N91-32612

LIGHTNING PROTECTION OF THE FOKKER 100 CFRP RUDDER.

A.J.M. Ruiter,
Fokker Space & Systems B.V.,
(formerly of Fokker Aircraft Corporation),
Amsterdam,
Holland.

ABSTRACT

This paper describes the construction of the structural parts of the Fokker 100 CFRP rudder with respect to the requirements for electrical bonding and lightning protection. Futhermore the philosophy for the selection of a consumable trailing edge is given. A description of possible alternative designs for trailing edges and their advantages and disadvantages with respect to damage after lightning impact will also be reviewed.

An overview of the tests performed on test samples and the rudder construction will be presented and discussed. The effectiveness of both the selected structural provisions and trailing edge will be described (and proven) by reporting the results of the simulated lightning tests performed at the High Voltage Laboratory of the N.V. KEMA, Arnhem, Holland. Proof will be presented that the trailing edge construction and its bonding through the structural parts of the rudder to the main aircraft structure is a solution which results in minor damage to the rudder after lightning impact. Furthermore it will be shown that the selected trailing edge construction is less favoured by the structural designers due to the weight penalty.

INTRODUCTION

Since the Fokker 100 empennage has a top mounted horizontal stabiliser which acts as a shield, the change of swept strokes or a direct lightning strike on the rudder's surface seems to be very small, but can not however be entirely excluded. In this case the rudder might become a part of the current path and would have to conduct a substantial current. The point of exit on the rudder of the lightning strike may either be at one of the bonding jumpers over the hinges at the trailing edge or at the static discharger.

Previous simulated lightning tests were based on direct impact damage in order to investigate the effectiveness of the protective layer on glass, aramid or carbon fibre reinforced test panels. The sample panels were positioned under a rod. The rod was positioned at a distance of about 1 cm above the test panel's surface. Futhermore, in these tests the effectiveness of several edge constructions was also tested. The latter was established by grounding the test panels at the aluminum supports at the edges (representing the aircraft's structure). The degree of damage to unprotected test panels was also established.

1. DESIGN CONSIDERATIONS

Due to the geometric shape and location of flight control surfaces like flaps, ailerons and rudders etc., the attachment or exit points of the lightning strikes will be localised at the trailing edge. The use of CFRP shall result in damage of the trailing edge after lightning impact. The degree of damage will strongly depend on the construction of the trailing edge used. After impact the current will be divided over the upper and lower skin panels of the affected flight control surface. This action will result in two effects:

- electromagnetic forces (causing delamination),
- resistive heating (causing vaporisation of the adhesive and/or resin, resulting in delamination).

Both effects will occur in cases where the upper and lower skins are terminated at the trailing edge and are connected by means of an adhesive layer (figure 1). In the case of a construction as shown in figure 2, the electromagnetic forces will dominate.

The degree of damage will be minimized by using a construction in which the trailing edge consists of a massive material (without resistivity change at the attachment point). Futhermore, this trailing edge must be connected to the upper and lower skins by means of rivets at a certain distance away from its extremity. In order to obtain the same degree of resistivity as the upper and lower skin panels the trailing edge has to be made from the same material (figure 3). Due to the absence of an adhesive layer the occurrance of an explosive expansion of this layer as a result of resistive heating is prevented. In addition, the degree of electromagnetic forces will be less at the connecting rivets of the skins to the trailing edge. This is because of the greater distance between the (skin) rivets and the lower current density in both skins (i.e. not concentrated at the trailing edge) compared to figures 1 and 2. The result will be that the actual electromagnetic force in the trailing edge will be les severe. So the degree of damage will only be dominated by the resistive heat build-up at the attachment point of the trailing edge.

Based on the above mentioned considerations it was decided to evaluate a trailing edge construction as shown in figure 3.

