some other means of tapping the transformer secondary winding. This is the open-circuit voltage control. A series inductance in the secondary side of the transformer is adjustable to give proper output characteristics under load.

Another design approach is to have taps selected by a switch on the secondary at about 4 to 6 volt increments and then use a saturable reactor for the fine voltage adjustment. Some designs use a stabilizer in the d-c circuit. These machines do not incorporate a polarity switch in the d-c output circuit. They are normally used with the negative terminal connected to the work.

In a third approach, a booster transformer with its secondary winding in series with either the primary or secondary of the main transformer is used. The secondary voltage of the booster transformer adds to the secondary voltage of the main transformer, producing a change in total output voltage. The primary of the booster transformer is fed by a variable transformer whose output is adjustable from 0 to 115 or 230 volts. When the variable transformer is adjusted, the voltage supplied by the booster transformer changes, and thus, the output voltage of the welding machine changes.

A fourth approach involves employment of a transformer, reactor in series with the secondary and a stabilizing reactor in the d-c circuit. The secondary of the transformer is tapped at 1 to 2 volt intervals for voltage control. The reactor is tapped for slope control, and the stabilizer may also be tapped. Switches on the control panel are used to select the proper tap.

Frequently, a separate control transformer is built in with a 115-volt secondary. The 115 volts is brought to a receptacle where it is available to power accessory equipment.

CONTROL DEVICES

Constant voltage rectifiers are provided with line contactors controlled through a receptacle on the control panel by the trigger on the welding gun. By this means the operator can prevent accidental arcs.

These units are normally supplied with both a voltmeter and an ammeter to permit monitoring of both arc voltage and current, primarily in order to aid in setting wire-feed speed, arc voltage and sometimes slope.

ELECTRICAL RATINGS

The primary rating is specified in the same way as for constant-current rectifier-type machines. The d-c secondary rating method is not as well established with respect to output voltage. The voltage ratings range from 25 to 50 volts. No-load (open-circuit) voltages go as high as 75 volts. For machines designed to include the low-voltage arc processes, the no-load voltage may be as low as 10 volts. Current ratings are from 200 to 1000 amperes.

SERVICE CLASSIFICATION

Rectifier-type constant-voltage machines are rated for industrial service only. The duty cycle rating is usually 100 percent.

APPLICATIONS

The applications for these machines are with semiautomatic and automatic welding processes using the gas shielded-arc, flux-cored electrode, small wire submerged arc and electroslag processes. It should be borne in mind that the volt-ampere curve (when all the reactance is in the circuit) of machines with the variable-slope feature is similar to that of a constant-current machine. Although this feature might appear to suggest suitability of constant-voltage machines for some applications that use constant-current units, it is not a wise use: if the reactance were inadvertently reduced to the minimum, very high current surges could take place during striking of the arc, and these surges could damage the machine.

SPECIAL POWER SOURCES FOR OTHER APPLICATIONS

MULTIPLE-OPERATOR WELDING

Multiple-operator welding equipment has proved economical where there are a number of welding stations in a small area. Multiple-operator welding equipment is used to advantage in shipbuilding and construction, for example.

Multiple-operator installations are supplied from either rotating-type motor-generator sets, static rectifier-type power supplies, or from transformers. Commercially available units vary from 500 to 2500 amperes for rotating units, from

500 to 1500 amperes for rectifier-type installations and from 500 to 2000 amperes for the transformers. Rectifiers used in these power supplies are silicon or selenium. Overload protection and circuit breakers protect the equipment from damage.

The usual practice is to provide a power source voltage of 70 to 80 volts with provisions for paralleling two or more units for combined output. The manufacturer's instructions should be followed to assure proper parallel operation.

Large copper bus bars are run from the power source to the welding centers and are there connected to welding outlet panels. Sometimes individual panels are installed for each welding operator. As many as ten circuits may be grouped in one panel. Each circuit is basically a resistor for direct current or a reactor for alternating current, connected in series with the electrode holder.

Individual Modules

One type of power supply consists of individual power-packed modules that, housed in a common cabinet, provide remotely controlled d-c welding current to individual stations at distances up to 200 feet from the main unit. Where the output of an individual module is not sufficient for a particular welding job, two or more modules may be paralleled. Common grounding connection of all modules is provided. Such a welding machine consists of eight separate modules powered by one three-phase power transformer. Each module consists of a d-c control coil, a-c control coil, rectifier stack, control rectifier, current control rheostat, stabilizer and thermal protection thermostat. Each individual welder can use whichever polarity he requires, since each module can be individually controlled. Individual control is also possible on multiarc systems using grid resistor banks, although two power sources are required for such applications.

