Review on Design and Development of Narrow Gap Welding Torches

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ABSTRACT

Narrow gap welding is an effective process for joining thick plates (2" to 12") of carbon steel, low alloys steel and high strength low alloy steels. But it requires some development in torch design, wire feeding mechanism and welding procedure for preventing all sorts of weld defects before practical application. Narrow gap welding technology is associated with various conventional arc welding technology like GMAW, GTAW, SAW, FCAW & SMAW. Several fabricators world over, especially in Japan have developed their own equipment working on different principles [1]

Standard torches for NGW are not available routinely in the market. Torches for NGW are specially designed (custom made) for various NGW applications. Design of torch will differ from processes to process and application to application. Paper highlights the different torch designs used by researcher for different narrow gap welding technologies like

I) Narrow Gap-Gas Metal Arc Welding (NG-GMAW) Torch Design
II) Narrow Gap-Gas Tungsten Arc Welding (NG-GTAW) Torch Design
III) Narrow Gap- Submerged Arc Welding (NG-SAW) Torch Design

1.0 INTRODUCTION

Following chart describe the characteristics features, advantages and disadvantages of NGW process.[2]

Process characteristics :
- narrow, almost parallel weld edges. The small preparation angle has the function to compensate the distortion of the joining members.
- multipass technique where the weld build-up is a constant 1 or 2 beads per pass
- usually very small heat affected zone (HAZ) caused by low energy input.

Advantages :
- profitable through low consumption quantities of filler material, gas and/or powder due to the narrow gaps
- excellent quality values of the weld metal and the HAZ due to low heat input
- decreased tendency to shrink

Disadvantages :
- higher apparatus expenditure, especially for the control of the weld head and the wire feed device
- increased risk of imperfections at large wall thicknesses due to more difficult accessibility during process control
- repair possibilities more difficult

Fig. 1 : Characteristics features, advantages and disadvantages of NGW process

2.0 NG-GMAW TORCH DESIGN

NG-GMAW process is classified into two categories. NGW-I and NGW-II.

In case of NGW-I : Contact tube is inserted into the gap, is also characterized by feeding of a small diameter electrode (0.8 mm to 1.2 mm). Electrode wire generally wound on convenient size spools or coils. Because of less wire diameter, will be less rigid and it has tendency to bend toward the one sidewall. The uniformity of winding and freedom from kinks or bends are important considerations for proper feeding of the electrode in deep narrow groove. In most cases, these techniques require serious modifications of standard wire feeders, which may include a wire straightener, a wire-bending device, torch rotating and oscillating devices

In case of NGW-II : Contact tube is above work piece, is also characterized by feeding of a relatively large diameter straight electrode. For these techniques, standard heavy-duty wire feeders for conventional GMAW can be used. One modification is needed, the addition of a wire straightening device.

If torch is designed for NGW-I, then major constraint in the design is thickness of the torch because torch has to move inside the joint gap. While incase of NGW-II this will not be the constraint but very thin wires cannot be used.

2.1 Characteristics feature of NG-GMAW torch for NGW-I process. [3]

i) Torch should reach up to the bottom of the n arrow gap: if torch is unable reach up to the bottom of the narrow gap then it leads to poor shielding behaviour.

ii) Torch should travel along the narrow gap without touching sidewalls and thus causing short circuit: Thickness of torch should be optimum to avoid any contact between side plates. In case of 10 mm narrow gap, the torch thickness should not more than 6 mm.

iii) Torch should ensure effective and reliable gas shielding to the weld pool and also prevent aspiration of air into the shielding zone: To get effective shielding inside the narrow groove (laminar flow of gas) is the major challenge in the design of the torch. Improper shielding leads to aspiration of air. To overcome this double shielding system is required in the torch design.

iv) Torch should not get overheated and it should able to carry the welding current. To avoid such problem torch should be internally water cooled, by constructing water channels. Torch body must be made from highly thermal conductive materials such as copper.

v) Torch body should be accept replaceable contact tip as and when it gets damaged in case of any burn back and due to improper welding variables.

2.2 Basic components of NG-GMAW torch.

2.2.1 Contact tube :

It is usually cylindrical or flat guide to direct electrode wire into the deep narrow groove. It is usually made of copper or its alloys. However in some case contact tube has been made from two tungsten plates, butt together with a hole between them for feeding the wire. To avoid short circuiting with the sidewalls of the groove, some research workers have insulated the guide with heat resistant materials, such as ceramic, Teflon etc. Normally the water cooling hoses and current carrying conductors are attached directly to the contact tube, so that the whole tube is electrically hot and insulation permits the torch to withstand heat.

2.2.2 Contact tip:

It is separate part of the contact tube. It is replaceable as and when it get damaged or worn out. It may be electrically insulated by ceramic. Ceramic shield may also used to preserve the water jacket of contact tube if melt back occurs. Melt back is the phenomenon wherein an arc climbs up the sidewalls and start burning between the sidewall and the hot contact tube. Contact tube may also destroy latter due to the close distance between them.

2.2.3 Shielding gas nozzles:

Nozzles are used to supply gas into the narrow groove, to provide reliable shielding for the molten weld pool. There are two type of shielding systems (a) Single shielding system (b) Double shielding system.

