# 1 Arc welding – an overview

1.1 History of welding

Methods for joining metals have been known for thousands of years, but for most of this period the only form of welding was forge welding by a blacksmith.

A number of totally new welding principles emerged at the end of 19th century; sufficient electrical current could then be generated for *resistance welding* and *arc welding.* Arc welding was initially carried out using carbon electrodes, developed by Bemados, and was shortly followed by the use of steel rods. The Swede Oskar Kjellberg made an important advance when he developed and patented the coated electrode. The welding result was amazing and formed the foundation of the ESAB welding company.
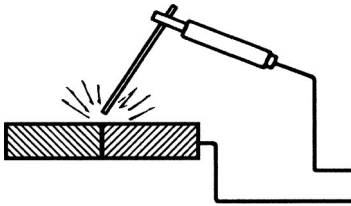
Figure 1.1 Principle of Manual Metal Arc (MMA) welding.

Another early method of welding which was also developed at that time was *gas welding.* The use of acetylene and oxygen made it possible to produce a comparatively high flame temperature, 3100°C, which is higher than that of other hydrocarbon based gas.

The intensity of all these heat sources enables heat to be generated in, or applied to, the workpiece quicker than it is conducted away into the surrounding metal. Consequently it is possible to generate a molten pool, which solidifies to form the unifying bond between the parts being joined.
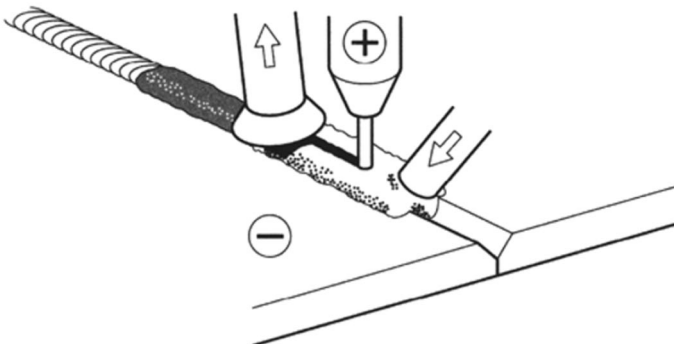

Figure 1.2 Submerged arc welding.

Later, in the 1930s, new methods were developed. Up until then, all metal-arc welding had been carried out manually. Attempts were made to automate the process using a continuous wire. The most successful process was ***submerged arc welding*** (SAW) where the arc is "submerged" in a blanket of granular fusible flux.

During the Second World War the aircraft industry required a new method for the welding of magnesium and aluminium. In 1940 experiments began in the USA with the shielding of the arc by inert gases. By using an electrode of tungsten, the arc could be struck without melting the electrode, which made it possible to weld with or without filler material. The method is called ***TIG welding*** (Tungsten Inert ***Gas)***.

Filler material
(if necessary)

Tungsten
electrode
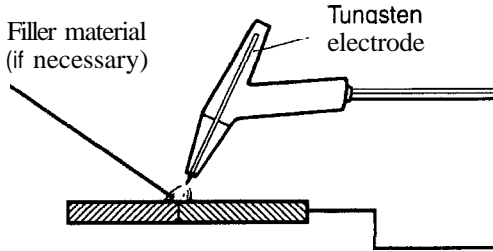
Figure 1.3 The TIG welding method.

Some years later the ***MIG welding process*** (Metal Inert Gas) was also developed using a continuously fed metal wire as the electrode. Initially, the shielding gases were inert such as helium or argon. Zaruba and Potapevski tried to use CO_2 as this was much easier to obtain and by using the "dip transfer" method they did manage to reduce some of the problems caused by the intense generation of spatter; however when using a relatively reactive gas such as CO_2 or mixed gases such as argon/CO_2, the process is generally called MAG welding (Metal Active Gas).
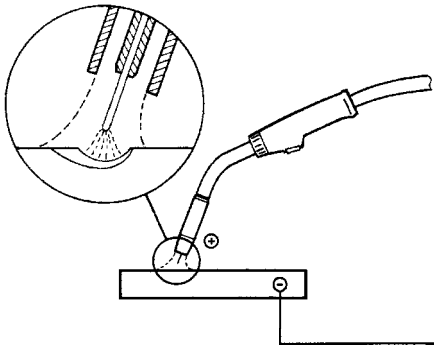
Figure 1.4 The MIG/MAG welding method.

The power-beam processes ***electron beam*** (EB) ***welding*** and ***laser welding*** have the most intensive of heat sources. The breakthrough of EB-welding came in 1958. The aircraft and nuclear power industries were the first to utilise the method. The main characteristics of EB-welding are its deep and narrow penetration. Its one limitation is the need for a vacuum chamber to contain the electron beam gun and the workpiece.

In some respects, *Laser welding* (and cutting) have ideal characteristics. The laser beam is a concentrated heat source, which permits high speed and very low distortion of the workpiece, unfortunately, a high power laser is large and expensive. The beam must also be conducted to the joint in some way. The light from a CO_2 laser must be transmitted by mirrors, while that from a Nd:YAG-laser can be carried by a thin glass fibre, which makes it attractive for use with robotic welding.

In the future it should be possible to utilise lightweight diode lasers with sufficient power for welding. The diode laser has a higher efficiency in converting electrical energy into the light beam. Although it has not yet been possible to produce diode lasers with the same power output and beam quality as present welding laser sources; these are already being used for welding metal up to about 1 mm thick. The low weight and size make them an interesting power source for use with robotic welding.

1.2   Terminology

Welding methods

Definitions of welding processes are given in ISO 857. Reference numbers for the processes are defined in ISO 4063. These numbers are then used on drawings (ISO 2553) or in welding procedure specifications (EN 288) as references.

TABLE 1.1 Reference numbers for some fusion welding methods (ISO 4063).

Welding method	Reference number
Metal-arc welding with coated electrode	111
Flux-cored wire metal-arc welding without gas shield	114
Submerged arc welding	12
MIG welding	131
MAG welding	135
MAG welding with flux-cored wire	136
TIG welding	141
Plasma arc welding	15
Oxy-fuel gas welding	31

Basic terms

Pressure welding. Welding in which sufficient outer force is applied to cause more or less plastic deformation of both the facing surfaces, generally without the addition of filler metal. Usually, but not necessarily, the facing surfaces are heated in order to permit or to facilitate bonding.

Fusion welding. Welding without application of outer force in which the facing surface(s) must be melted. Usually, but not necessarily, molten filler metal is added.

Surfacing. Producing a layer of different metal by welding, e.g. with higher corrosion, abrasion or heat resistance than the parent metal.

Welding procedure specification (WPS). A document specifying the details of the required variables for a specific application in order to assure repeatability (EN 288).

Deposition rate. Amount of metal supplied to the joint per unit time during welding.