Adjustable Resistor Banks

A second type of power supply is a constant-voltage motor-generator set or transformer-rectifier providing 75 to 80 volts to a group of adjustable resistor banks. Use of two power sources permits individual polarity selection by the welder. Three-phase full-wave bridge rectifiers are used to change the output of the transformer from a-c current to d-c welding current.

Current Control

The current that will flow in the circuit is limited to the value that produces a voltage drop in the ballast equal to the difference between the constant-potential source voltage and the arc voltage. Varying the value of the ballast resistance or reactance will change the value of current required to produce this drop, thus permitting control of the welding current.

Advantages

In large installations, use of multiple-operator equipment usually results in the reduction of fixed costs of equipment, cables and the amount of power used. Maintenance costs are also reduced since only one power supply must be maintained in place of the many it replaces. The individual resistor bank or reactor panels can usually be located close to the welder to enable him to make current adjustments conveniently. Although most installations are direct current, some shipyards are using a-c multiple-operator apparatus.

SUBMERGED ARC WELDING

The power supply used for submerged arc welding may be d-c constant current, d-c constant voltage or alternating current. Direct-current power supplies may be either motor generators or rectifiers. Transformers are used for a-c power supplies. The power supply and the wire-drive mechanism must be designed to operate together so that effective control of the arc length can be maintained. Constant-current types of power sources are used with arc voltage controls. If current control is used to regulate the arc length, a constant-voltage power supply must be used. Submerged arc welding generally is done at higher currents (350 to 1200 amperes) than other types of arc welding, so the power supply must have a high current rating at high duty cycles.

A standard NEMA-rated motor-generator or rectifier-type d-c welding power supply can be used for submerged arc welding if the machine is rated high enough for the application. Machines may be paralleled to obtain the necessary current capacity; however, this should only be done by an experienced operator or an electrician. Duplex units are available consisting of two single-operator units assembled and connected for single or parallel operation. The use of these machines as well as the single units of larger current ratings is preferred over the use of standard power supplies, individually or in parallel.

Constant-voltage power supplies, either motor generators or rectifiers, used for submerged arc welding should have an open-circuit voltage in the 50 volt d-c range and a current rating high enough for the application. With this type of power supply, the arc voltage is adjusted by raising or lowering the open-circuit voltage of the power unit. The welding current is automatically controlled by the feed rate of the electrode wire. One of the advantages of this method is the simple control system used. This system provides a uniformly stable arc voltage, which is of particular advantage for high-speed, light-gage welding, as well as more consistent starting because of the high initial surge current.

The higher load voltage of some submerged arc applications causes additional load on the motor driving the generator. At a given current, the input to the generator is roughly proportional to the load voltage of the generator. Care should be taken to select units having adequate motor rating. This precaution also applies to some rectifier-type machines when arc voltage exceeds the rated output voltage of the welding machine.

The flow of d-c welding current is started and stopped by means of a magnetic contactor in the welding circuit, or by means of a relay in the generator field circuit, depending upon the design and characteristics of the generator. Rectifier-type power supplies control the current by means of a contactor in the primary (a-c input) line of the machine. Duplex rectifier welding power supplies are generally equipped with primary contactor control.

Magnetic deflection of the arc (arc blow), a characteristic of direct current, usually limits the magnitude of direct current which can be used in submerged arc welding. Reference should be made to Chapter 24, Submerged Arc Welding, for additional details. Although some applications of multiple-arc welding employ alternating current, most applications use direct current on one or more electrodes and alternating current on others, or direct current on both.

Transformers with standard ratings, up to and including 2000 amperes, are available with special features adapting them to submerged arc welding application. A schematic of a standard welding transformer is shown in Fig.

25.25. The main factors to be considered are special control features, high current and high load voltage. Remote control adjusters, actuated by controls on the operator's panel, are usually required for convenience.

