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NARROW-GAP SUBMERGED-ARC WELDING WITH A MULTIPLE-WIRE ELECTRODE

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The article treats a completely new variant of narrow gap welding. First, nine different welding heads for narrow gap welding are described and shown schematically. The core of the article is devoted to a description and schematic representation of a unit for welding with twin-wire and triple-wire electrodes respectively and a description of technology for narrow-gap submerged-arc welding of thick workpieces. A macrograph of the weld is shown too, and basic optimum welding parameters for attaining a quality weld are given. Finally, main advantages of multiple-wire narrow-gap submerged-arc welding are stated.

Key words: *submerged arc welding, twin-wire electrode, triple-wire electrode, narrow gap*

Elektrolučno zavarivanje pod prahom višestrukom žičanom elektrodom u uskom rasporu. U članku je prikazan potpuno novi način zavarivanja u uskom rasporu. Najprije je opisno i shematski prikazano devet različitih glava za zavarivanje u uskom rasporu. Glavni dio članka predstavlja opis i shematski prikaz uređaja za zavarivanje dvostrukom i trostrukom žičanom elektrodom, kao i opis tehnologije zavarivanja debelih radnih komada u uskom rasporu pod prahom. Isto tako prikazan je makro obrus vara i navedeni su osnovni optimalni parametri za postizanje kvalitetnog vara. Na kraju članka navedene su glavne prednosti zavarivanja u uskom rasporu sa višestrukom žičanom elektrodom pod prahom.

Ključne riječi: *elektrolučno zavarivanje pod prahom, dvostruka žičana elektroda, trostruka žičana elektroda, uski raspor*

INTRODUCTION

Welding of rather thick workpieces may prove to be quite a problem in practice. Various manufacturers have found different solutions to the problem. These solutions are often related with the kind of material used, mechanical properties of the welded joint required, accessibility of the welding area and the number of products to be made.

Conventional one-side welding of a single-V butt weld entails high costs related to workpiece preparation, consumption of filler material and welding time. We can cut down on these costs by double-side welding and making a double-V butt weld. The greatest lowering of costs, however, is achieved by narrow gap welding. In this case the consumption of filler material and energy is the lowest and the time for weld edge preparation and welding is the shortest.

In practice several types of welding units for narrow gap welding are known at present. They are divided regarding the welding process (tungsten inert-gas welding, metal-arc inert-gas welding, metal-arc active-gas welding, submerged-arc welding, electro-slag welding), the number of wires used (single wire, two electrodes, twin electrode), and the number of passes in a layer (single-pass, double-pass).

Welding with a multiple-wire electrode is a new technique used with narrow gap welding which has not been discussed in literature yet. The present article treats fundamental characteristics of narrow-gap submerged-arc welding with a multiple-wire electrode.

LITERATURE REVIEW

Narrow gap welding of thicker workpieces has been known and treated in literature for three decades. The first publications in this field can be traced in the sixties [1-5].

Studies on narrow gap welding have continued all the time. In numerous references various models of units for various welding processes have been found. For an easier approach the literature review and the description of narrow gap welding units will follow according to various welding processes.