Figure 1.5 Schematic presentation of the most common welding methods.
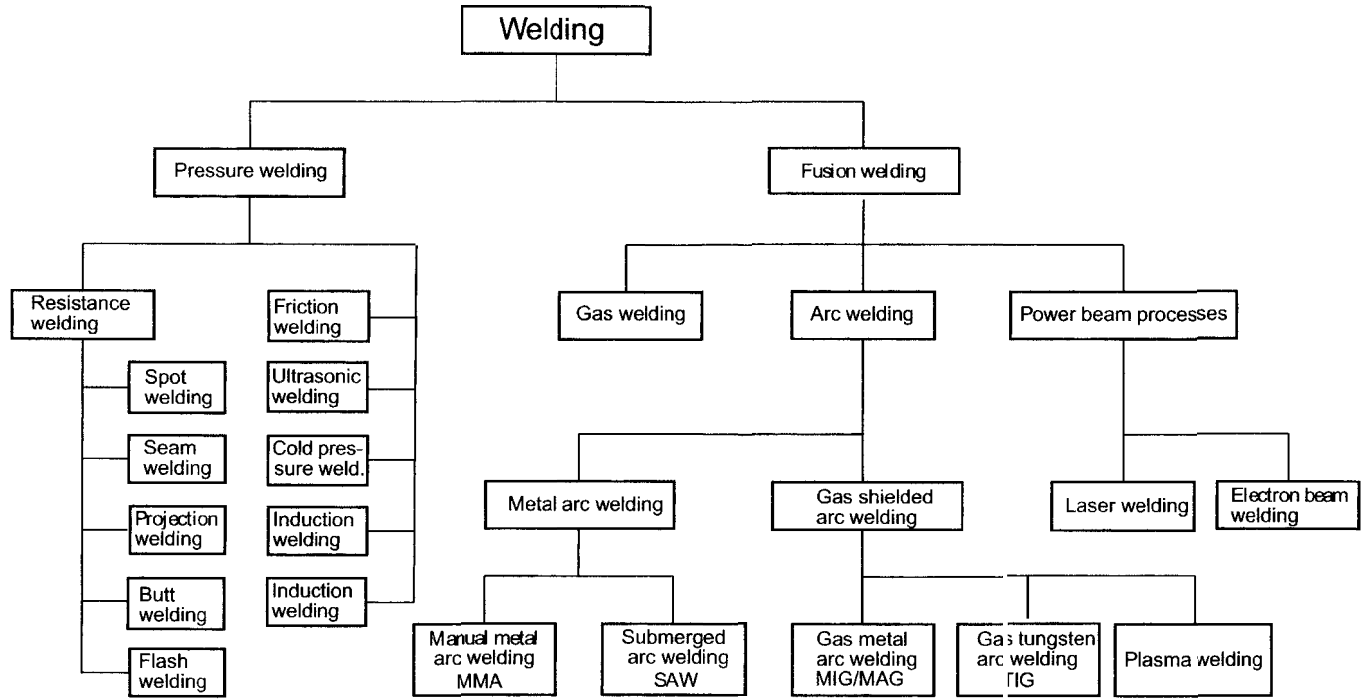
Heat input. The heat input has great importance for the rate of cooling of the weld. It can be calculated from the formula:

$$Q = \frac{U \cdot I \cdot 60}{V \cdot 1000} \cdot \text{Efficiency}$$

Efficiency*:
MMA: 0.75
MIG/MAG: 0.90
SAW: 0.90
TIG: 0.80

where Q = heat input (kJ/mm)
       U = voltage (V)
       I = current (**A**)
       V = welding speed (mm/min)

*) *These efficiencies are close to physical measured values. Always check if other values are given in the regulations or standards used by your company.*

Heat Affected Zone (HAZ). The heat affected zone, (Figure 1.6), is that area of the base metal not melted during the welding operation but whose physical properties are altered by the heat induced from the weld joint.
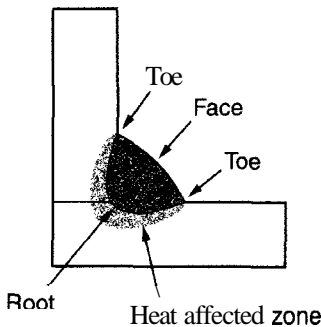

Figure 1.6 Fillet weld showing the location of weld toes, weld face, root and heat affected zone.

Throat thickness. Fillet welds are calculated by reference to the throat size. The size required is specified on drawings in terms of throat thickness, t, or the leg length, l, see Figure 1.7.
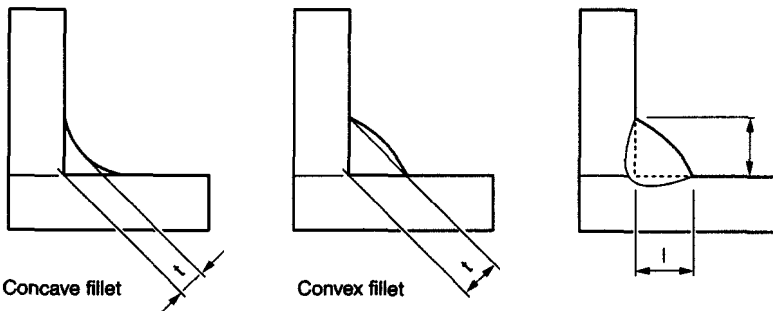

Figure 1.7 Throat thickness (t) and leg length ⦿ in a fillet weld

Joint types

Joint types are chosen with regard to the welding method and plate thickness. The ideal joint provides the required structural strength and quality without an unnecessarily large joint volume. The weld cost increases with the size of the joint, and the higher heat input will cause problems with impact strength and distortion.

Joint preparation **can** also be expensive; therefore it is preferable to use joint types where the joint faces are parts of the workpiece. This means that fillet welds are probably the most commonly used joints.
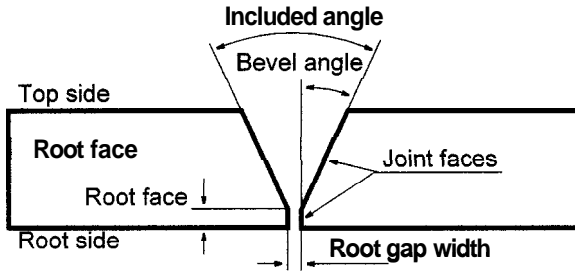
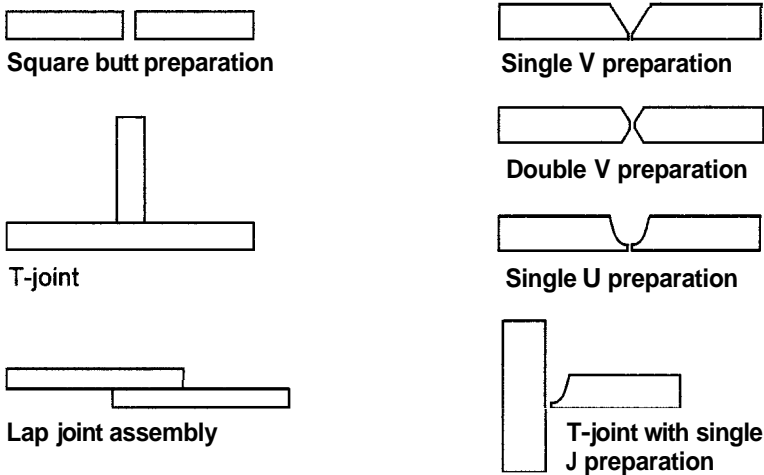*Figure 1.8 Joint terminology.*

Figure 1.9 Examples of joint types.