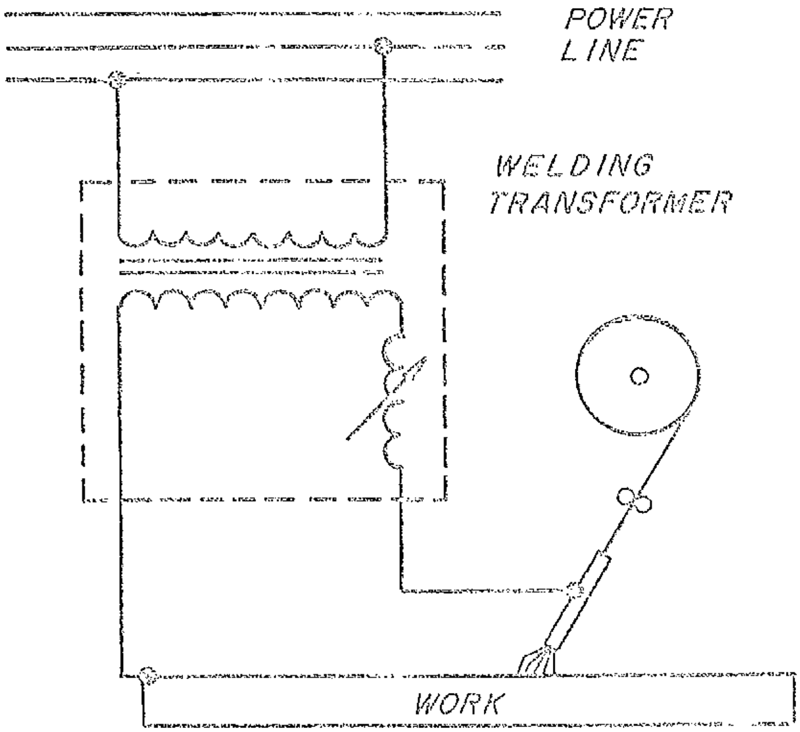


Fig. 25.25.—Alternating-current arc welding transformer supplying single submerged arc welding machine

Alternating current arc welding units of similar design may be paralleled to obtain additional welding current. The relatively high arc voltage, plus the reactive impedance drop in the high current welding circuit, usually require the use of units with at least 80 volts (open circuit) but preferably 85 to 100 volts.

Welding current for multiple-arc welding may be supplied in a number of different ways. For parallel arc welding, a d-c power supply can be used, connected in the conventional single-electrode manner. With this method, the two or more welding wires are not insulated from each other and are usually fed by a single-drive head through a common contact nozzle or jaw.

A single transformer or d-c power supply can be used for supplying two independent welding heads feeding into the same puddle, by connecting the power supply work lead to a second welding head. This is called a series arc system and requires a power supply with a high open-circuit voltage.

High-speed tandem welding generally utilizes two independent welding heads, supplied by multiple-transformer units using either a closed delta or a Scott connection across a three-phase line. Since heavy currents are frequently used

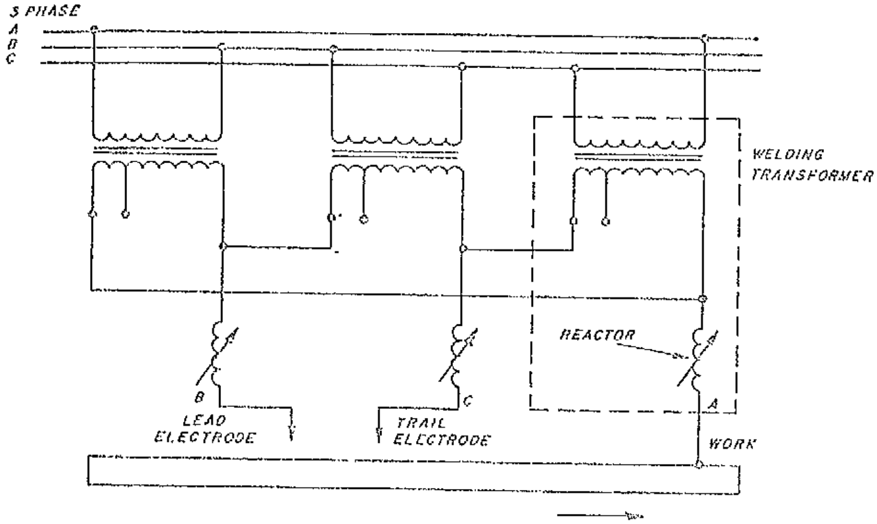


Fig. 25.26.—Alternating-current arc welding transformer connections for three-phase closed delta system

in tandem welding, these systems have the advantage of equalizing the load fairly evenly on the three phases.

The closed delta system requires the use of welding transformers with separable reactors, so that the transformer secondaries can be connected in closed delta ahead of the reactors (Fig. 25.26). This system provides maximum flexibility in the adjustment of welding currents in the two arcs, the ground current and phase-angle displacement between the three currents. Adjustment of these conditions is important to obtain desired arc deflection (magnetically), penetration and weld contour.

The Scott-connected system uses two transformers connected as in Fig. 25.27; these may be specifically designed, but standard units can be used if at least one has a center tap connection on the primary. It is also preferable that the units have secondary OCV connections for 85 and 100 volts. Although this system does not provide the extreme flexibility of adjustment inherent in the closed delta system, it gives, in a simpler manner, the essential requirements for current and phase-angle adjustment, and is considered easier to control.