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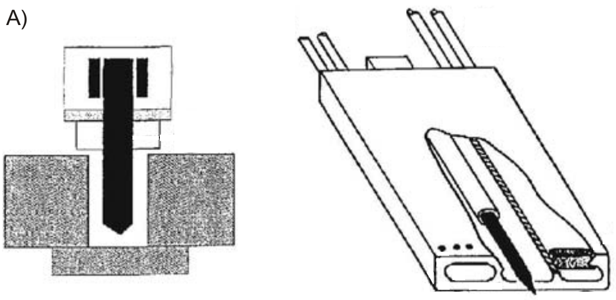
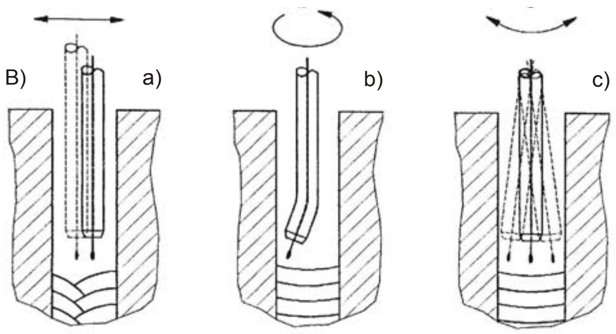
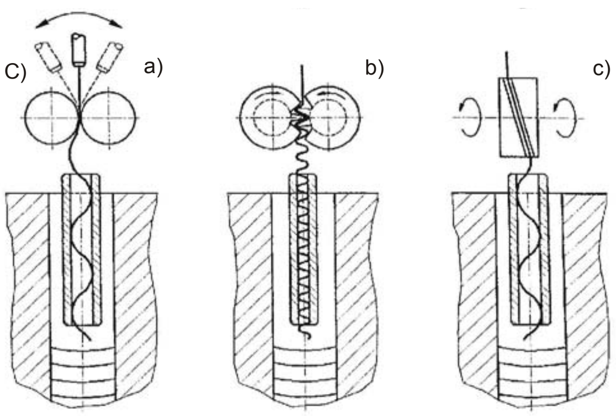


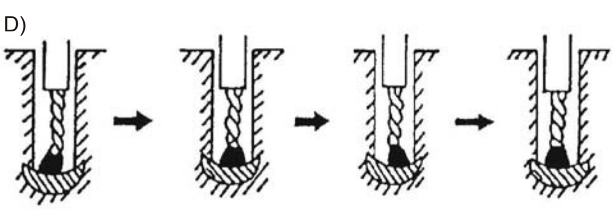
Welding head for narrow-gap TIG welding (right) and conventional welding head for narrow-gap TIG welding of thinner workpieces (left)
Glava za TIG zavarivanje u uskom rasporu (desno) i klasična glava za TIG zavarivanje u uskom rasporu tanjih radnih komada (lijevo)



Narrow-gap MIG/MAG welding
MIG/MAG zavarivanja u uskom rasporu



Narrow gap welding with a wire which deforms before entering the contact tube
Zavarivanje u uskom rasporu žicom koja se deformira prije dolaska u vođicu žice



Narrow gap welding with a wire deformed "around" its axis
Zavarivanje u uskom rasporu žicom deformiranom "oko"njezine osovine

Figure 1. **Different equipment for narrow-gap welding**
Slika 1. **Različita oprema za zavarivanje u uskom rasporu**

Narrow-gap TIG welding is suitable for welding of workpieces having thickness up to 30 mm. Welding is carried out in a neutral-gas shielding with hot or cold wire addition. It is possible to weld with a conventional TIG welding unit (Figure 1. A) up to a thickness of 12 mm, whereas a special welding head has to be constructed for workpieces thicker than that [6].

At any rate in TIG welding with a hot wire higher productivity and better energy efficiency are achieved than in TIG welding with a cold wire [7- 8]. A special application of narrow-gap TIG welding is orbital welding of pipes [7, 9]. Ellis [10] gave a description of a narrow-gap TIG welding unit for a thickness up to 200 mm.

MIG and MAG welding processes differ in the gas which provides the shielding and the purpose. MAG welding is used for welding of low-alloy and medium-alloyed steels. The shielding is provided by an active gas, i.e. CO_2, or by its mixture with Ar, He and O_2.

MIG welding in an inert gas atmosphere (Ar, He) is used for welding of non-ferrous metals and high-alloy steels.

Conventional welding with a single-wire electrode may be carried out with a straight wire or a wire deformed at the contact tube outlet to the left workpiece and to the right workpiece by turns [11-13] (Figure 1. B a). Productivity of welding with a single-wire electrode is comparatively low. Higher efficiency may be achieved by a twin-wire electrode or with two wires connected each to its own power supply. The wires in the contact tube are arranged in the way to travel parallel to each other or one after another in the welding direction, i.e. in the gap direction [14-16].