Welding positions

There are essentially four different fundamental welding positions, namely flat, horizontal-vertical, overhead and vertical position. Vertical position welding can be carried out as vertical upward or vertical downward welding. In addition, fillet welds can be made in the horizontal-vertical position or in the flat position, see Figure 1.10.
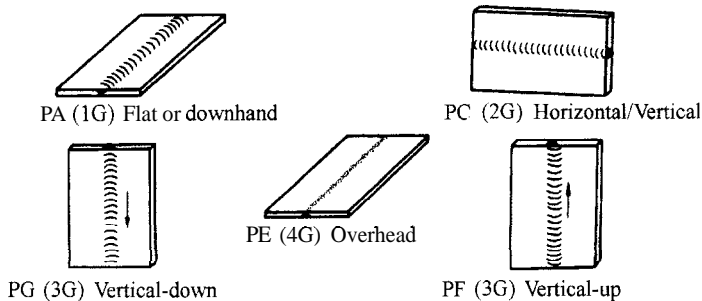
PA (1G) Flat or downhand

PC (2G) Horizontal/Vertical

PE (4G) Overhead

PG (3G) Vertical-down

PF (3G) Vertical-up

Figure 1.10 Definitions of welding positions for butt welds, as given in EN 287-1. AWS designation in parenthesis.

PA (1F) Flat position

PB (2F) Horizontal/Vertical

PD (4F) Overhead

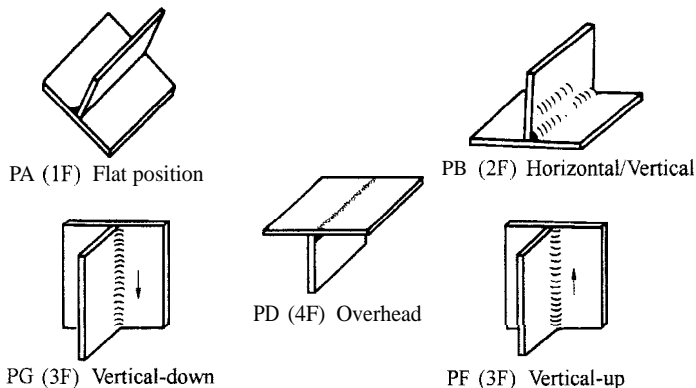PG (3F) Vertical-down

PF (3F) Vertical-up

Figure 1.11 Definitions of welding positions for fillet welds, as given in EN 287-1. AWS designation in parenthesis.

1.3 Distortion

All fusion-welding methods produce the weld by moving a molten pool along the joint; when the heated metal cools, the shrinkage introduces residual stresses and distortion in the welded structure. The stresses produce longitudinal and rotational distortion.

Longitudinal distortion. "Shortens" the weld, but may in many cases not be a serious problem. An example of this type of distortion is a welded beam that can be bent if the weld is not located symmetrically (in the centre of gravity of the cross section). If more than one weld is used, they must be symmetrical.

Rotational distortion. The rotational distortion (see Figure 1.13) can be minimised by making the weld bead symmetrical about the neutral axis or by having a parallel-sided single pass weld, as with electron beam welding. A stiff section can also prevent this type of distortion from appearing.
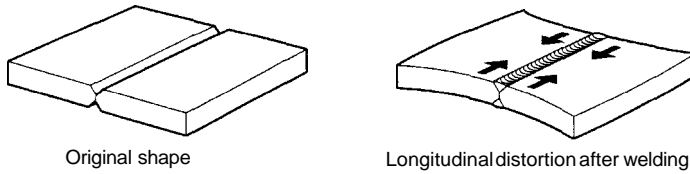
Figure 1.12 Longitudinal distortion.

Distortion is often minimised by offsetting the joints prior to welding, or by placing weld beads in a suitable sequence.
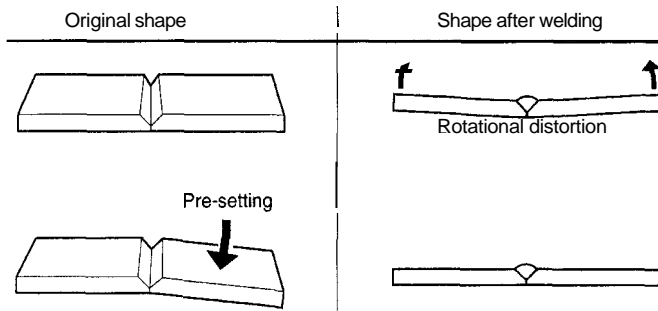

*Figure 1.13 Rotational distortion **can** be prevented by pre-setting to compensate for distortion.*

Limiting the heat input can also reduce distortion. A more intense heat source allows higher speed, lower heat input and less distortion. See Figure 1.14.
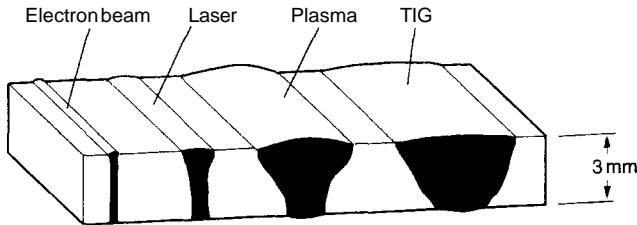

Figure 1.14 Penetration profile for some different welding methods.

1.4   The welding arc

A welding arc is an electric discharge between two electrodes. The welding current is conducted from the electrode to the workpiece through a heated and ionised gas, called plasma. The voltage drop and current in the arc give the amount of electric power that is released, the heat of which, melts the electrode and the joint faces.

The power must also be high enough to keep the temperature of the arc sufficient for the continued transport of the current. The temperature maintains ionisation of the gas, i.e. it creates electrically charged particles that carry the current.

Depending on the choice of shielding gas, different temperatures are needed to keep the plasma ionised. Argon, for example, is easier to ionise than helium. That means that welding in helium or helium-mixed gases produces a higher voltage drop and higher heat input to the weld pool.

When welding with a consumable electrode, such as MIG/MAG welding, the arc has two main functions. One is the above-mentioned supply of heat for melting the materials; the other is the transport of the molten electrode material down to the weld pool. This droplet transfer is very dependent on the electromagnetic forces and surface tension in the arc region. These forces have a great influence on the behaviour of the welding process, and enable one to distinguish between different arc types.

Spray arc

At high current, the resulting magnetic forces are directed downwards which helps the droplet to be released from the surface tension at the electrode. The droplet transfer is characterised by a stream of small droplets.

Short arc

At lower current it has the opposite effect. The magnetic forces are smaller and are also directed upwards. The droplet hanging at the tip of the electrode tends to increase in size and the process runs the risk of being unstable. A way to overcome this problem is to keep the arc length so short that the droplets will dip into the pool before they have grown too much. Surface tension will then start the transfer of the melted material and the tail of the droplet will be constricted by the magnetic forces, the so-called "pinch effect".

No metal is transferred in the form of free droplets across the arc gap. The stability of the short circuiting transfer is very sensitive to variations in the shielding gas, the chemical composition of the electrode and the properties of the power source and wire feed system.