In case of single shielding system, there is a long copper tube attached to contact tube from both sides of the latter, this is called single shielding gas system. It may not work properly in a deep groove because of intense air sucking. This leads to formation of porosity in weld bead or poor weld bead quality, to overcome this problem double shielding system is preferred.

In case of double shielding system, secondary nozzle is added to supply secondary gas stream from both sides of the contact tube. Primary gas stream pressure can be used to improve the surface of the bead along the groove sidewalls.

2.2.4 Water cooling system:

NG-GMAW torch which is designed for the NGW-I technique, it must have water cooling system for following reasons.

a) Water cooling is used to dissipate the heat generated near and around the torch. Without it, torch become hot and it may damage conduit of the torch

b) Water cooling permits the torch to carry higher welding current.

2.3 Comparison between torches designed by different research workers.

Literature is available on NG-GMAW processes, but it is very difficult to get the detail about the design and fabrication aspects of NG-GMAW torch. Most of the authors has not discussed or highlighted the detail of NGGMAW torches. Mailn [3] has reported and discussed about NG-GMAW torches. In order to get proper design aspects of NG-GMAW torches, patent filed in the area of NG-GMAW torches all over the world have been referred [4,5,6].

Comparison has bee made between few patents on important aspects of torch design.

Table 2 : Comparison between different NG-GMAW torches

Variables for Comparison	US Patent no. 4,591,685 (by G.W. Hinger, Kent R.S. Crial [4]	US Patent no. 3,826,888 (by G.Garfield, C. H.Rout [5]	US Patent no. 3,992,603 (by R.w. Reynolds [6]
Assembly	Torch was made in three different parts, each part connected with other by non conductive pins. Orientation/ alignment of different parts with each other as well as with sidewalls have to be perfect because of the limitations of narrow gap.	Torch was made from single piece of copper block and copper tube.	Torch consists of an assembly.
Water Cooling	Total four different channels were provided for effective water cooling to reduce the flow of shielding gas and to avoid spatter sticking. Shielding gas flow rate : 42-61 lit/min.	Single water channel was provided at centre of the block for the optimum cooling.	Single water cooling tubes was provided for water cooling adjacent to the wire feed tube.
Insulation	Gas bars were made from the electrically non conductive materials or Gas bars should be insulated. Insulation was compulsory between gas bar and central bar. A coating of ceramic such as zirconium oxide required for protection against the short circuit for central bar.	Zirconium oxide coating is used for protection against short circuit. In order to prevent intermittent arcing as welding wire is fed down in a metal contact tube, an insulation (Teflon) liner is placed inside the wire feed tube.	Combination of graphite and aluminum oxide is used for protection against short circuit. Because of spring effect of wire, wire feed tube is made of molybdenum because of its high hardness and its high melting point.
Lack of Sidewall Fusion	Twisted wire has been used to prevent lack of sidewall fusion. Rotational movement of the arc is characteristic of twisted wire, not of the torch. Different diameter of twisted wire can be used.	Orifice contact tip is angularly oriented so that welding wire is adopted to pass there at an angle. Lack of sidewall fusion is controlled through single layer double pass technique. After each pass wire directed towards the each sidewall. Orifice of contact tip is angularly oriented, so it required different contact tips for different diameter wire.	Single layer double pass technique is used to controlled lack of sidewall fusion.

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Design	Two plugs provided for water circulation in one gas bar. Two gas bars required four plugs. Increased number of plugs increases complexity in design of the torch and fabrication by drilling. Figure 2(a) Shows design of Torch	Design was simple. Figure 3 (a) shows design of Torch Figure 3 (b) plan view of torch Figure 3 (c) Torch inside the joint gap	Separate supply has given for shielding gas bar. Design was comparatively simple than US Patent no 4,591,685. Figure 4(a) Shows design of Torch.
Shielding	Gas bars were equipped with a removable diffuser plate. The diffuser plate has flanged end which incorporates with a notch in the gas bars to hold the diffuser plate in position. A mean of fastening such as screw is used to attach the diffuser, as shown in figure 2(b)	Front and rear end of body for purpose to the mounting a front shield and inert shielding gas. Both shield have porous sintered bronze diffuser, which pass the inert gas to the weld area.	Flat tubing was provided in the assembly adjacent to wire feed tube, through which inert gas directed to the weld area so as to reduced oxidation of weld metal. Figure 4(b) Sectional view of torch. Figure 4 (c) view of torch inside the joint gap.
Shielding Gas Device	Gas handling equipment, those adjacent to the welding arc, may still be susceptible to damage from the spattering of metal as well as heat and requires periodical replacement.	Gas handling equipment (porous sintered bronze diffusers) were adjacent to the welding arc. There was no mention about susceptibility of damage from the spatter, heat and about periodical replacement shielding device.	Gas handling equipments were adjacent to the welding arc. There is no mention about susceptibility of damage from the spatter, heat and about periodical replacement shielding device.
Mounting Block	Special mounting bar preferably from an electrically non conductive materials so that two gas bar and central bar electrically insulate from each other. Matching connections are required for passing supply line in mounting block.	Entire torch was made from single piece. There was no mention about the mounting block.	Mounting holes were provided to allow fastening of the torch to a weld carriage assembly for automatically propelling the torch along the gap between the plates to be welded.
Thickness of Torch and Joint Gap	Thickness of torch in the range of 8.95-11.25 mm. No information about gap.	No Information	Torch thickness 4.7 mm and joint gap 6.35 mm.
Comments	Twisted wire is not available commercially. Thickness of torch is high. In fact the challenge and novelty of the torch design lies in reducing the thickness of the torch.	Torch design is suitable for single layer double pass, as shown in figure 3 (d)	Complex insulation provided to the torch body. Torch design is suitable for single layer double pass.