2. PURPOSE

Simulated lightning tests were carried out to investigate and verify the adequacy of the selected trailing edge and its fastening method. During the same tests the interfaces at the bonding jumper connection were subjected to the same test currents. For other reasons, it was decided at a later stage to mount a static discharger on the rudder. The method of fastening the static discharger base was also subjected to simulated lightning tests. The simulated lightning tests were performed at the High Voltage Laboratory of the N.V. KEMA, Arnhem, Holland and were in accordance with "Aerospace recommended practice: Lightning effect tests for aerospace vehicles and hardware" [1]. The test currents were based on zone 2 requirements [1]. Futhermore, the tests were mainly performed to determine the effects on the electrical bonding methods after being submitted to simulated lightning tests; this in accordance with MIL-STD-1757A [2].

3. TEST SET UP

During the tests the lightning current generator was connected either to one of the bonding jumpers and the trailing edge or between two bonding jumpers. This in order to simulate a possible current path through the rudder. After the aircraft has been hit by a lightning flash the lightning currents may flow through one bonding jumper (or enter at the trailing edge). These currents may enter the rudder either at the rudder construction at one of the bonding jumpers or at the trailing edge. Conductive tests were carried out in order to determine the capability of the structure to conduct the currents to which it will be subjected. For these tests the high current source was solidly connected to the test sample at one of the bonding jumpers or at the (for this reason extended) trailing edge. A rod was only necessary in order to create an attachment at the trailing edge. However the applied test current wave forms were the same.

All test specimens were subjected to a current impulse consisting of two components in accordance with reference 1 for zone 2. The first component was a current wave with a maximum amplitude of 100 kA and a duration of 2 μs. After 100 μs from the start of the first component a second component consisting of a current wave with an amplitude of 1,8 kA and a virtual duration (the time during which the amplitude of the impulse is greater than 10% of its peak value) of 3,5 ms was applied [1].

4. TEST SPECIMEN DESCRIPTION

4.1. Test specimen 1.

Test specimen 1 consisted of two CFRP sandwich skin panels connected at the trailing edge by means of a CFRP trailing edge member (figure 3). The specimen dimensions are representive for the Fokker 100 CFRP rudder at the location between the middle and upper hinge (figure 4). Due to the weight penalty caused by rivetting, the design office preferred to adhesively bond the trailing edge to both skin panels. In order to compare the effects of adhesive bonding and rivetting, the trailing edge of the test specimen was split into two sections. The upper section was adhesively bonded while the other section was rivetted (figure 5). The trailing edge was also extended for some distance in order to be able to make a connnection to the lightning current generator. Futhermore the sandwich skin panels were fixed in the correct position by means of two dummy (PU) ribs.

4.2. Test specimen 2 and 3.

4.2.1. First test series configuration.

Both test specimens consisted of CFRP sandwich panels representing a skin of the Fokker 100 rudder. Both test specimen cross sections were the same as for test specimen 1, but one of the corners was made representative for the spigot area. So both panels were equipped with two bonding jumpers: one for the middle hinge and one for the spigot area. Compared with test specimen 1 the construction was modified as follows:

1. bonding jumpers (greater cross section for the previous selected one had failed),
2. electrical bonding provisions at the bonding jumpers (e.g. a CFRP insert at the attachement area),
3. totally rivetted trailing edge,
4. additional CFRP layer at the outer surface of the outer skin, orientated perpendicular to the trailing edge (mainly for strength reasons, but the fibre direction will be beneficial by influencing the desired direction of current flow in the surface layer of the outer skin).

Futhermore the test specimens were equipped with dummy front-spar flanges and rib-flanges (spigot area). See figure 6.

4.2.2. Second test series configuration.

The (delaminated) front-spar flanges of both test specimens were replaced by a representative part of a production spar (complete). The (delaminated) dummy-rib flanges of both test specimens were replaced by another dummy. At test specimen 2 two monel rivets were mounted at the "ends" of the spar-rib flanges and at the "end" of the dummy rib (at the trailing edge location). Futhermore the number of rivets at the bonding strip of the middle hinge area was doubled.