Magnetic arc blow

The force or 'arc blow' that arises when the magnetic field around the arc is not completely symmetrical, is a well-known problem with arc welding. In critical cases, it can result in a defective weld.

- The weld pool, and thus the weld bead, can be deflected towards one side, producing a defective weld.
- If the arc is deflected along the joint, the width of the bead and the penetration can be affected.
- The protection provided by molten slag or gas can be affected, resulting in the formation of pores.
- The problem becomes worse, and more noticeable, as the welding current increases, as this results in a corresponding rapid increase in all the electromagnetic forces in and around the arc.

Possible causes

The return current connection is asymmetric

Welding close to a return current connection, or with an asymmetrically connected connection, is a common cause of this problem.
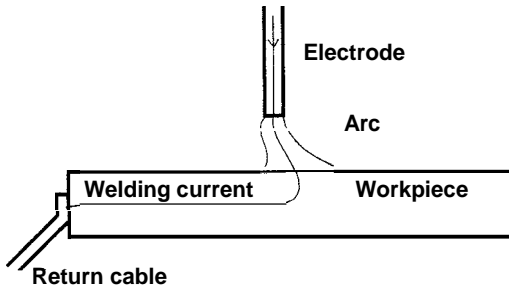

Figure 1.15 Rule of thumb no. 1: The magnetic forces from the welding current attempt to widen the current path.

The workpiece is asymmetric

The magnetic arc blow that arises when welding close to an edge or where the metal thickness increases.
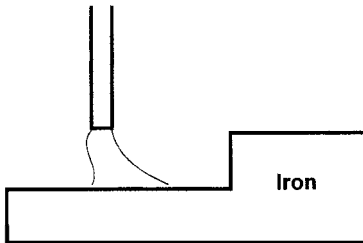

Figure 1.16 Rule of thumb no. 2: If magnetic material (iron) in the workpiece is asymmetrically distributed, the arc will move in the direction where there is the most metal.

Electrodes close to each other when using multi-electrode welding

Common in connection with, for example, submerged arc welding. Each current-carrying conductor is surrounded by its own magnetic field. The magnetic field from one electrode can interfere with the arc from an adjacent electrode.
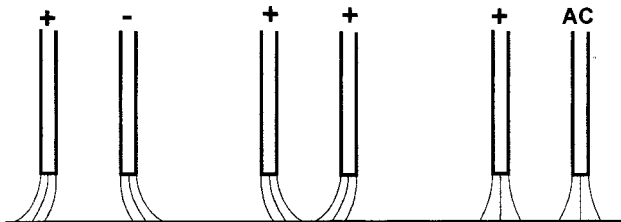

Figure 1.17 Effect from a nearby electrode.

Induced magnetic fields from the welding current

When welding in steel, the workpiece can provide a path for the magnetic field. An example of this occurs in connection with internal longitudinal welding of a pipe or tube, where the welding current supply cable induces a magnetic flux in the tube. The joint produces a break (also known as an air gap) in the magnetic path, so that the magnetic flux spreads out and affects the arc.

### Permanent magnetic fields

These are magnetic fields from magnetic clamping bedplates, or remanence (residual magnetisation) in the workpiece from, for example, lifting magnets, magnetic non-destructive testing or parts of jigs that have become magnetised by the welding current. Even the earth's magnetic field can be concentrated close to the ends of long steel items lying in a north-south direction, affecting the arc.
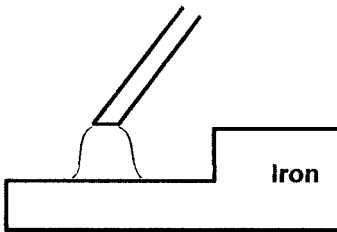
Figure 1.18 Example: Holding the electrode at an angle (see rule of thumb no. 1) can compensate for the arc blow on asymmetric workpieces (rule of thumb no. 2).

Recommended measures

- Do not connect the return current connector close to the position of the weld. Welding towards the return current connection is often preferable. When welding long items, the current can be more evenly distributed by attaching equally long return current cables to each end of the object.

- The use of adequately sized starting and finishing discs can reduce problems at the beginning and the end of a joint.
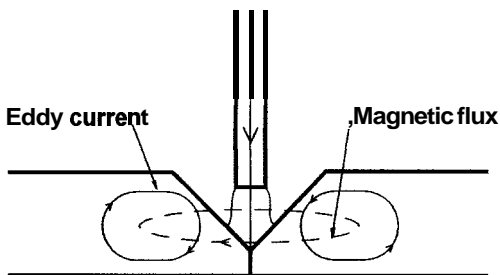
Figure 1.19 Eddy currents in the workpiece limit the magnetic flux when welding with AC.

- AC welding is often better than DC welding: the interference from an external magnetic field is symmetrical, due to the constantly changing direction of the current, and there is less risk of interference resulting from induced fields. This is because the constantly reversing magnetic flux is opposed by eddy currents in the workpiece.

1.5   Shielding gases

The most important reason to use a shielding gas is to prevent the molten metal from the harmful effect of the air. Even small amounts of oxygen in the air will oxidise the alloying elements and create slag inclusions. Nitrogen is solved in the hot melted material but when it solidifies the solubility decreases and the evaporating gas will form pores. Nitrogen can also be a cause of brittleness. The shielding gas also influences the welding properties and has great importance for the penetration and weld bead geometry.

Argon (Ar)

Argon is one of the most popular shielding gases thanks to its suitable properties. As an inert gas it has no chemical interaction with other materials. Therefore it is suitable for sensible materials such as aluminium and stainless steel. At MIG welding of mild steel an addition of CO_2 or a small amount of oxygen will increase the welding properties, especially for short arc welding. Contents of up to $20\,\%$ CO_2 improves the penetration (limits the risk of lack of fusion) while 5–8 % will give reduced spatter.

Helium (He)

Helium like argon is an inert gas. It gives more heat input to the joint. Mixed with argon it increases welding speed and is advantageous for the penetration in thick-walled aluminium or copper where it compensates for the high heat conduction.

Drawbacks with helium is a high cost and the low density. At TIG welding, high contents of helium will reduce the ignition properties.

Carbon dioxide (CO_2)

Pure carbon dioxide (CO_2) can be used for short arc welding. It is a cheap gas, it has good properties for welding of galvanised steel and gives better safety against lack of fusion than argon based gases. Drawbacks are a higher amount of spatter and the fact that the gas cannot be used for spray arc.

Hydrogen (H_2)

Small additions of hydrogen can be used to increase heat input and welding speed in the same manner as helium, but it is much cheaper. Because of the risk of cracks, hydrogen can only be used for welding of austenitic stainless steel. It actively reduces the oxides and is therefore also used in root gases.

Oxygen (O_2)

Oxygen is also used as a small addition to stabilise the arc at MIG welding.

Nitrogen (N_2)

Nitrogen can be used as an alloying element in ferritic-austenitic stainless steels. A small additive of nitrogen in the shielding gas compensates for the losses when welding.

1.6 Power sources

The importance of the power source for the welding process

The main purpose of the power source is to supply the system with suitable electric power. Furthermore, the power source performance is of vital importance for the welding process; the ignition of the arc, the stability of the transfer of the melted electrode material and for the amount of spatter that will be generated. For this purpose it is important that the static and dynamic characteristics of the power source is optimised for the particular welding process.