Welding with a rotating or oscillating arc and wire belongs to the second group of narrow gap welding processes [17-18]. With a rotating arc the centre of wire rotation is located in the contact tube. The welding wire deforms a little at the contact tube outlet so that the wire extension tip and the arc make a regular circle. The circle diameter depends on welding parameters and should agree with gap width and welding speed *v* (Figure 1. B b).

Welding with an oscillating wire and arc in the narrow gap is shown in Figure 1. B c [19].

The third group of narrow-gap MIG/MAG welding units consists of various systems which make possible simultaneous wire feed and curving into various shapes (Figure 1. C).

Through the contact tube outlet a deformed wire is fed which ensures arc oscillation from the left face to the right one and vice versa [13, 18, 20-22].

For narrow gap welding not only the above-mentioned deformed wire may be used but also a wire deformed "around" its axis, i.e. snaked wire, as shown in Figure 1. D [23]. The wire deformed "around" its axis is formed actually of two mutually interwoven wires. With the fusion of both wires the arc rotates around the centre of both wires and ensures good fusion of both fusion faces of the narrow gap.

Submerged-arc welding is a high-productivity process for joining materials with high energy and filler-material efficiencies. In practice a number of submerged-arc welding units are known.

This is a well known procedure also for narrow gap welding and in practice it is often used for very thick workpieces (up to 670 mm) [24]. As with MIG/MAG welding processes also with submerged-arc welding various types of narrow gap welding units exist [25].

DEVELOPMENT OF A WELDING HEAD FOR NARROW GAP WELDING WITH A MULTIPLE-WIRE ELECTRODE

In welding with a multiple-wire electrode several wires are arranged in a joint contact tube. All of them have the same wire feed speed v_w, a joint regulation and are supplied by a single power source. Figure 2. shows a schematic multiple-wire electrode welding unit.

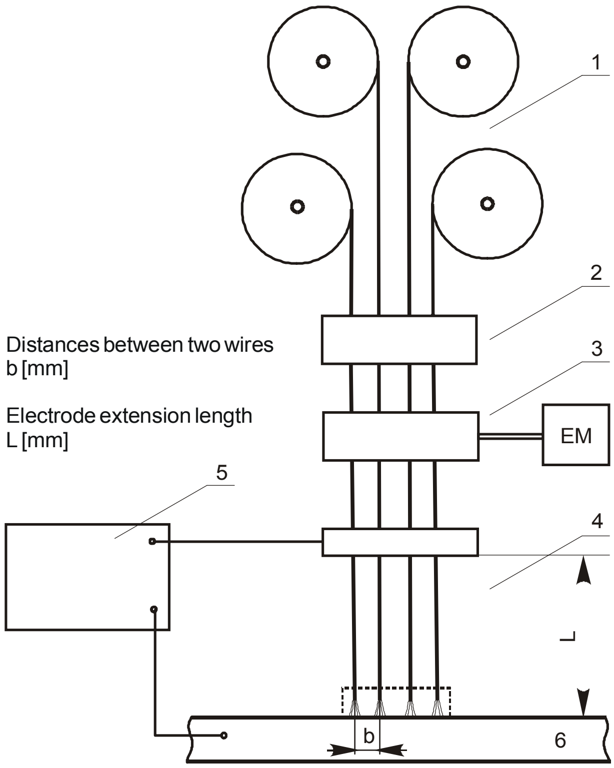


Figure 2. **Schematic representation of a unit for welding with a multiple-wire electrode: 1 - wire spools; 2 - straightening mechanism; 3 - wire feed system; 4 - contact tube; 5 - power source; 6 - workpiece**

Slika 2. **Shematski prikaz uređaja za zavarivanje višestrukom žičanom elektrodom: 1 - kalemi za žicu; 2 - ravnalni mehanizam; 3 - sistem za dovod žice; 4 - vođica žice; 5 - izvor struje; 6 - radni komad**

Wires in the joint contact tube may be arranged in various ways, i. e., in a line, in a triangle etc.

Development of a contact tube for twin-wire electrode welding

First studies of narrow gap welding were made with a unit permitting simultaneous welding with two wires. The wires were fed through a contact tube as shown in Figure 3.. For optimum welding not only welding parameters and wire extension length *L* but also the distance *b* and the angle between the wires at the contact tube tip are very important.