4.2.3. Third tests series.

The delaminated production front spar of test specimen 2 was removed and replaced by another one. Futhermore the delaminated dummy-rib flange was also replaced. At the ends of the front spar flange and of the dummy-rib flanges metal strips were rivetted (figure 7). This is in order to simulate the (heavy) metal parts at the hinges and in the spigot area.

5. TEST RESULTS

5.1 Test specimen 1.

5.1.1. Test performed over the bonded trailing edge.

Before testing it was decided to add four rivets to one side of the adhesively bonded trailing edge (lower part of figure 8A). This was done at the request of the design office. They estimated that four rivets at the adhesively bonded trailing edge would be sufficient to conduct the simulated lightning currents. This in order to obtain a configuration with the lowest possible weight penalty. After being submitted to the simulated lightning current wave form, the adhesively bonded trailing edge was delaminated. In-house investigations revealed later that the trailing edge was delaminated over more than 75% of the cross section of its connection to the skin panel (upper part of figure 8A).

The trailing edge connection provided by four rivets was also delaminated, although to a much lesser extent. Furthermore, the outer skin plies of the trailing edge at all rivets was also heavily delaminated.

5.1.2. Tests performed over the rivetted trailing edge.

The rivetted trailing edge showed minor damage after the simulated lightning test. The damage was limited to small delaminations of the outer plies at some rivets. After this test the simulated lightning tests were repeated a further three times.

The damage to the trailing edge after the simulation of an attachment was limited to local burning of the resin (see figure 9A and 9B). The damage shown is the result after two subsequent tests.

After completion of these two tests a dummy static discharger base was mounted on the rivetted trailing edge. The subsequent simulated lightning tests showed that the fastening of the base by means of three rivets is sufficient to preclude structural damage after lightning attachment.

5.1.3. General.

At the bonding jumper area (representing the middle hinge) the CFRP skins of both skin panels were delaminated. Futhermore one of the bonding jumpers was broken during the simulated lightning tests.

5.2. Test specimen 2 and 3.

5.2.1. First test series.

5.2.1.1. Bonding jumper area.

At the bonding jumper connection of the middle hinge for both test specimens some arching and delamination of the outer CFRP plies (at the inner side of the rudder) occurred after the tests. This was considered to be unacceptable for the following reasons. In the event that the aircraft is struck in actual service it is difficult to establish damage inside the rudder. Furthermore, this was not acceptable in view of maintenance considerations.

No damage was detected on either of the two test specimens at the bonding jumper connection at the spigot area and at the trailing edge.

5.2.1.2. Flanges.

The dummy front-spar flanges of both test specimens were delaminated at both ends after the tests (figure 10A and 10B). The dummy rib flange of both test specimens was also delaminated at the end situated at the trailing edge area. The ends of the dummy rib flanges of both test specimens at the bonding jumper connection of the spigot area did not suffer any damage.

5.2.2. Second test series.

5.2.2.1. Test specimen 2.

Two simulated lightning tests were performed between the bonding jumper of the middle hinge and the trailing edge. Despite the two rivets installed at the ends of the front spar flanges, both areas suffered from delamination of the outer CFRP plies at the rivets.

5.2.2.2. Test specimen 3.

After the simulated lightning tests between the bonding jumpers of the middle hinge and the spigot area the end of the front-spar flange was heavily delaminated (figure 12A). At the end of the flange the resin in its "neck" had been vaporized blowing away carbon fibres (figure 11A and 11B). Futhermore, the inner and outer skin of the test specimen was delaminated at the honeycomb connection. This occurred in the region from the inner skin via the CFRP insert at the middle hinge area to the outer skin (figure 12B).

5.2.3. Third test series.

After two simulated lightning tests minor delamination occurred at the middle hinge bonding jumper attachment area of the inner skin (figure 13). This delamination occurred after the seventh simulated lightning test applied to this test specimen. The test specimen was subjected to a further three simulated lightning tests. No sign had been found to indicate that the delamination had grown after each single test. Futhermore no delamination occurred at the ends of the front-spar flange and at the end of the dummy rib flange (in the trailing edge area).