2.4 Latest NG-GMAW Torch Design by SPA Welding Systems, Germany. [7]

Single part: Copper gas nozzle : That is flattened at the bottom and coated with an anti-spatter coating **(Fig. 5a)**

Two part : Current contact tube: Which is coated with a ceramic current insulating coating and protection cap made out of thermal shock resistant, spatter repelling ceramic.**(Fig. 5b)**

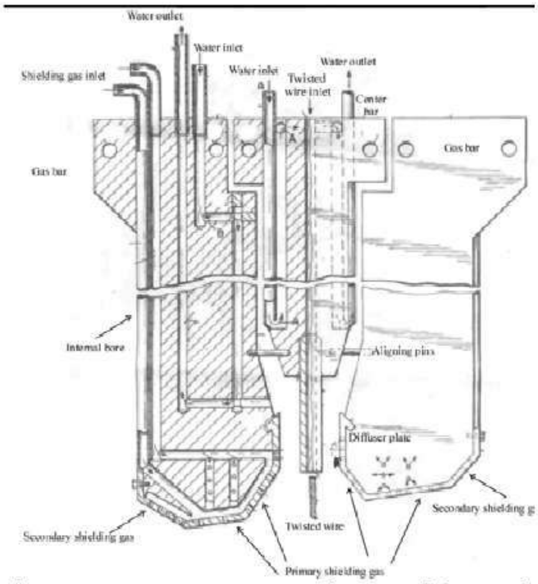


Fig. 2a : Narrow Gap Gas Metal Arc Welding Torch

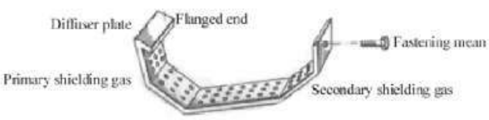


Fig. 2b : Diffuse Plate of NG-GMAW Torch

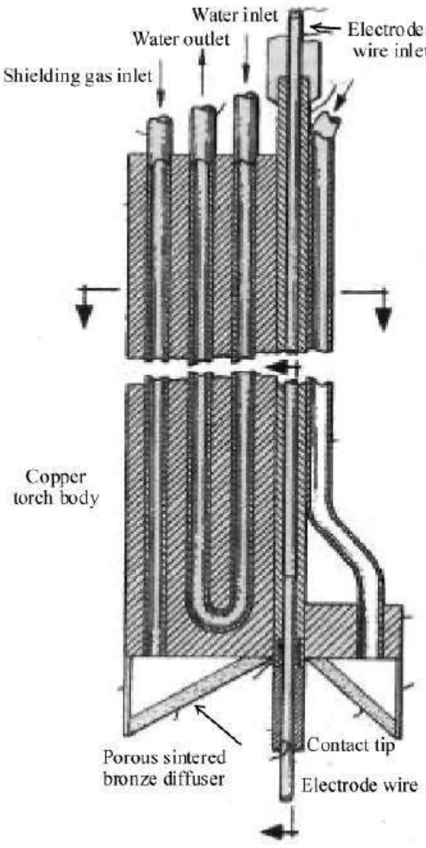


Fig. 3a : NG-GMAW Torch

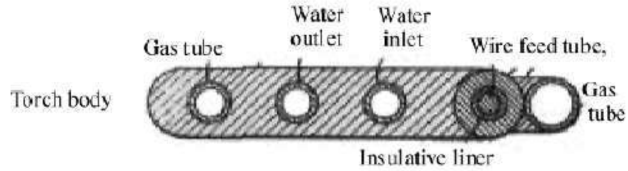


Fig. 3b : Plan view along line 2-2 of fig. 2.10a

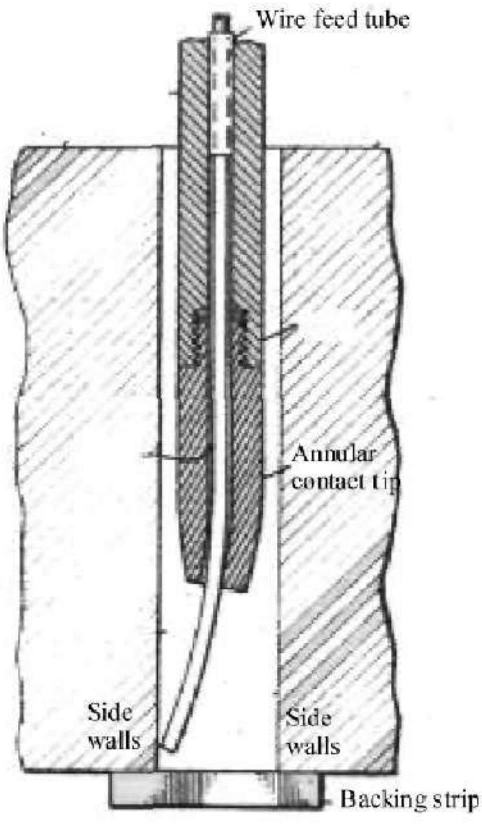


Fig. 3c : NG-GMAW torch inside the joint gap

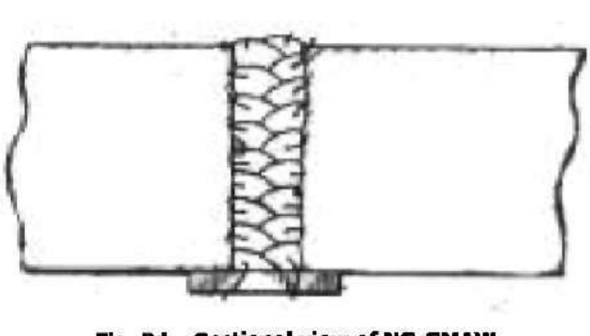


Fig. 3d : Sectional view of NG-GMAW joint (Herringhome pattern)