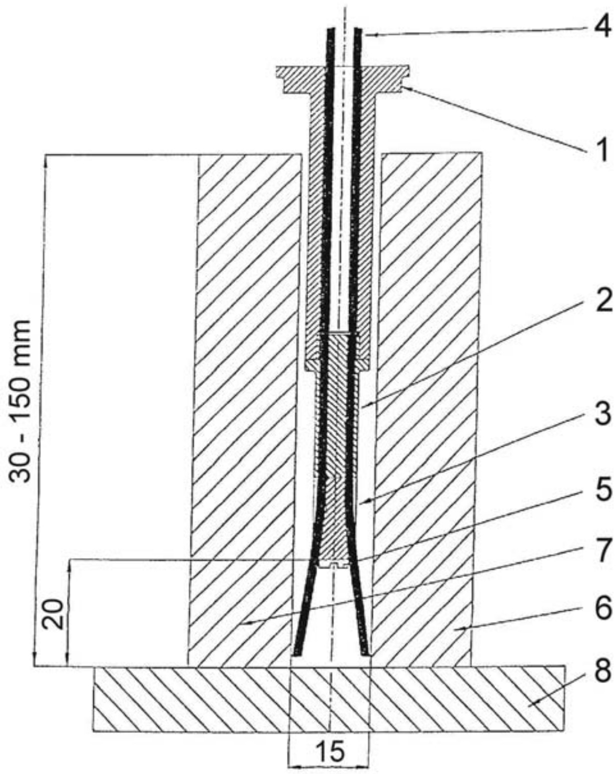


Figure 3. **Welding head for narrow gap welding with a twin-wire electrode: 1 - tube supporting structure, 2 - contact tube, 3 - wire-guide nozzle, 4 - welding wire, 5 - screw, 6 - workpiece, 7 - workpiece, 8 - backing bar**

Slika 3. **Glava za zavarivanje dvostrukom žičanom elektrodom u uskom rasporu: 1 - nosač cjevnog kontakta, 2 - cjevni kontakt, 3 - vođica žice, 4 - žica za zavarivanje, 5 - vijak, 6 - radni komad, 7 - radni komad, 8 - podloga**

With optimum parameters mentioned before a stablee welding process and qualitynarrow gap welds may be obtained. Very simple but efficient criteria for quality welding are the shape and size of the rounding in points 1 and 2. in Figure 4..

If in points 1 and 2 (Figure 4.) a nice rounding is obtained, it is with great certainty that we may expect a quality welded joint. It is only under the conditions shown in Figure 4. that both narrow-gap fusion faces may be fused well, mixing of the filler material and parent metal will be good, slag will float to the surface of the weld pool and will be easy to remove from the weld surface after welding.

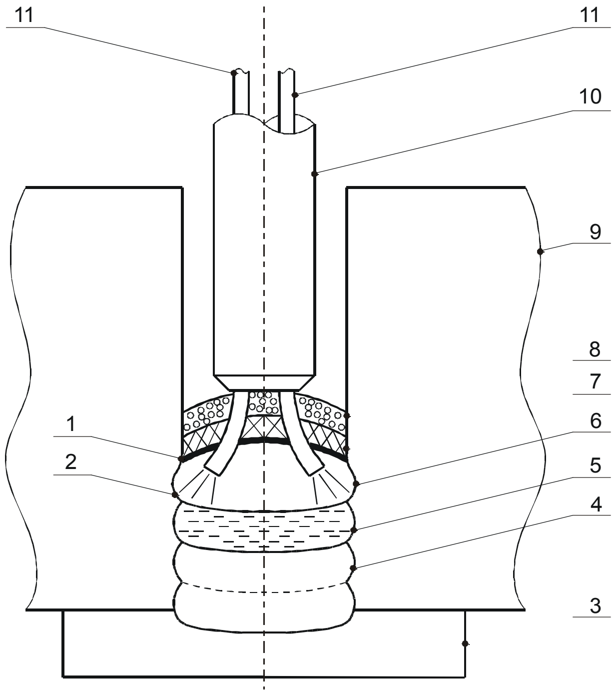


Figure 4. **Contact tube for narrow-gap submerged-arc welding with a twin-wire electrode: 1 - point 1, 2 - point 2, 3 - root backing, 4 - solified weld deposit, 5 - weld pool, 6 - welding cavity, 7 - slag, 8 - flux, 9 - workpiece, 10 - contact tube, 11 - welding wire**