6. DISCUSSIONS.

For the actual Fokker 100 rudder design a rivetted trailing edge had been selected. This despite the weight penalty. Futhermore, the bonding jumper areas of the middle and upper hinge were designed simular to the configuration tested as described in chapter 5.2.3. Futhermore the ends of the front spar flanges of the rudder are well protected against damage by the heavy metal parts at the upper hinge and the spigot area. No metal parts at the ends of the top and bottom ribs have been applied. This decision is justified by the number of rivets and fasteners installed over the length of both ribs.
This had been a requirement from the Dutch Airworthiness Authorities. For strengthreasons the design could not be permitted to rely solely on the quality of the adhesively bonded ribs. The same observation had been made for all the other ribs and the front spar. On the other hand this requirement was favourable for the electrical bonding of the structural parts of the rudder. Futhermore it would be very difficult, if not impossible, to apply a metal strip at the ends of both the top and bottom rib in the trailing edge area.

7. CONCLUSION.

Although the tests were not performed on a full scale rudder, the simulated lightning current was not reduced. So the skin current density and the current through the rivets and the bonding jumpers had a magnitude which is above the design requirements, resulting in worst case conditions.

The simulated lightning tests have resulted in a rudder design which is capable of conducting lightning currents. The result will be minor damage at the trailing edge.

Futhermore it is believed that:

1. the damage after (a possible) attachment to the trailing edge can be temporarily repaired, if necessary, by means of a so called high speed tape. The required cosmic repair can be performed later at the home base of the airliner.
2. No inspection of the (inner) rudder construction is necessary after the aircraft has been struck by a lightning flash.

8. REFERENCES

1. SAE Committee AE4L, Special Task F: Aerospace recommended practice "Lightning effects tests on Aerospace vehicles and hardware.
2. MIL-STD-1757A: Lightning Qualification Test Techniques For Aerospace Vehicles and Hardware.

9. ACKNOWLEDGEMENT

The author wishes to thank Fokker Aircraft Corporation for allowing him to present this paper. Futhermore the author wishes to thank Mr. W. Scholten of Fokker Aircraft Corporation for his cooperation during the tests and for his comments on this paper.

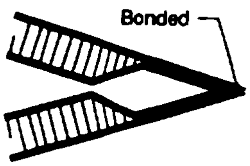
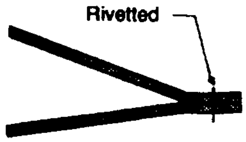


Figure 1.



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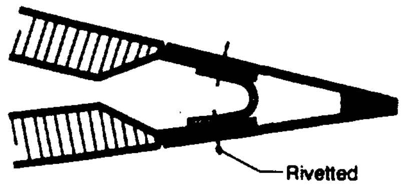

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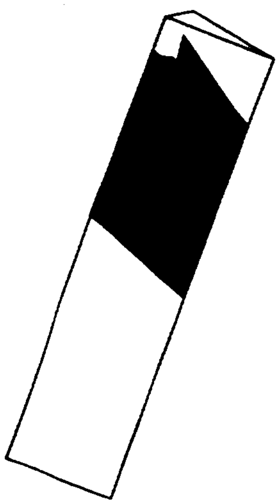