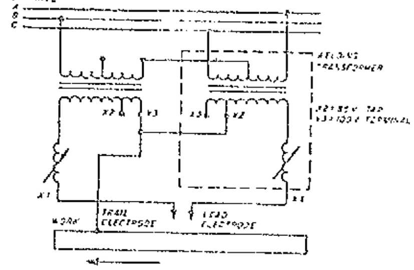


Fig. 25.27.—Alternating-current arc welding transformer connections for Scott-connected system

STUD WELDING

Electric arc stud welding must be done using a d-c power source—a motor generator, an engine generator, a transformer rectifier or a battery unit. Because stud welding demands more capacity, more consistency and better control than is normally afforded with conventional d-c power sources, special power sources have been designed for this process. The general characteristics desired in a stud welding power source are:

1. High terminal voltage in the range of 70 to 100 volts d-c open circuit.
2. A drooping volt-ampere characteristic such that 30 to 38 volts dc appears across the arc at maximum load.
3. A rapid current rise time.
4. High current capacity for a relatively short time. The current requirements are higher, and the duty cycle is much less in stud welding than in other types of welding.

Each of the various types of special power sources available, including motor generator, battery unit and transformer-rectifier units, has its own characteristics. This is why it is difficult to compare these types with other sources of power. One method of comparison would be to evaluate each power supply in terms of current output and stud welding base diameter. Table 25.6 indicates the range of requirements. A power source would be expected to develop the required current on any size of stud under the following conditions: terminal voltage during weld, 50 volts minimum; open-circuit voltage, 75 volts minimum; welding voltage across the arc, 33 to 37 volts; welding cable in the circuit, 150 ft 4/0; duty cycle—minimum (12 studs 7/8 in. in diameter per minute), 20 percent.

Table 25.6—*Maximum stud welding capacity of various power sources*

Power Sources	Stud Weld Base Diameters, In., Max
400 ampere d-c NEMA-rated units	7/16
600 ampere d-c NEMA-rated units	1/2
Two 400 ampere units in parallel	5/8
Two 600 ampere units in parallel	3/4
Battery unit*	1/2
"1000" power unit†	5/8
Two "1000" power units in paralle	3/4
"2000" power unit‡	7/8
Two "2000" power units in parallel	1

*Used where 230 or 460 volt power is not available; requires 115 volts, a-c power for charging batteries while welding is being performed.
†Furnishes power for welding from 10 gage pins to 5/8 in. diameter studs with recommended stud welding unit; requires 230 or 460 volt, three-phase incoming power.
‡Requires 230 or 460 volt, three-phase power.

Table 25.7 shows the approximate weld time, in cycles, and the actual weld current, in amperes, required for the various stud weld base diameters. It should be noted that the currents are actual weld current readings and have no relation to generator settings.

GAS TUNGSTEN-ARC WELDING

Almost any type of power source, either ac or dc, may be used with the gas tungsten-arc welding processes; however, special power sources designed for the particular application are preferred. Special welding power sources designed for use with the gas tungsten-arc welding process may be as simple as a mechanically controlled a-c unit with built-in high-frequency stabilization, or as sophisticated as a three-phase d-c power source that has facilities for completely programming gas tungsten-arc welds.

The choice of a particular kind of welding current, either ac or dc, depends on the type of metal to be welded, the type of shielding gas used, the welding techniques, etc. Selection is normally based on metal type. Alternating current is usually used for the light metals such as aluminum and magnesium. The basic reason for this selection is that ac provides the cleaning action necessary during the reverse polarity half-cycle.

Some excellent d-c welding techniques have been developed recently for gas tungsten-arc welding of aluminum. Helium shielding gas is employed with direct current straight polarity for this type of welding application. With these procedures, aluminum up to 1 in. thick has been welded in two passes. Direct current straight polarity is normally used for welding steel, low-alloy steel, stainless steel, copper and its alloys, refractory metals, etc. Very little direct current reverse polarity is used for the gas tungsten-arc welding process. Chapter 23, Gas Shielded-Arc Welding contains additional information.

Alternating-current welding power sources of the transformer type, designed especially for the gas tungsten-arc welding process, are equipped with gas and water solenoid valves, a gas timer and usually some means of arc stabilization. Alternating-current power sources usually have an open-circuit voltage between 70 and 80 volts rms, which is sufficient for consistent arc establishment on straight polarity half-cycles when the electrode is negative, but is insufficient when the electrode is positive during the reverse polarity half-cycles. The result is a very unstable, erratic arc, unless some method is used to impress a suitably high voltage into the welding circuit at the start of each reverse polarity half-cycle. The impressed high voltage serves to re-establish an ionized path in the arc region and produce a stable arc condition.

When changing direction, current must come to a stop before it can reverse. At the instant the arc is struck, the current begins flowing in one direction. As the current reverses direction no current flows; then for an instant the arc will either be reignited or remain extinguished, depending upon the electrical characteristics of the system and the particular arc conditions.