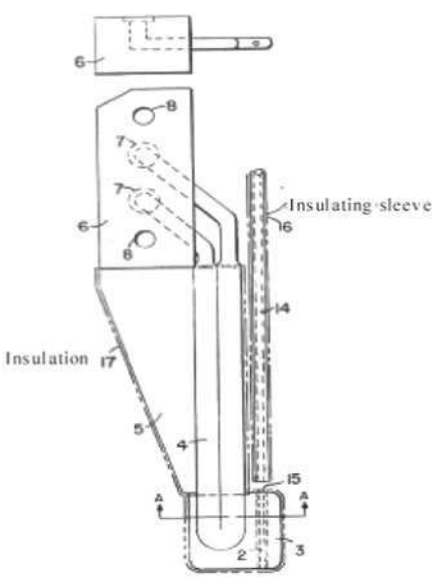


Fig. 4a : Side view of NG GMAW torch

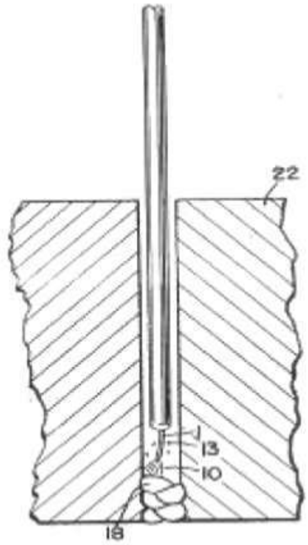


Fig. 4c : End view of torch inside the joint gap between two partially welded plates.

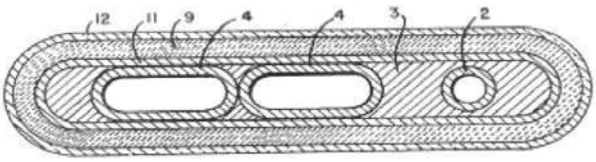


Fig. 4b : Sectional view of torch at A-A

1. Electrode wire
2. Wire feed tube (Molybdenum)
3 End piece of tube
4. Copper water cooling tube
5 Steel stiffener
6 Supporting block
7 Holes
8 Mounting holes
9. Alumina coating
10 Hostile environment
11 Undercoating of sprayed metal
12 Coating of finely divided graphite.
13 Spatters
14 Wire feed guide tube
15 Torch tip
16 Insulating sleeve
17 Insulation
18 Weld bead
19 Wire feed mechanism
20 Motor
21 Flat tubing for shielding gas
22 Sidewalls.

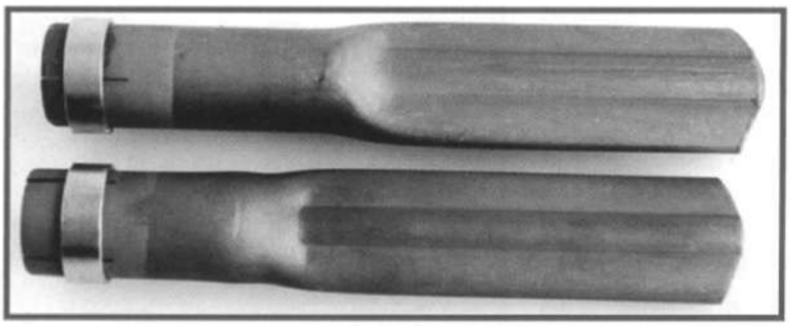


Fig. 5a : Single part - Copper Nozzle (Flattened at bottom)