Slika 4. **Vođica žica za elektrolučno zavarivanje pod prahom u uskom rasporu dvostrukom žičanom elektrodom: 1 - točka 1, 2 - točka 2, 3 - podloga, 4 - očvrsnuti materijal zavara, 5 - kupka taline, 6 - šupljina kod zavarivanja, 7 - troska, 8 - prah, 9 - radni komad, 10 - vođica žice, 11 - žica za zavarivanje**

Development of a contact tube for triple-wire electrode welding

In welding with a triple-wire electrode the wires in the contact tube are arranged in the shape of a triangle (Figure 5.). The first wire is located in the middle of the contact tube and of the narrow gap and shifted a little in the welding direction. The remaining two wires are guided through the contact tube similarly as in welding with a twin-wire electrode.

For optimum welding results, the distances b_1 and b_2 are important. The distance b_2 has to be greater than b_1. All the wires should build a joint welding cavity. Current intensity I, arc voltage U, wire extension length L and the type of flux used should be such as to ensure spray material transfer from the wires through the arc. Only the spray transfer permits good penetration of fusion faces and a favourable structure of the weld metal. For a quality weld produced by welding with a triple-wire electrode a similar law applies as in welding with a twin-wire electrode. This is shown in Figure 5. It is extremely important that the arrangement of both wires travelling parallel with both narrow-gap fusion faces is optimum. This includes an optimum distance between the wires (b_1 and b_2), an optimum wire diameter d and an optimum angle between the wires when they are leaving the contact tube. The wire travelling as the first in the welding direction (Figure 5.) serves only to fill the centre of the weld.