Static characteristics
The static characteristics of a power unit can be plotted by loading the power unit with an adjustable resistive load. We speak of *drooping characteristics, constant-current characteristics* and *straight characteristics (constant-voltage characteristics).*
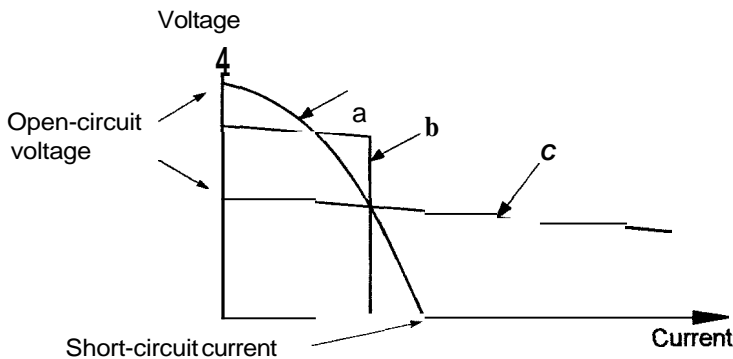

Figure 1.20 Examples of a) a drooping characteristic, b) a constant-current characteristic and c) a straight or slightly drooping characteristic.

A *constant-current characteristic* is used when the arc length is controlled by the welder, e.g. in TIG welding. If the arc length is unintentionally changed, the arc voltage changes to maintain a constant current.

A *drooping characteristic* is used for MMA welding, where it is an advantage if the short-circuit current is somewhat higher than the normal load current in order to prevent the electrode from 'freezing' to the workpiece when attempting to strike the arc. **A** drooping characteristic, as compared with a straight characteristic, also permits a higher no-load voltage, which is needed when welding with AC in order to prevent the arc from extinguishing too easily.

Straight characteristic (constant-voltage characteristic)
If the voltage remains almost constant when it is loaded it is known as a constant voltage or flat characteristic. Typically a voltage drop of 2–5 V/100 A is normal. **A** straight characteristic maintains good control of the arc length when welding with methods involving a continuously fed filler wire, such as MIG or perhaps submerged arc welding. In this case, the current is determined by the speed of the filler wire (i.e. the quantity of filler material being fed into the weld).

Self-regulation of the arc

The point of intersection between the arc characteristic and the power unit load charac-
teristic is referred to as the ***working point.*** The working point at any particular time
represents the welding current and voltage at that time. If the arc length is to be stable,
the power source characteristic must not slope too much.

Voltage

Original length of the arc

Shorter arc
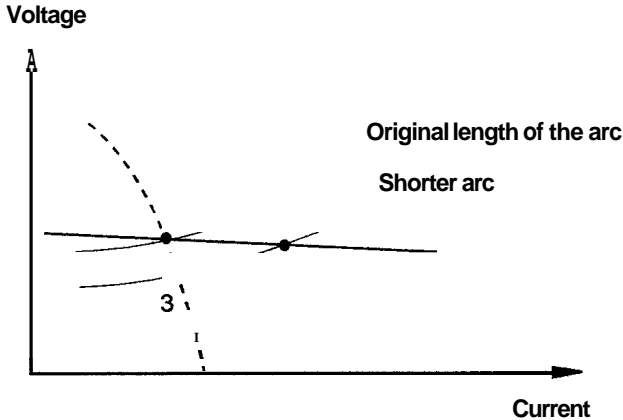
Current

*Figure 1.21 How the slope of the power unit characteristic affects the welding current if
the arc length is altered.*

If, for example, something happens so that the length of the arc is reduced, the
voltage drops and the current increases. It can be seen from Figure 1.21 that the current
increases from working point 1 to working point 2 if the slope of the characteristic is
slight, but only to working point 3 if the characteristic has a steep slope. The increase in
current raises the rate of melting of the electrode, and the arc length is restored. This is
known as the self-regulation characteristic of the arc length. MIG/MAG power units
have a straight characteristic in order to provide good self-regulation performance.

Setting the current and voltage

When ***welding with coated electrodes,*** or when performing TIG ***welding,*** it is the
current that is set on the power unit, with the arc voltage then depending on the arc
length that is used.

When ***welding with a continuously supplied filler wire,*** e.g. MIG/MAG welding, it is
the **voltage** that is set on the power unit. The voltage then determines the length of the
arc. This is a result of the arc's self-regulation characteristic: if the welder raises the
welding torch, the arc length does not alter: instead, it is the wire stickout that alters.
The current cannot be set directly: instead, it depends on the wire feed speed (and wire
diameter) used.

The current, in other words, sets itself so that it is at just the value needed to melt the
filler wire at the same rate as the wire is fed out. Changing the voltage, for example, does
not greatly affect the current.
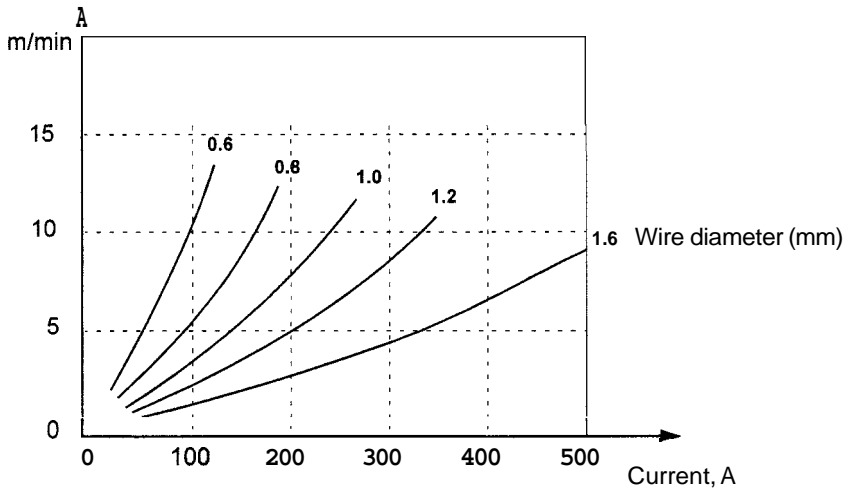
Figure 1.22 The relationship between current and rate of melting for MIG/MAG welding with normal stickout. (Filler wire: ESAB Autrod 12.51).

When performing submerged arc welding, and some other welding processes, with thicker electrodes, it can sometimes be preferable to use power units with drooping characteristics. The current then depends on the current setting in the power unit: as a result, the setting procedure is the reverse of what is normally the case. As self-regulation does not work very well with a drooping characteristic, an arc voltage regulator is used to control the wire feed speed. As a result, the arc and the arc length are kept constant.

Dynamic characteristic

With relatively slow changes in the arc, one can assume that the working point follows the power unit static characteristic. However, in the case of more rapid changes, the dynamic characteristics of the power unit (mainly its inductance) increasingly determine how quickly the current can change to suit. This is important, particularly when welding with short-circuiting drop transfer.

Power units for short arc welding usually incorporate an inductor in their output. The action of the inductor can be likened to the effect of a flywheel in a mechanical system; if the voltage changes instantaneously, as when a droplet of molten metal short-circuits the arc, the current will rise much slower. Therefore it is important that there should not be a current surge during the short circuit, as this would result in high electromagnetic forces that would cause spatter and oscillations on the surface of the weld pool.