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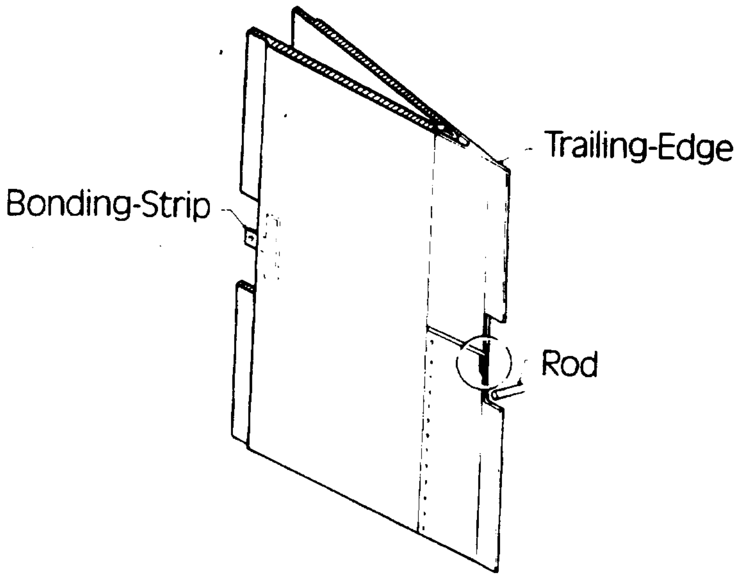

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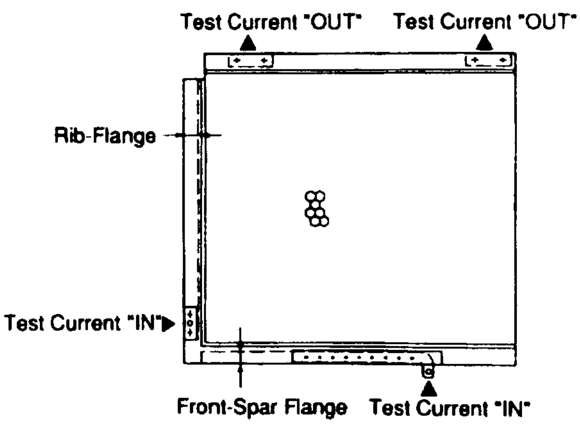

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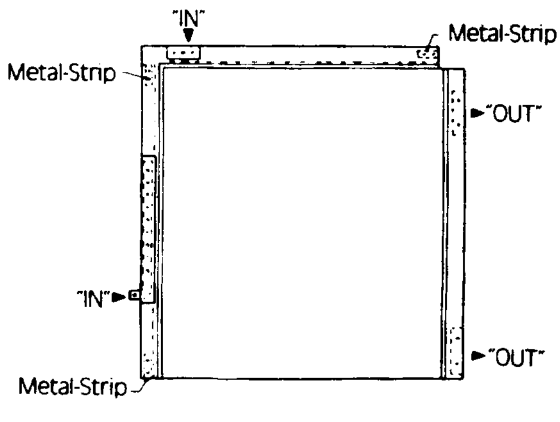

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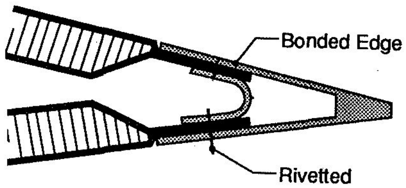

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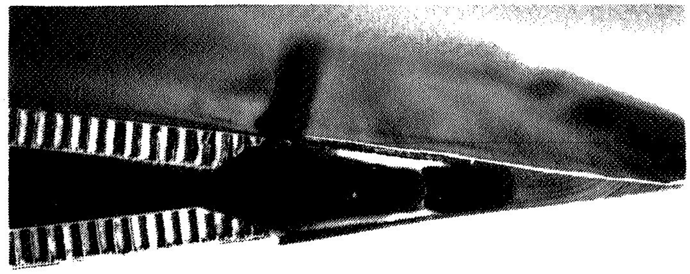