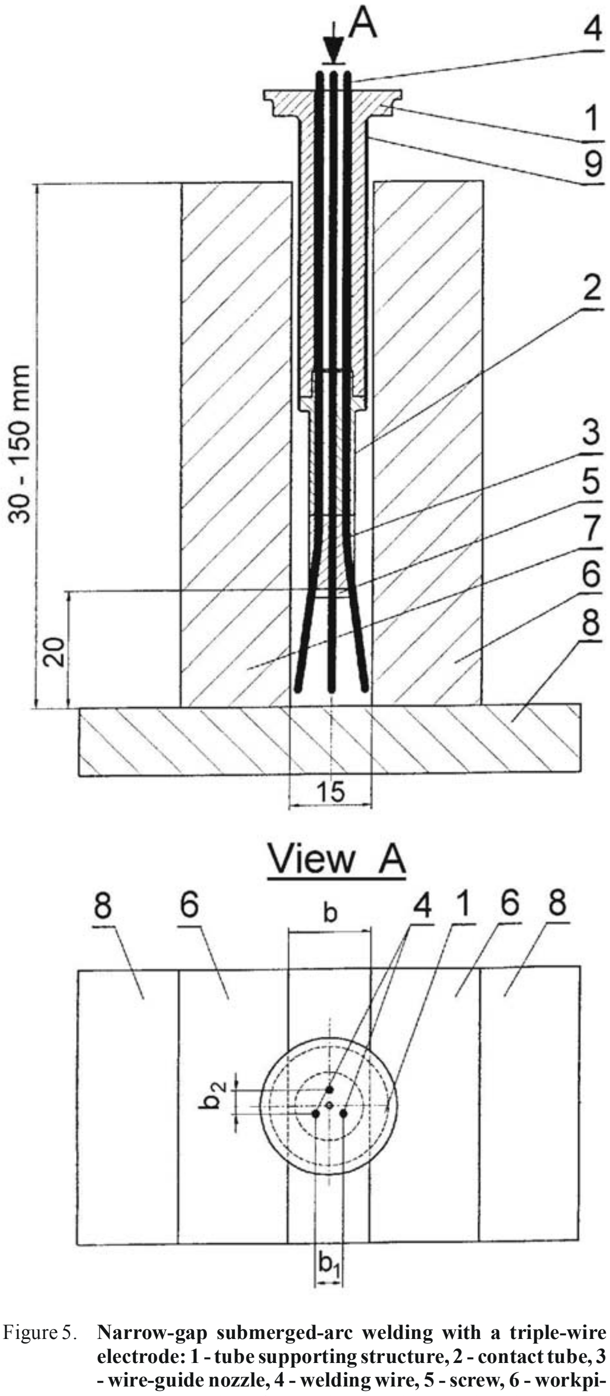


Figure 5. **Narrow-gap submerged-arc welding with a triple-wire electrode: 1 - tube supporting structure, 2 - contact tube, 3 - wire-guide nozzle, 4 - welding wire, 5 - screw, 6 - workpiece, 7 - workpiece, 8 - backing bar, 9 - electrical insulation**

Slika 5. **Elektrolučno zavarivanje pod prahom u uskom rasporu trostrukom žičanom elektrodom: 1 - nosač cjevnog kontakta, cjevni kontakt, 3 - vođica žice, 4 - žica za zavarivanje, 5 - vijak, 6- radni komad, 7 - radni komad, 8 - podloga, 9 - električna izolacija**

PRACTICAL WELDING

Practical welding tests were carried out in the welding laboratory of the Faculty of Mechanical Engineering of the University of Ljubljana. The first studies were to find the optimum distance between the wires *b*, angle at which the wires should be leaving the contact tube and welding parameters. The best results were obtained with wires of 1.2 mm and 1.6 mm in diameter *d*. The distance between the wires *b* was 5 mm in both cases. The wire extension length *L*, i.e. the distance between the contact tube and the workpiece, was 20 mm in both cases. On the basis of these data a 14 mm wide narrow gap was selected with the two fusion faces parallel and perpendicular to the surface of the workpieces. In order to find and confirm the optimum parameters a number of practical tests in welding in various narrow gaps was made. Figure 6. shows a macrosection of the weld produced in 14 mm gap with a twin-wire electrode.

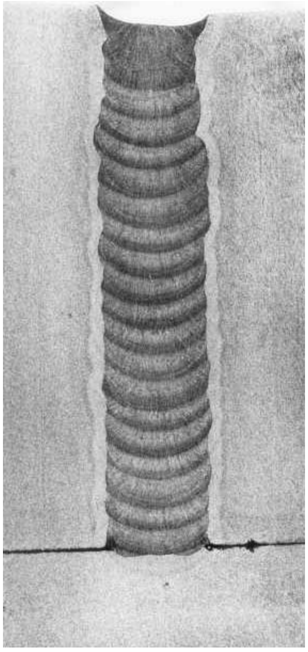


Figure 6. **Macro specimen of a weld produced by narrow-gap submerged-arc welding with a twin-wire electrode; x1**

Slika 6. **Makro izbrusak zavara izrađenog elektrolučnim zavarivanjem pod prahom s uskim rasporom dvostrukom žičanom elektrodom; x1**

Welding was carried out with a 1.2 mm wire. Current intensity *I* in both wires was 320 A and arc voltage *U* 32 V. A rutile-basic shielding flux was used, which provides a good quality weld and permits easy removal of slag after welding.

CONCLUSIONS

The studies made showed that it was possible to weld with a multiple-wire electrode in a narrow gap. The present article is the first to publish a figure showing a schematic representation of a welding head with twin-wire and triple-wire electrodes.

The greatest advantages of narrow gap welding with the unit described are simplicity and a low price of the whole system. All the wires are supplied from one power source, have one wire feed unit, and joint regulation. The welding head need not be cooled by water since heat input in the workpiece is comparatively low. During welding the head position need not be changed since it always travels along the same line. Only a shielding flux is to be supplied to the welding area and slag is to be removed after welding.