The aim is to achieve a high, steady short-circuiting frequency, with finely distributed droplets. The arc should strike quickly and cleanly. It is essential that the power unit has the correct dynamic performance.
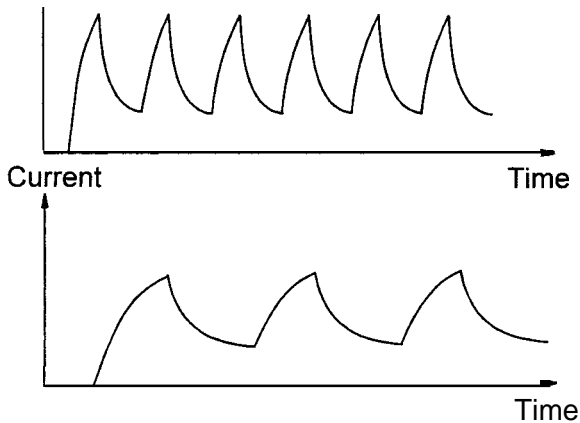
Current

Time

Current

Time

Figure 1.23 Welding current in short arc welding with low inductance (top) and with high inductance.

Welding with alternating current

AC is a popular choice for welding due to the fact that it uses a simple and inexpensive power unit. Introducing alternating current does however lead to complications because unless special steps are taken, the arc will extinguish on each zero crossing. The need to re-ignite the arc also restricts the choice of coated electrodes and requires a sufficiently high open-circuit voltage, of at least 50 V, or more. However, electrical safety require-ments currently restrict the open-circuit voltage to 80 V. (Special regulations apply in confined or damp areas: see Electrical safety requirements on page 24).

The advantages of alternating current are reduced risk of magnetic arc blow effect and good oxide-breaking performance when TIG-welding aluminium. AC welding can be a good alternative with certain coated electrodes, as it provides a higher melting rate and reduced smoke generation.

Special power units for AC welding, with a square wave pattern, have been developed. They are electronically controlled, and can have such rapid zero crossing transitions that they can be used for processes that would otherwise require a DC power source, e.g. TIG or MIG welding. An additional function on these power units is that it is possible to control the relative proportions of the power supply during the positive and negative parts of the cycle, known as balance control.

Different types of welding power units

The welding power unit converts the high voltage of the mains supply to a non-hazardous level, i.e. it provides a means of controlling the current or voltage and produces the necessary static and dynamic characteristics as required by the welding process. Figure 1.24 shows the historical development of welding power units.
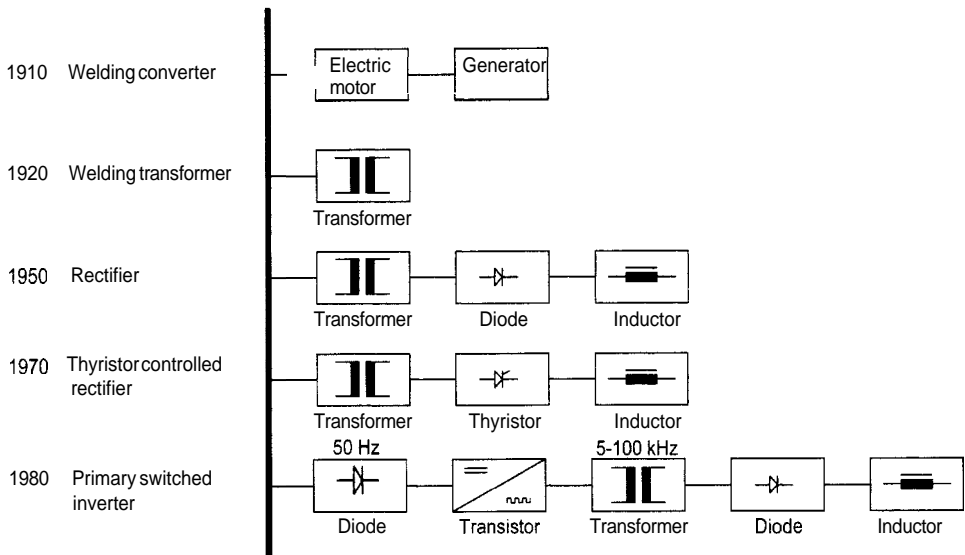
Figure 1.24 Historical development of welding power units.

Motor-generator sets

Motor-generator sets were popular for many years, and are still sometimes used, although no longer manufactured. High cost and poor efficiency made it difficult for them to compete with modem welding power units. However, their welding characteristics can be excellent. They consist of a (3-phase) motor, directly coupled to a DC generator; as the motor speed depends mainly on the mains frequency, these units are relatively insensitive to variations in the supply voltage. They can be remotely controlled by varying the excitation current.

Welding generator power units driven by petrol or diesel engines are still made, and fill a need: they are used at sites without a supply of mains electricity.

The welding transformer

Welding transformers provide alternating current, and are the cheapest and perhaps the simplest type of power unit. They are used primarily for welding with coated electrodes, although they can also be used with other welding methods when the use of alternating current is required. As opposed to other transformers, welding transformers generally have a drooping characteristic. A common way of effecting this is to separate the primary and secondary windings so that there is a certain leakage of magnetic flux. Adjusting the required welding current is then carried out by moving an additional section of core in or out of the windings by means of a handwheel. More advanced power units, for use with TIG, submerged arc and occasionally MIG welding, can be controlled by thyristors or transistors using square-wave switching technology. In such cases, it is common for them to be able to switch between AC and DC, producing what is known as AC/DC-units.

Welding rectifier

A traditional welding rectifier power source produces DC, and usually consists of a large 3-phase transformer with some form of rectifier on the secondary side. Power sources having a straight characteristic, for use with MIG/MAG weldiig, **generally** arrange for voltage control by means of a tap-changer on the transformer. An alternative is to use a thyristor-controlled rectifier bridge. Unfortunately, this **has** the disadvantage of chopping the output voltage, which makes it also necessary to fit a smoothing inductor. This is because the smoothness of the current **has** a considerable effect on the welding characteristics. Thyristor control also provides a means of **stepless** remote control and insensitivity to variations in the mains supply voltage, Overall efficiency is **70–80 %.**

The response speed of the thyristors is limited by the mains frequency, but is nevertheless **sufficiently** fast to allow the static characteristics of the power unit to be controlled. This means that the characteristic can be given varying slopes, from straight to drooping, so that the unit can be used with several different welding methods.