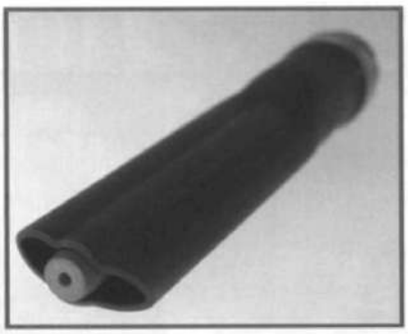


Fig. 5c : Assemble of torch design

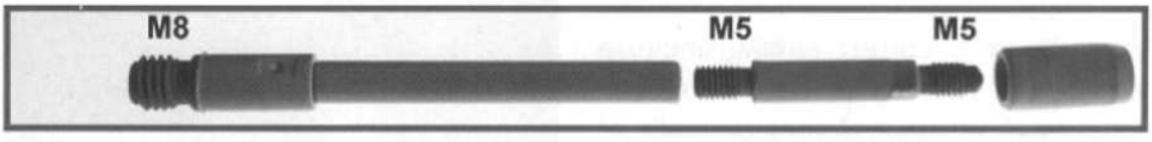


Fig. 5b : Two parts - Current contact tube

[Extension screwed into the welding torch neck (left), the quick -change actual current contact tube (centre) and the ceramic protection cap (right)]

Mounting of the two-part current contact tube to the torch neck makes no difference to a common current contact tube, it is screwed on with a usual M8 thread. The contact tip is screwed on the contact tube with a M5 thread. Here the transfer of welding current on the wire electrode is happening. At last protection cap is screwed on top. (**Fig. 5b**)

The flattened gas nozzle, is slipped or screwed on, depending on the design of the torch. Due to the current insulating coating of the current contact tube the size of the gas nozzle could be reduced tremendously, the width is only 27 mm and the thickness only 11 mm. The ceramic protection cap on the current contact tip protrudes the gas nozzle at 2 to 3 mm. This improves additionally the sight on the welding arc. (**Fig. 5c**)

The shielding gas passes, parallel to the current contact tube, cover the weld pool beneath and beyond the welding arc spot and lead the shielding gas close to the weld. Because of this precise gas conduction the current contact tube can be longer than usual, in doing so lengths up to 150 mm are customary. For some application current contact tube up to 300 mm long are indispensable. Therefore start-on respectively run-off plates as well as welding units with longer adjustable pre -weld gas flow time are recommended. Thus, pores, as consequence of insufficient supply of shielding gas, can be avoided. It has mentioned that, there is no need to rethink the shielding gas type or the gas flow. All conventional type of shielding gas can be used and gas flow from 10 to 15 l/min can be adjusted as usual.

With this torch design, welding in flat, vertical up and vertical down position is possible. As the shape of gas nozzle and its gas flow designed for narrow gap welding, it is advisable to weld to weld the final pass with conventional gas nozzles. This counteracts the occasional pore formation by insufficient gas supply on the usual broader final pass.

3.0 NARROW GAP-GAS TUNGSTEN ARC WELDING (NG-GTAW) TORCH DESIGN

NG-GTAW process involves use of insulated water cooled contact tube having non consumable tungsten electrode. GTAW process requires separate addition of filler metal to provide adequate weld metal to fill the joint gap. Filler metal can be added either manually but mostly through automatic means. Automatic filler wire feeding may be used either as cold wire or hot wire. Process is more suitable for special metals (Stainless steel, Titanium and its alloy and Aluminium) rather than for routine metals. **Fig. 6** shows the working principal of NG-GTAW [8].

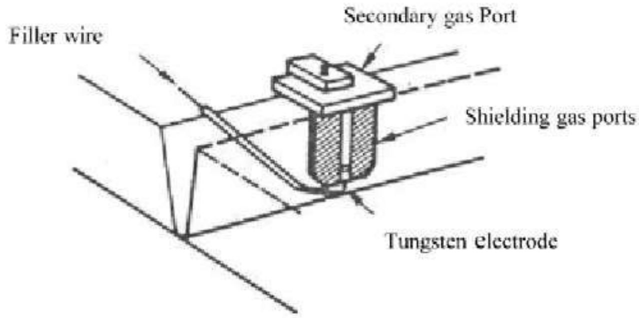


Fig. 6 : Working principal of NG-GTAW [8]

3.1 NG-GTAW torches

NG-GTAW torches are similar to those for conventional GTAW. However, the contact tube for the tungsten electrode and the guide for filler wire are extended to reach the bottom of the deep narrow groove. In a hot wire, the wire contact tip is insulated from the electrical ground and is the last point of physical contact to the wire before the latter enters the weld pool.

For material up to 40 mm thickness, a conventional TIG machine torch can be used with the gas shielding nozzles above the top surface of the joint. For greater thickness a narrow gap GTAW torch is used with a secondary surface gas box to ensure adequate shielding [9]. The primary nozzles provides the central flow of the gas around the tungsten electrode, while the secondary nozzle provides side flow in front and rear areas with regards to the direction of welding. However such arrangement adequately protects the tungsten electrode, the wire and the weld pool only in the confinement of the groove, while the top passes require an additional protection in the form of a shielding box (triple shielding system) located above the work piece [3]. Sidewall penetration control can be obtained by oscillation of the tungsten electrode mechanically or by magnetic filed. [8] **Fig. 7** show NG-GTAW torch.

