Ex. Pinch effect and plasma stream

The arc in welding is generally operated under a high current condition and the magnetic field created by the current has a great influence on the welding arc. The figure shows the plasma stream in the arc caused by electromagnetic pinch effect. Complete the figure with the appropriate words in the list.

List of words:

- a. Lorentz force (electromagnetic force)
- b. magnetic field
- c. plasma stream
- d. anode
- e. cathode
Magnetic Pinch Effect

An electric current passing through a liquid or gaseous conductor makes its cross section to shrink as a result of the electro-magnetic forces. This is called as Magnetic Pinch Effect.

The electro-magnetic force, i.e. Lorentz force is expressed as follows,

\[ F = J \times B \]  

where \( J \) is the current density and \( B \) the magnetic flux density.

In a certain condition, the pinch effect is applied to control the metal transfer mode in arc welding, as the molten metal on the tip of wire electrode is pinched off.

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The magnetic pinch effect causes an axial force under the condition that the current path is expanding, as shown in the figure. The axial force \( F_a \) is approximately expressed as follows,

\[ F_a = 10^{-5} \times I_0^2 \ln \left( \frac{R_a}{R_b} \right) \]  

where \( I \) is current, \( R_a \) and \( R_b \) upper and lower radius of current path.

In welding arc, the current path is expanding from electrode to work-piece, this force is called as Arc Force.
The electro-magnetic force has an important role on the metal transfer in MAG welding. The figure shows the effect of electro-magnetic force on the metal transfer. The E-M force: \( F_{em} \) is given approximately by Eq(1).

\[
F_{em} = \frac{I^2}{2\pi} \ln \left( \frac{R}{r_a} \right)
\]

where \( I \) is current, \( \mu \) is permeability, \( R \) is wire-diameter and \( r_a \) is diameter of current zone at the top of molten drop as shown in the figure. According to Eq (1), the force is not small and the direction of the force depends on the anode-size in MAG arc.

Fig 1. Current path in various transfer modes (Norrish, J., Advanced Welding Processes, IOP Pub. 1992)

Globular transfer mode
[Drop transfer and Repelled transfer]

Courtesy of Paton Welding Institute
The welding arc, of high current, is affected by its own magnetic field. The figure shows schematically the influence of the electro-magnetic effect on TIG arc.

In the arc column, a gaseous flow, called "plasma stream", is induced by the electro-magnetic force due to the arc current. And an "arc pressure", caused by the pinch effect and the plasma stream, acts on the molten pool surface.

As shown in the figure, the arc pressure depends on the shielding gas, and its peak value $P_a$ strongly depends on the arc current $I$ and its density $\beta$, i.e. $P_a \propto I \beta$.

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Sources:
- Yamauchi, N., Taka, T., IIW 212-452-79, 1979
The welding arc, of high current, is affected by its own magnetic field. The figure shows schematically the influence of the electro-magnetic effect on TIG arc. In the arc column, a gaseous flow, called “plasma stream”, is induced by the electro-magnetic force due to the arc current. Consequently, the arc is stabilized by the plasma stream and is formed along the direction in which the electrode points, as shown in the figure. This arc property is called as “arc stiffness”.

(a) Arc stiffness under high current, where arc is formed in the electrode direction.  
(b) Low current arc where arc stiffness is not observed

Under a certain condition, an asymmetrical magnetic field is produced around the welding arc, and the magnetic field disturbs the arc and makes it difficult to produce a satisfactory weld. This magnetic disturbance is called “arc blow”.

The figure shows two typical examples of arc blow.

In figure (a), an asymmetric magnetic field is caused by the welding current path from the work-piece lead to the electrode, where the dotted circles shows schematically the magnetic field created by the welding current.

In figure (b), the arc blow is caused by the asymmetric arrangement of magnetic materials around the arc, where the magnetic flux pass through the magnetic material more smoothly than through air. As shown in the figure, the arc is always blown toward the magnetic materials.