Welding inverters

Inverter units appeared on the market during the second half of the 1970s. In a primary-switched inverter unit, the 50 Hz mains supply is first rectified and then, using power semiconductors, is turned back into AC at a higher frequency, usually in the range 5–100 kHz. This reduces the weight of the transformer and inductor to a fraction of what is needed for a 50 Hz unit, making the power unit small and portable. Low losses result in high efficiency, to the order of 80–90 %. The high working frequency also allows the unit to be controlled at a speed that is comparable with the rapid processes occurring in connection with droplet transfer in the arc. Such units can therefore have excellent performance. In comparison with traditional power sources, inverter units offer the following advantages:

- Low weight and small size
- Good weldiig performance
- Several welding methods can be used with the same power source
- High efficiency

N = Number of turns
I = Current
U = Voltage
A = Iron core area
B = Max flux density
f = Frequency
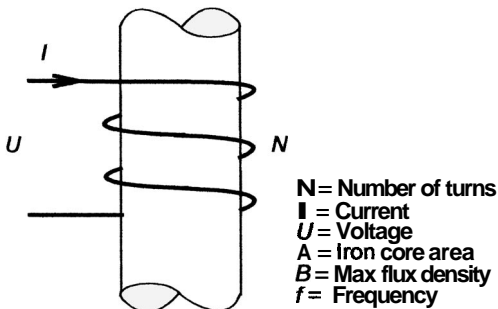
Figure 1.25 The size of the transformer and inductor depend on the number of turns and the cross-sectional core area, both of which can be reduced as the frequency is increased.

$$N \cdot A = \frac{U}{4, 44 \cdot f \cdot B}$$

A primary-switched inverter power source therefore combines low weight with good control arrangements. Its drawbacks are: that it is more complicated and difficult to make adjustable for different mains supply voltages.

For stationary applications, where weight is unimportant, a secondary-switched inverter power source can provide a useful alternative. These units use a conventional transformer, followed by a rectifier and a switching section that controls the current with the same precision as in a primary-switched inverter power source.

Development trends

Modern electronics and computer technology have had a considerable effect on the development of arc welding equipment. This applies not only to the power circuits, but also to the control electronics in the power unit and in other parts of the electrical equipment used for welding. This rapid rate of development may seem confusing, providing many new potential setting instruments and controls. The following pages provide a review of the new opportunities and concepts that are available.

Inverter control

Where welding characteristics were previously determined by the design and limitations of the heavy current circuits, control can now be provided by electronics and/or computers. Effectively, the high-speed power circuit operates as an amplifier, providing new opportunities not only for control of the welding parameters, but also for control of the process itself.

Electric and welding characteristics

Different types of welding methods require different static characteristics. Electronic control increases the flexibility of the power source, and it is relatively simple to incorporate features enabling it to be used with several different welding methods. In addition to MIG/MAG, a power source may perhaps also be suitable for use with coated electrodes and TIG welding, without necessarily involving any significant extra cost. Many of the more advanced units are therefore suitable for use with several different types of welding.

However, it is not sufficient to simply modify the static characteristic in order to suit a power source to different welding methods. Appropriate dynamic characteristics are needed in order to achieve smooth, stable welding without spatter, particularly when using filler wire processes where the arc is short-circuited by molten droplets.

Conventionally designed welding power sources could only be used for one particular type of welding method. They were generally optimised for a particular range of electrodes, materials and shielding gases. Electronically controlled power sources, on the other hand, with fast reactions, make it possible to adjust the characteristics of the power source to suit the particular process.

Controllable welding characteristics

The welding characteristics of the power source dictate how well the power source performs when welding, e.g. that starting is immediate and without problems, that the arc is stable with a smooth transfer of droplets and that any spatter formation is limited and finely distributed. As a rapidly controllable power source does not essentially have any characteristics of its own, they have to be produced by the electronic or computer control.

Good characteristics are particularly important when using short-arc welding, especially when considering the stream of molten droplets to be transferred to the weld pool. Detachment of each droplet is critical, bearing in mind possible spatter formation and the forces that can cause surging of the molten metal in the weld pool. Correct control can maintain a high, consistent short-circuit frequency, resulting in stable transfer of fine droplets with a minimum of large spatter droplets. These characteristics are particularly important when using CO_2 as the shielding gas.
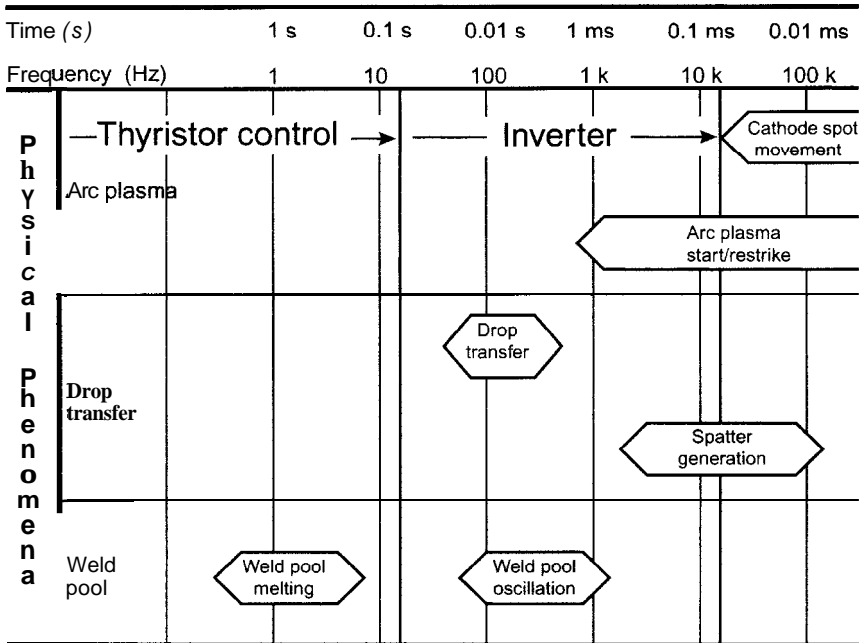
Figure 1.26 The speed of response of the power source is decisive in determining and controlling various processes in the arc.

Computer control

The most advanced power sources generally incorporate some form of computer control. The computer can be used for communication with the user selecting the welding method and making the necessary parameter adjustments. A memory provides a means of saving and reusing previously used settings. Computer control allows maximum utilisation of the flexibility provided by modem power sources.

- Software control of current output and the welding process
- Multi-process possibilities - MIG, TIG and MMA welding with the same equipment
- Synergy line characteristics, providing optirnised settings/performance for each situation
- Pulsed arc MIG welding
- Feedback control of welding parameters, guaranteeing improved accuracy and reproduction

- Improved welding start and stop functions
- Man/machine communication with the user through the control panel

The ability to achieve the intended welding quality is improved by the availability and/or use of various functions, examples of which are shown in Table 1.2 below.

TABLE 1.2 Examples on functions available on advancedpower sources.

	Function	Process
Start of welding	**Creep start**	MIG
	Gas pre-flow	MIG, TIG
	Hot start	MIG. MMA
	HF-start	TIG
	Lift arc	TIG
	Slope up	TIG
Continuous welding	**Pulsed MIG welding**	MIG
	Arc length control	MIG
	Step-less inductance setting	MIG
	Synergy lines	MIG, MMA
	Pulsed TIG	TIG
	Slope up	TIG
	Arc force	MMA
	Feedback controlled parameter settings	MIG, TIG, MMA
Finishing a weld	**Crater filling**	MIG
	Slope down	TIG
	Bum back time setting	MIG
	Shake off pulse	MIG
	Gas post flow	MIG, TIG

MIG/MAG and other welding processes require several welding parameters to be optimised in order to achieve the best results. A popular way of doing this is the use of single-knob control, known as synergic setting of the welding parameters. This represents combinations of parameters that have originally been established by skilled welders, e.g. combinations of wire feed speed, current, voltage etc., with the results being stored in the memory of the power source. Users start by selecting the required welding method, followed by the type of material, wire diameter and shielding gas. Any subsequent change in the wire feed speed is then compensated by the power source which, at all times, adjusts the other parameters as necessary. Nevertheless, the welder can also override the settings and make manual adjustments from these default characteristics if required.