In an inert-gas atmosphere, current flows more readily in one direction than in the other from a tungsten electrode to another metal. The difference in current flow is considerable with some metals (aluminum, magnesium and copper) and is

Table 25.7—Time and average current required for welding steel studs

Stud Weld Base Diameter, In.	Weld Time, Cycles	Weld Current, Amperes
1/4	10	425
5/16	15	500
3/8	20	550
7/16	25	675
1/2	30	800
5/8	38	1200
3/4	44	1750
7/8	55	2175
1	62	2500

greater in the presence of heavy oxide films than with chemically clean metal. This resistance to current flow in one direction produces a tendency toward rectification of alternating current, which is the unbalanced flow in that one direction. Arc reignition and maintenance following current reversal are difficult and uncertain on one half of the cycle but easy and sure on the other. The easiest flow is obtained when the electrode is negative (the straight polarity half of the cycle).

Exhaustive tests have shown that during current reversals involving change from electrode negative to electrode positive about 150 or more volts rms are required for reliable arc reignition. The exact voltage differs for different metals and varies with surface condition, amperage, gas and electrode type used.

Figure 25.28 illustrates the various electrical conditions: partial and complete rectification, arc stability with ordinary unstabilized a-c machines, and the effect of stabilizing accessories and systems. Figure 25.28A illustrates partial and complete rectification from greater resistance to flow in one direction than the other with added resistance in one instance and complete blockage in the other.

Both partial and complete rectification normally occur together when standard 75 to 80 volt welding transformers are used without stabilizing accessories. Partial rectification occurs when reverse polarity half-cycles ignite the arc but impose higher resistance to current flow than the the straight polarity half-cycles. Complete rectification occurs when reverse polarity half-cycles fail to ignite the arc at all. Both conditions, as well as the extra voltage required for ignition of reverse polarity half-cycles, are illustrated in Fig. 25.28A, together with a wave form typical of welding arc voltage.

Three methods have been developed for commercial use in obtaining the voltage necessary to ignite the reverse polarity half-cycles and thus stabilize the arc. These methods are:

1. A superimposed high-frequency voltage of 3000 to 5000 volts.
2. The use of a welding transformer having a relatively high open-circuit voltage of 150 to 200 volts rms.

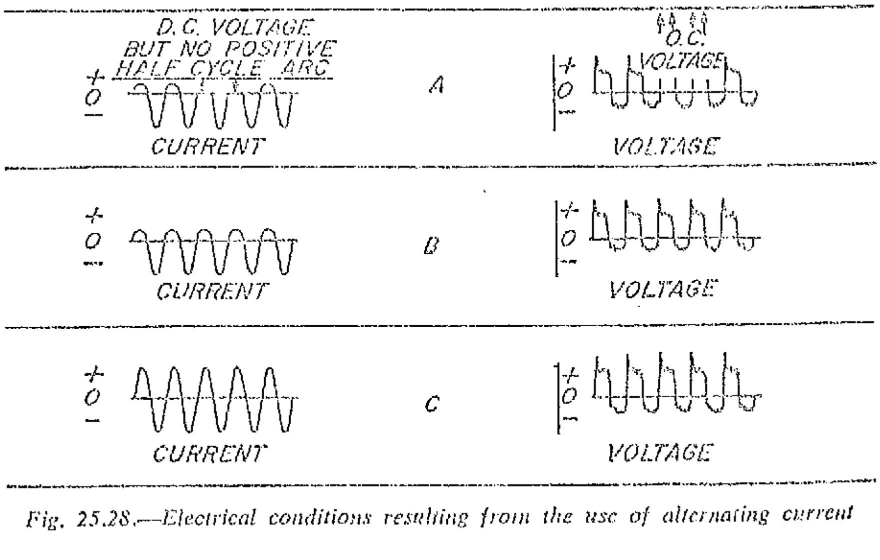


Fig. 25.28.—Electrical conditions resulting from the use of alternating current

3. Surge injections wherein a 200 to 400 volt condenser charge is injected into the welding circuit at the start of each reverse polarity half-cycle.

The effect of arc-stabilizing accessories, such as superimposed high-frequency, voltage surge injection or high-voltage transformers, is shown in Fig. 25.28B. Figure 25.28C illustrates the effect of current-balancing systems.

Balanced flow can be achieved by the use of condensers in the welding circuit, or by placing batteries in the circuit in such a way that their voltage will be additive to the reverse polarity half-cycle and subtractive from the straight polarity wave side. Six to eight volts of battery power are usually sufficient to accomplish balancing with at least 100 amp-hours of storage battery capacity per 100 amperes of maximum welding current.

The advantages of balanced current flow are as follows:

1. Better oxide cleaning action is obtained with full reverse polarity current flow.
2. Smoother, better welding action is obtained.
3. Electrical upset in the welding transformer, resulting from unbalanced core magnetization, is lessened. Unbalanced core magnetization occurs from rectification and the resulting d-c component.