Torches specifically designed for NG-GTAW are usually elongated as shown in **Fig. 8**. The shielding gas is delivered to rectangular slots either side of the electrode and in addition gas may be supplied through holes in the side of the blade.

In NG-GTAW, not only torch linear movement has to be controlled accurately but arc length has to be maintained within limits so to control the heat input.

Mitsubishi Heavy Industries, Japan had developed NG-GTAW process for welding heat exchanger. **Fig. 9** shows the new NG-GTAW welding torches used for the manufacturing of heat exchanger [10].

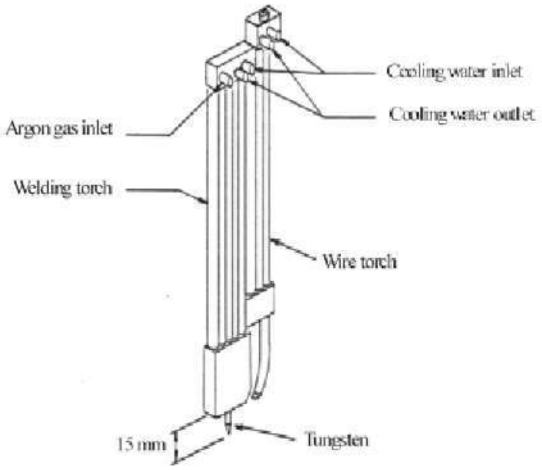


Fig.7 : NG-GTAW torch designed by Malin V.Y [8]

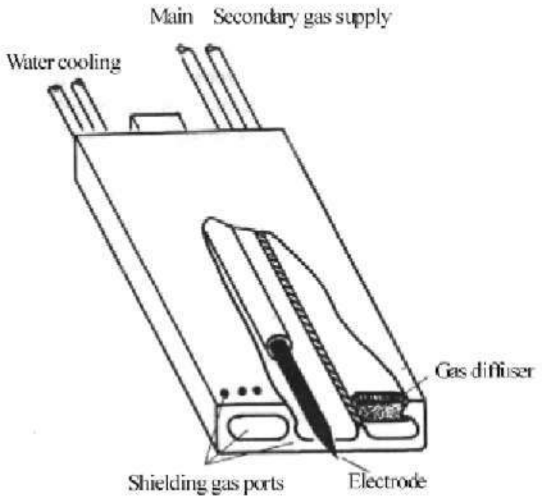


Fig.8 : NG-GTAW torch designed by Render G.S [9]

3.1.1 Design 1 : Shield box type : The shield box torch ensures the shield at the groove bottom by providing shield gas discharge ports before and after the tungsten electrode. In addition, to prevent air inclusion, a shield box is installed to supply shield gas inside the groove in the curtain fashion.

3.1.2 Design 2 : Shield cap torch : The shield cap torch has a water-cooled shield cap at the torch tip so that shield gas, first discharged into the shield cap to create a near –laminar flow, is then discharged to the groove bottom in such a way as to envelop the tungsten electrode. It provides excellent shield at all times with constant shield gas flow, regardless of the groove depth.

3.1.3 Design 3 : Rotary electrode torch: The rotary electrode torch is an improvement of the shield cap torch. The tip of the tungsten electrode is slanted to tilt the arc relative to the tungsten electrode axis. The rotation or repeated rotary motion in opposite direction (called oscillating rotation) of tungsten electrode constitutes oscillation welding without the motion of the torch itself. A motor for the oscillating rotation of the electrode, a potentiometer for detecting the rotation position of the electrode and a belt for conveying the motor motion to the electrode are installed at the top of the torch. It has mentioned that rotary electrode torch design can be used for narrow gap welding in vertical, horizontal, overhead or all position, as well as in flat position.