Investigations in this field will proceed in two directions. The first direction is construction of a smaller and narrower welding head for welding with a multiple-wire electrode. Two wires may be arranged one after another. One is to be guided to the left fusion face and the second to the right one. The welding head could for this arrangement be made even smaller and the gap narrower. Three wires may be arranged one after another in the welding direction. The first wire should be guided towards one fusion face in order to fuse it, the second perpendicular to the surface of the weld metal, and the third towards the other fusion face to fuse it. All three wires have to ensure a joint weld pool.

The second direction is an investigation of mechanical properties of narrow gap welds. For this purpose destructive and non-destructive testing methods will be used. Toughness of welds and weld junction as well as other mechanical properties are to be found out.

Physical quantities / Popis fizikalnih veličina

b, b_1, b_2	- distance between two wires, mm
d	- wire diameter, mm
h_u	- penetration depth, mm
I	- welding current, A
L	- electrode extension length, mm
U	- arc voltage, V
v	- welding speed, m/min
v_w	- wire feed speed, m/min

REFERENCES

1. R. P. Meister, D. C. Martin: British Welding Journal 13 (1966) 5, 252-257
2. J. E. Jackson, M. B. Sargent: Welding Journal 46 (1967) 11, 905-914
3. C. A. Butler, R. P. Meister, M. D. Randall: Welding Journal 48 (1969) 2, 102-108
4. D. A. Dudko, Y. A. Sterenbogen, A. G. Potapievsky: Automaticheskaya Svarka (1957) 3, 58-63
5. Kurowaka et al, Doc.-XII-316-66. International Institute of Welding, Delft 1966
6. J. Norrish: Advanced Welding Processes, Institute of Physics Publ., Bristol 1992
7. K. E. Knipström, B. Pekkari: Doc. XII-1063-88. International Institute of Welding, Wien 1988
8. E Cook,. P. C. Levick: Welding Journal, 64 (1985) 8, 27-31
9. N. N.: Metal Construction 9 (1977) 10, 464-467
10. D. J. Ellis: Doc. XII-994-86. International institute of Welding, Tokyo 1986
11. R. W. Reynolds: Narrow Gap Welding Torch. United States Patent - 3, 992, 603, 16. Nov., 1976
12. I. D. Henderson, K. Seifert, H.-D. Steffens: Einseitenschweißen 300 mm dicker Smiedestücke nach dem Engspaltverfahren. Vorträge der Große Schweißtechnische Tagung "Schweißen und Schneiden", Essen 1977

13. R. Probst, F. Hartung: ZIS-Mitteilungen, Halle 29 (1987) 8, 812-821
14. R. Gröger, J. Koivula: Industrie Anzeiger 106 (1984) 39, 28-33
15. A. T. Nazarchuk, V. D. Kovalev, V. J. Stukin: Automaticheskaya svarka (1989) 5, 73-74
16. W. Kast, E. Scholz: Oerlikon-Mitteilungen 40 (1982) 100, 4-10
17. Y. Sugitani, Y. Kobayashi, M. Murayama: Welding International 5 (1991) 7, 577-583
18. V. Y. Malin: Welding Journal 62 (1983) 4, 22-30
19. T. Ito: Development of Arc Oscillating Narrow Gap Welding Process. Proceedings of 2nd International Symposium of JWS "Advanced Technology", Osaka 1975
20. M. J. Lucas: Narrow Gap Welding Apparatus and Method. Patent Specification - 1 492 226. The Patent Office London, 1977
21. F. Hartung, R. Oertelt, Schweißtechnik, Berlin 36 (1984) 8, 343-344
22. Y. Yabuki et al.: Doc. XII-B-212-77. International Institute of Welding, Copenhague 1977
23. N. N. Schweißtechnik: Wien 36 (1982) 6, 103-109
24. H. Hantsch, K. Million H., Zimmerman: Welding Journal 61 (1982), 6, 27-34
25. W. Austel, U. Dilthey, G. Grote, K. Hock: Schweißen und Schneiden 35 (1983) 12, 593,595