The disadvantages of balanced current flow are as follows:

1. Larger electrodes are required.
2. The higher open-circuit voltages generally associated with some wave-balancing means may constitute a safety hazard.
3. The addition of a wave-balancing system increases equipment cost considerably.

Although desirable for some applications, balanced flow is not essential for most manual welding operations. It is, however, desirable for high-speed mechanized welding.

Available voltage at the start of the reverse polarity half-cycle is the main factor in arc stability with alternating current, but other details, such as electrode size, current density, type of shielding gas, shape of the electrode tip and type of electrode, also influence arc stability. Pointing the electrode at low current density is helpful for stability. High current density in the electrodes is also beneficial, however, pointing is not necessary as the electrode will ball at the end because of the high current density. It is good practice, therefore, to use the smallest electrode capable of carrying the required amperage.

Direct-current power sources of the transformer-rectifier and motor-generator types designed especially for gas tungsten-arc welding have drooping volt-ampere characteristics, with open-circuit voltage between 70 and 80 volts rms. The current rating of the power source depends on the particular application. Power sources with current ratings between 200 and 600 amperes are available. These machines are equipped with built-in high-frequency oscillators for arc initiation, gas and water control circuits, and a welding current control circuit.

The increased demand for thin-skin structural members in commercial and military products has led to the development of electronically controlled power supplies for automatic gas tungsten-arc welding. One such power supply designed for automatic gas tungsten-arc spot and seam welding has a drooping volt-ampere characteristic that has been extended to the extreme to produce a steep (almost vertical) volt-ampere curve. Changes in arc length will not cause

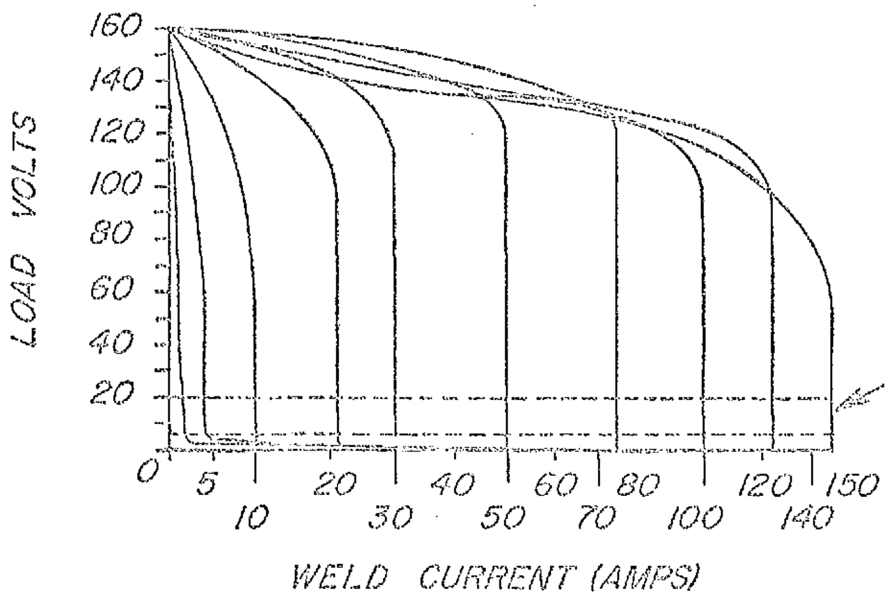


Fig. 25.29.—Relationship between load voltage and welding current; arrow indicates gas tungsten-arc welding range

changes in welding current. Novel magnetic circuitry and a high open-circuit voltage provide a power source that displays a very high internal impedance. Load voltages from 4 to 40 volts do not materially affect the output current. Tape-wound cores are used for the magnetic elements. A hybrid connection utilizes the best characteristics of both the saturable reactor (stable, with good starting characteristics) and the magnetic amplifier (fast response, wide range).

The curves in Fig. 25.29 show the results in a single welding range of direct current from 2 to 150 amperes. A larger model provides currents to 400 amperes. Since the achievement of the vertical volt-ampere curves is attributed primarily to the magnetic circuitry of the power source, it was possible to considerably simplify the required electronic circuitry. The electronic systems are not compelled to make extremely large corrections.

Fig. 25.30 is a block diagram of a typical electronically controlled gas tungsten-arc welding machine. A closed-loop feedback system is used, wherein the output welding current is continuously compared with the desired value, and any error corrected. The output current-sensing element is a special d-c current transformer utilizing "square hysteresis loop" core material. The design of this transformer is such that its output voltage is directly proportional to the integrated heating value of the welding current.