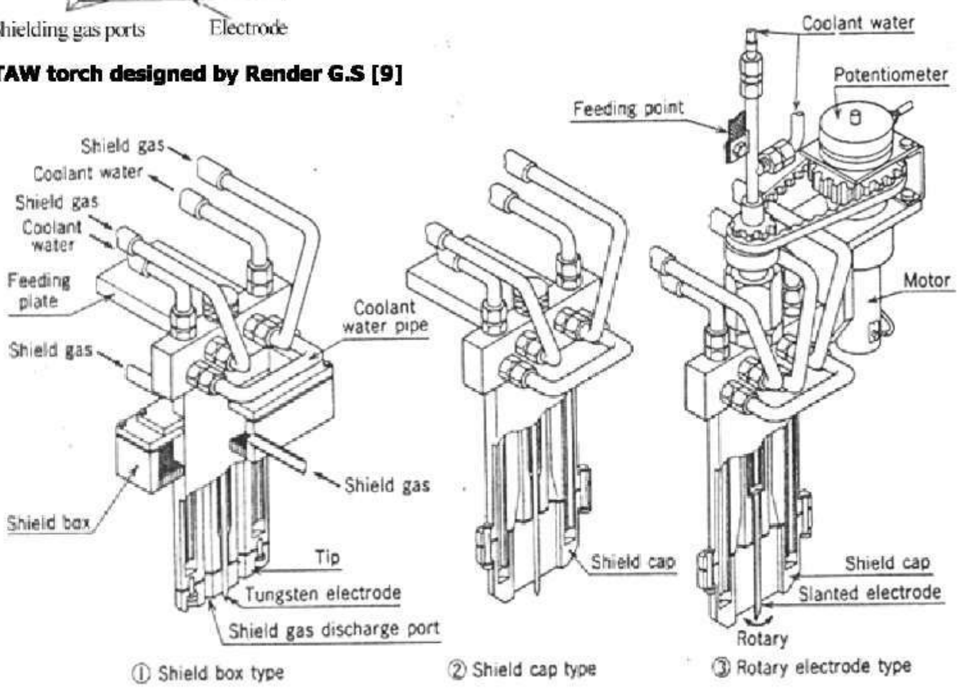


Fig. 9 : Different NG-GTAW Torch designs

4.0 NARROW GAP - SUBMERGED ARC WELDING (NG-SAW) TORCH DESIGN

NG-SAW process involves separate addition of the flux through a hopper provided near to a contact tube. Arc is created and molten metal is generated under the flux cover, which melt partially and solidify. After each pass removal of powdered as well as melted and solidified flux becomes necessary. **Fig. 10** show the working principal of NG-SAW

4.1 NG-SAW torches

NG-SAW torches are specially designed. However, they are much simpler than those for NG-GMAW, since they are not subjected to heat radiation and spatter and do not require complicated gas shielding systems. In order to extend the range of plate thickness to be welded, one or more torch extensions are attached to the contact tube. Utilisation of thick wire leads to extensive wear of the contact tip which may impair current transfer. To avoid this, wire is pressed to the contact tip by spring tension. Generally service life of the tips depends on welding wire type and wire surface quality. Minimum service life of a tip at feeding by means of smooth roller is 50 and 100 hours for small nozzles and massive tip respectively [12]. A flux nozzle is also inserted into the groove to supply flux. The nozzle is usually a long, flat tube attached to the contact tube in front of the latter.

4.1.1 Characteristics of the NG-SAW torch

P. Radic and et al [12,13] had designed different types of NG-SAW torches for welding of material from 150 mm to 450 mm in thickness. They have also suggested chief features of NG -SAW torch.

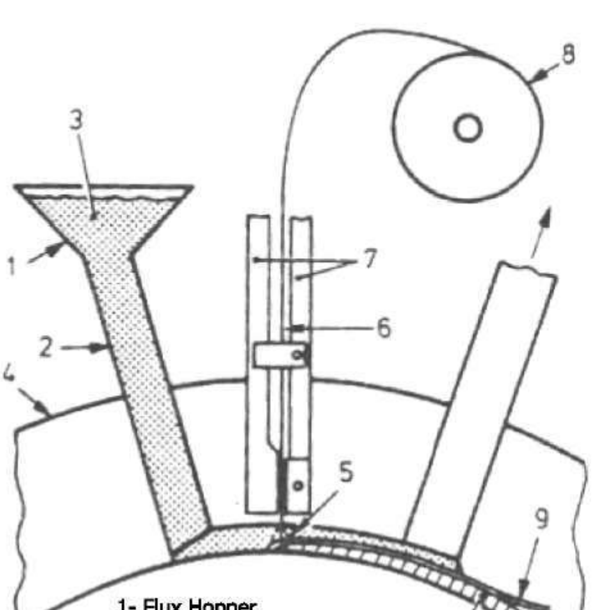
i) Nozzle tip as well as load carrying parts of the torch body should be at parallel position to the groove.

ii) Side surface of the nozzle (which is in close vicinity of the material to be welded) should be covered by a slight, uniform, insulating and high temperature resistant layer. This protective layer prevents failure during contact of the nozzle with base metal. (**Fig. 11**, position 3 & 4)

iii) Water cooling should be provided in one massive part of the torch body (position 4). It is the upper part of the nozzle body which does not come into contact with the weld gap during welding.

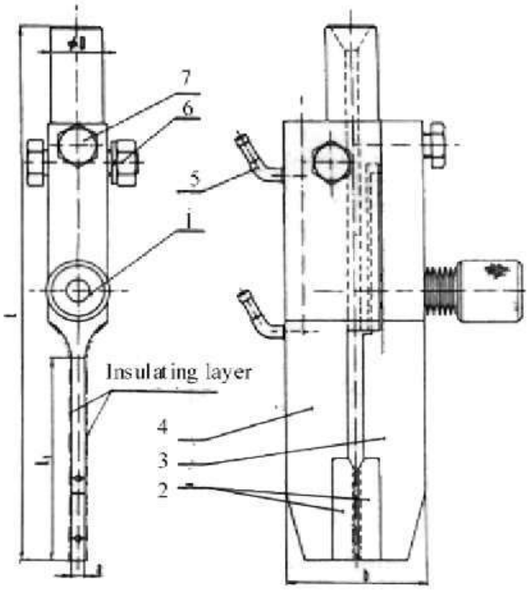
iv) The nozzle should serve for welding with wire 2 to 4mm in diameter in dependence to type of special tip (**Fig. 11**, position 2).