Rating data for power sources

The power source rating plate lists the design ratings of the power source, with the most important being the related values of rated current, rated voltage and duty cycle. Other interesting information shown on the rating plate includes efficiency and power factor, open-circuit voltage, and insulation class etc. IEC 974-1 gives details of how power sources are to be tested and of what information is to be shown on the rating plate.

Figure 1.27 Rating plate.

Standard for welding power sources
The International and European Standard IEC/EN 60974-1 specifies demands on power sources regarding electrical safety. It defines important design principles, rating and testing of the equipment to ensure a safe operation.

Application class [S]
This symbol shows that the power unit is designed for use in areas of elevated electrical risk, i.e. where conditions are cramped (with electrically conducting walls or equipment etc.), or where it is damp.

Enclosure class
The IP code indicates the enclosure class, with the first figure indicating the degree of protection against penetration of solid objects, and the second figure indicating the degree of protection against water. IP 23 is suitable for use indoors and outdoors.

Class of insulation
The transformer and inductor insulation material limits the maximum temperature on the windings. If a power source uses class H insulation material it means that it is made for 180°C (20 000 hours). At a heating test of the power source with this class of insulation it is controlled that the rise of temperature in windings not exceeds 125 degrees above ambient temperature.

Rated current

The rated current is the current for which the power source is designed. In some cases, a number in the name of the unit may give the impression that it can supply a higher current: always check the technical data or the rating plate to make sure what the actual value of rated current is.

Rated voltage

IEC 974 specifies a standard load line which, for each value of rated current, shows the voltage at which the power source must be tested and with which it must be marked. This means that it is easier to compare the rated data for power sources from different manufacturers. The relationships specified by IEC 974 differ from one welding method to another: for currents up to 600 A, the voltages are as follows:

MMA and SAW:	$U = 20 + 0.04 \cdot I$	For currents above 600 A:	$U = 44$ V
TIG:	$U = 10 + 0.04 \cdot I$	For currents above 600 A:	$U = 34$ V
MIG/MAG:	$U = 14 + 0.05 \cdot I$	For currents above 600 A:	$U = 44$ V

Duty cycle

The power source rating is also determined by its duty cycle, which indicates for what proportion of a period of ten minutes that the power source can be operated at the specified load. 400 A at 35 % duty factor, for example, means that the power source can supply 400 A for 3.5 minutes in every ten minutes indefinitely without overheating.

Efficiency and power factor

The efficiency indicates what proportion of the input power finds its way through to the welding process. If the efficiency is 75 %, this means that 25 % of the input power is dissipated in the form of heat losses in the power source.

$$\text{Input power} = \frac{\text{Welding current. Welding voltage}}{\text{Efficiency}}$$

The actual power demand can then be calculated if the efficiency is known. The active power supplied to the source is measured in kW, and determines the energy cost.

The current to be supplied by the mains, and thus passing through the supply fuses, increases if the efficiency is poor. However, in order to be able to work out the supply current, we also need to know the power factor. For a 3-phase supply, we have:

$$I_1 = \frac{P_1}{U_1 \cdot \sqrt{3} \cdot \lambda}$$

where:

I_1 = mains current [A]

P_1 = input power [W]

U_1 = supply voltage [V]

λ = the power factor

The power factor depends partly on the phase displacement between the current and the voltage, and partly on the shape of the current waveform if this departs from a sine

wave. Multiplying the current and voltage gives the reactive power, which is measured in kVA and which is of importance when determining the capacity of the electrical supply system.

Typical values of power source efficiency are in the range 0.75–0.85. The power factor can be as high as **0.95,** e.g. for a semi-automatic power source with tap-changer control or for certain inverter units, although it is usually considerably lower for MMA power sources. The power factor of large welding transformers with drooping character-istics is often improved by the fitting of phase compensation capacitors, which can improve the power factor from for example **0.40** to **0.70.**
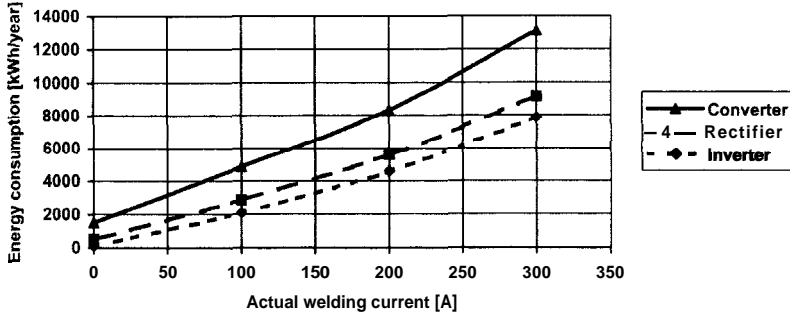
Figure 1.28 Annual energy consumption for different types of manual (MMA) power sources. The differences are due to the different efficiencies and no-load losses of the power sources.

Electrical safety requirements

It is important from the point of view of electrical safety that the open-circuit voltage of the power unit is not too high. This is particularly important when using AC for welding, where a high open-circuit voltage is often required in order to ensure a stable arc. At the same time, health and safety requirements are particularly strict in connection with the use of AC. IEC **974** permits a maximum of **80** V AC, as compared with 113 **V** DC. Open-circuit AC voltage may not exceed **48** V in wet areas or confined spaces, which are regarded as presenting a higher electrical safety risk. Special devices intended to reduce the open-circuit voltage are available to allow safe welding without affecting the welding characteristics.

A welding circuit is not protectively earthed: therefore it is particularly important that the power source is well insulated in order to ensure that the mains voltage cannot reach the secondary circuits.

Transformer winding insulation is exposed to high temperatures, so the material must be of a suitable insulation class to withstand the temperature. A rise of 10°C reduces the life of the material by half. Therefore it is particularly important to keep the interior of the power source clean in order to maintain adequate cooling performance.

Power sources used outdoors should be designed so that moisture and rain cannot degrade the insulation performance.

Despite all these measures, the welder should still take care: the use of gloves, together with undamaged dry clothing, is recommended.

Fire risks

Welding or thermal cutting are common causes of fire. Experience shows that the risks are greatest in connection with temporary work in premises or areas not normally intended for welding. If such work has to be carried out, the person responsible for safety must decide on what protective measures need to be taken.

- Cleaning and removal of combustible materials in the risk zone.
- Any holes or gaps in combustible materials used in the building must be covered or sealed so that weld spatter or sparks, **e.g.** from gas cutting, cannot find their way in.
- Dampening surfaces with water.
- Screening off the work area.
- Ensuring that adequate extinguishing equipment is available.
- Supervision and subsequent checking after welding has been concluded.

Figure 1.29 Risks are greatest in connection with temporary work in premises or areas not normally intended for welding