The magnetic amplifier-reactors feed the desired amount of three-phase current from the constant-potential transformer into the rectifiers. Tape-wound magnetic cores are used. The rectifier is a three-phase, heavy-duty, low-leakage selenium stack chosen for its ability to handle the transient voltages encountered. The individual components used in the rectifier stack of this machine must be chosen for reliability, because of the greater number used, as compared

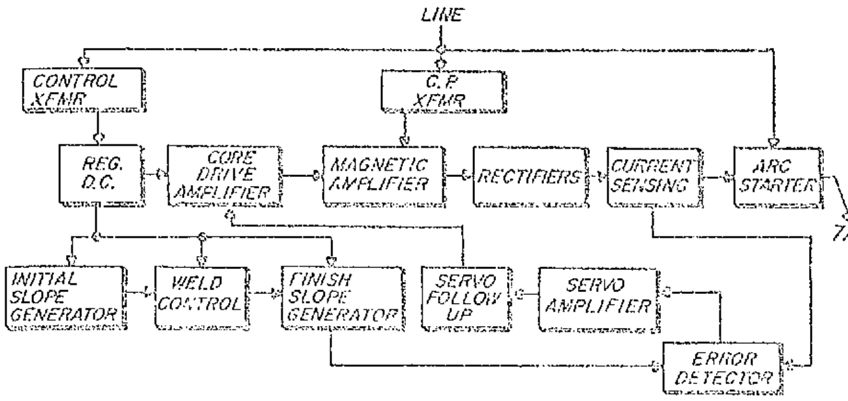


Fig. 25.30.—Block diagram for gas tungsten-arc welding machine

to a standard welding machine and, hence, because of the greater cost involved. The output choke serves as a moderate ripple filter at low currents where arc outages would be more likely to occur, and prevents the pulse generated by the arc starting mechanism from entering the welding machine, thereby routing it to the electrode holder (torch). The choke, in combination with the magnetic amplifier-reactor and high open-circuit voltage, contributes to the "intensified" arc produced. Efficiency has been subordinated in favor of performance. Power factor correction brings the power factor to 100% at a 40 ampere load.

The arc is started and stabilized by the use of an impulse type of arc starter that was developed for use with the power supply. This device provides the high-voltage spark necessary to break down and initially ionize the gas and, secondly, to superimpose on the spark a short pulse of lower voltage, higher current. The arc zone and electrode are given an initial heat sufficient to reliably strike a stable arc.

The impulse polarity is reversibly independent of the basic machine polarity with a two-position front panel toggle switch. Storage capacitors are precharged with a front panel "intensity" control. The characteristics of the pulse, with respect to slope of the leading edge and total width of the pulse, are of considerable importance. The time of discharge must be long enough to definitely "light" the arc, yet short enough to allow an output reactor to block the pulse effectively from the power source. The system is safe because of the extremely short duration (milliseconds) of the starting impulse. Radio interference problems associated with high-frequency starting are greatly reduced because of the short duration of this starting impulse.

No special electrode holders or extra cables are required to use the system. The impulse suffers no severe losses owing to long conductors. In practice, impulse starting allows the operator greater freedom of electrode shape. In production spot welding, for instance, erosion can be minimized because the electrode need not be ground down to a fine point to ensure good starts but can be tailored for the desired arc cone and nugget diameter.

ELECTROSLAG AND ELECTROGAS WELDING

The equipment used for electroslag and electrogas welding is very similar,

LEXIQUE

LEXIQUE

1-	Alternative Current Power Source	-	Poste courant alternatif
2-	Buried Arc	-	Dépôt par globule de métal
3-	Butt Joint	-	Joint en bout
4-	Constant Current and Constant Voltage Power Service	-	Poste à courant constant au voltage constant
5-	Diffusion Welding	-	Soudage par bossage
6-	Dip Soldering	-	Etamage dans un bain
7-	Direct Current Welding Generator	-	Générateur de courant continu
8-	Drooping Voltage	-	Caractéristique tombante de tension (volt)
9-	Election Beam Welding	-	Soudage par panneau d'élection
10-	Electrogas & Electroslag Welding	-	Soudage sous laiter avec ou sans gaz
11-	Filler	-	Métal d'apport
12-	Flash Welding	-	Soudage par étincelage
13-	Flux Cored Arc Welding	-	Soudage avec fil fourré
14-	Gas Metal & Flux Cored Arc Welding	-	Soudage sous flux gazeux et fil solide ou fourré
15-	Gas Tungsten Arc Welding	-	Soudage sous flux gazeux avec électrode tungstène
16-	Hold Time	-	Temps de maintien
17-	Induction Soldering	-	Etamage par induction
18-	Key Hole Arc	-	Arc avec déforcement
19-	Laser Beam Welding	-	Soudage par laser
20-	Maintenance	-	Entretien
21-	Melt-in Mode	-	Arc sous déforcement
22-	Needle Arc	-	Arc à faible intensité
23-	Non Transferred Arc	-	Arc non transféré
24-	Nozzle	-	Orifice de fusil (canon)