v) The nozzle (knife shape-as shown in **Fig. 12**) can be used



1- Flux Hopper,
2 - Flux feed tube,
3 - Flux,
4 - Component being welding,
5 - Arc,
6 - Welding Wire,
7 - Nozzle,
8 - Payoff reel,
9 - Slat,
10 - Weld Metal

Fig. 10 : NG-SAW Welding Equipment [12]



1 Pressing System of welding nozzle to welding wire
2 Special exchangeable tip
3&4 Load carrying parts of nozzle body
5 Cooling system of welding nozzle
6 Welding current supply to the nozzle
7 Compensating screw [12, 13]

Fig. 11 : Block diagram of a narrow gap submerged arc welding nozzle

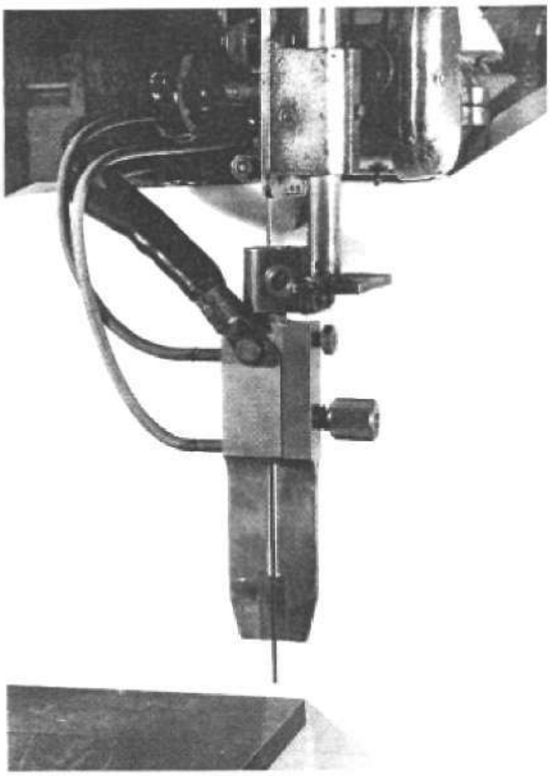


Fig. 12 : Knife shape welding nozzles mounted in welding equipment [12,13]

for joining material with maximum 150 mm in thickness with joint gap in range of 12 mm and above and it should assure high stability of the welding process during several hours of operation.

5.0 DISCUSSION:

Thickness of the torch is major design parameter. In order to avoid short circuiting of torch with sidewalls, thickness should be as less as possible. Many researchers have used ceramic coating on the torch body to avoid short circuiting with sidewalls [4, 5, 6, 7]. Contact with the sidewalls could be avoided by taking precaution in torch movement as well as with correct selection of welding variables.

It is most challenging to secure proper shielding (laminar flow of gas) in such a narrow gap. Important task for NG-GMAW is to supply gas into the very narrow deep groove to provide a reliable shield for the molten weld pool without sucking air into it. Conventional torch (GMAW, GTAW) consist of gas cup of the diameter of 16 -18 mm as well diffuser to get proper shielding condition, here thickness is the major constraint.

For welding very thick plate, the standard system of gas shielding was found unsatisfactory under such condition, it is usual to mount a gas box over the joint. Gas box is flexible skirt, to which seal the top edges and to direct side jets into the joint to prevent aspiration of air into the gas shield. Researcher have used either side flow technique to weld thick sections, which will replace at top of joint with gas box or combination of side flow jet as well as gas box to shield welding area.[14]

It has been reported in one of the study on narrow gap MIG welding by S. Minehisa that the flat type of nozzles/torch when used in narrow grooves except near the plate surface proved good performance. Near the plate surface, air contamination will increase and another type of shielding nozzle shall be app lied at the plate surface. [15]

Devices which are use to get coherent streaming are mesh screens, porous materials and fibrous packing. Principal function of these devices is to reduce the level of irregularities in the gas flow [1 6]. The degree of control impose on the gas is related to finesses and close spacing of the pores rather than thickness of the barrier. In general, the smaller the pore size the greater is the control over the gas going through it.

A comparison between the performance of fine mesh screen, fibrous packing and porous material has been studied by E. F. Gorman. [17]. Fine mesh screen give uniform distribution of gas velocity because of the uniformity of size and spacing of the pores. The fibrous packing and porous compact frequently produced irregular distribution unless particular care was taken during their construction to ensure uniform gas permeability. These porous walls act on the gas to focus it's into a beam much as a glass lens acts in shaping a beam of light.

6.0 CONCLUSION :

For NGW welding processes other than lack of sidewall fusion problem, major challenge is lie with design and development of NGW torch for different welding application and processes. Standard torches for NGW are not available routinely in the market. Torches for NGW are specially designed (custom made) for various NGW applications. Design of torch will differ from processes to process and application to application.

Authors have already published few papers in the area of NG-GMAW, it includes, the development of NG-GMAW torches for 50mm carbon steel plate [18,22,23], authors had also studied the effect of residual magnetism on sidewall fusion in NG-GMAW [19], in addition to above investigation authors had designed the torch oscillation system and studied effect of torch oscillation parameters on mechanical and metallurgical properties of NG-GMAW welds [20-21,24-25].

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