LEXIQUE
(suite)

25-	Offtime	- Temps d'ouverture
26-	Oven Soldering	- Etamage au four
27-	Plasma Arc Welding	- Soudage avec arc Plasma
28-	Projection Welding	- Soudage par bossage
29-	Pulsed Arc	- Arc pulsé
30-	Resistance Seam Welding	- Soudage continu à la malette
31-	Resistance Soldering	- Etamage par résistance
32-	Resistance Spot Welding	- Soudage par point
33-	Shielded Metal Arc Welding	- Soudage avec électrode enrobé
34-	Short Circuit Arc	- Dépôt par court-circuit
35-	Slag	- Laitor
36-	Soldering Iron	- Fer à souder
37-	Soldering Techniques	- Techniques d'étamage
38-	Spray Gun Soldering	- Etamage au pistolet
39-	Spray Transfer	- Dépôt par pluie de gouttelettes
40-	Squeeze Time	- Temps d'accostage
41-	Stored Energy	- Energie accumulée
42-	Submerged Arc Welding	- Soudage sous flux granulé
43-	Tap Joint	- Joint par recouvrement
44-	Torch Soldering	- Etamage au chalumeau
45-	Transferred Arc	- Arc transféré
46-	Ulrasanic Soldering	- Etamage par éclosion
47-	Wave Soldering	- Etamage dans un bain turbulent
48-	Weld Time	- Temps de soudage

and the same power sources can be used for either process with one exception: a-c power supplies cannot be used with the electrogas process. Both a-c and d-c power supplies can be used with the electroslag process. Any standard a-c or d-c power supply with an open-circuit voltage up to 80 volts and capable of delivering 600 amperes continuously is suitable for electroslag welding; any standard d-c power supply with an open-circuit voltage up to 80 volts and capable of delivering 600 amperes continuously is suitable for electrogas welding. The power supplies should be equipped with remote controls for use with either process. The number of power supplies required depends on the number of welding wires being used. One power supply is required for each welding wire used; therefore, a two-wire welding head would require two power sources.

Special constant-potential d-c power supplies designed for electroslag and electrogas welding are available. These power supplies are transformer-rectifiers having an open-circuit voltage of 74 volts and are rated at 750 amperes at 50 volts output, 100% duty cycle. The primary input is 60 Hz, three phase, 75 amperes at 460 volts or 150 amperes at 230 volts.

PLASMA ARC WELDING

Conventional direct current power supplies with drooping volt-ampere characteristics and 70 volts open circuit are suitable for most plasma arc welding applications where argon or a mixture of argon and up to 5% hydrogen is used. However, if helium or an argon–hydrogen gas mixture containing more than 5% hydrogen is used, additional open-circuit voltage is required for reliable arc ignition. This may be accomplished by connecting two power supplies in series. An alternate approach, requiring the use of only one power supply, is to strike the arc in pure argon and then switch over to the desired argon–hydrogen, or helium mixture for the welding operation.

The power supplies may be either rectifiers or motor generators; however, rectifiers are preferred because they have better current stability during the time required for the power supply to warm up to operating temperature.

Because of the relative insensitivity of the plasma arc process to arc length variations, arc voltage control equipment is not normally used. However, arc voltage control can be used with the process for applications such as welding contoured joints if precautions are taken to lock out the height control when current or gas sloping is used.

Plasma arc controls have built-in high-frequency generators for arc ignition; therefore, the power supply does not have to be equipped with high frequency. Special power supplies designed specifically for plasma arc processes are now available. These power supplies were developed to meet the specialized requirements of plasma arc surfacing and cutting, as well as welding and, therefore, are not generally compatible with other welding applications. They are usually rated between 500 and 1000 amperes with a 100% duty cycle and an open-circuit voltage of 400 volts.

PULSED ARC WELDING

A pulsed arc welding machine normally consists of a three-phase transformer-rectifier providing a constant d-c voltage output together with a single-phase half-wave rectifier, which is superimposed on the d-c or background current.

Both transformer-rectifiers are mounted in a single configuration with appropriate controls for adjustment of background and pulsed current.

The pulsed arc welding process is used with electrodes and shielding gases that normally operate only in the high current density or spray-transfer region. The power level is between the spray-transfer and dip-transfer regions and fills an operational gap between them.

The pulsed arc welding machines have the advantages of welding at lower mean welding currents, controlling the size of the metal droplet transferred and using lower average welding currents for a given wire size.

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