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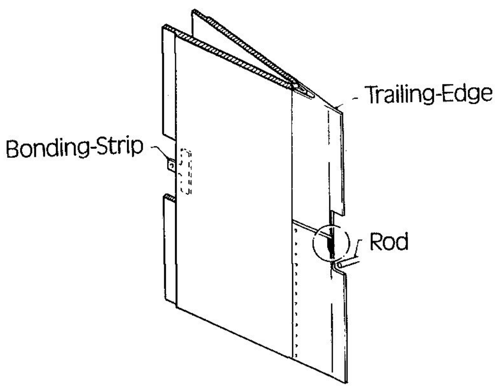
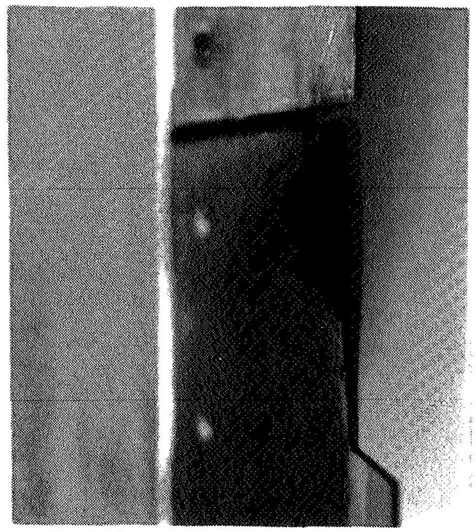


Figure 9A.



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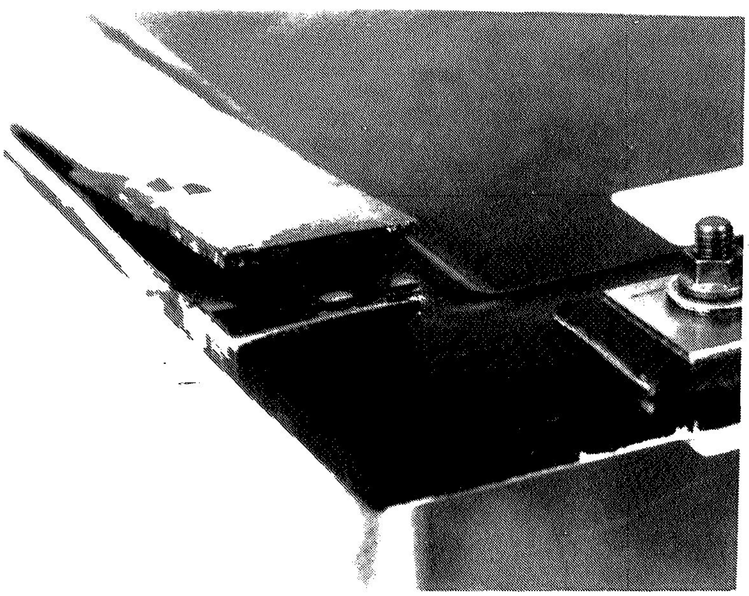

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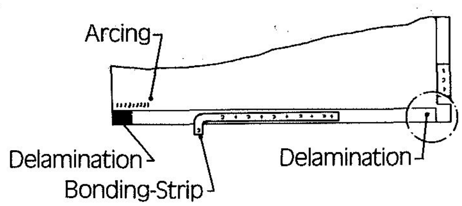

Figure 10B.

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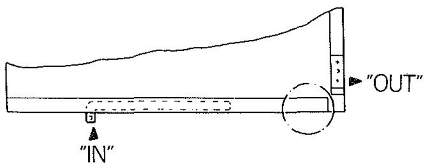
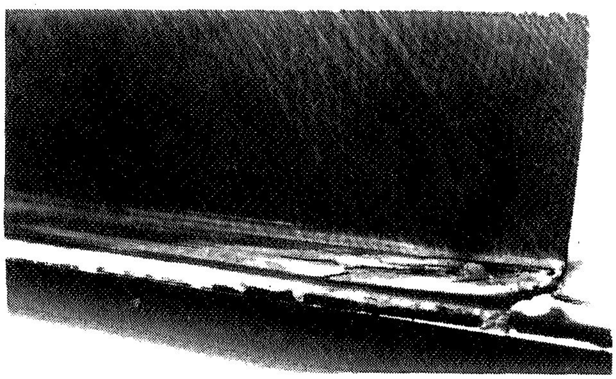


Figure 11A.

Figure 11B.



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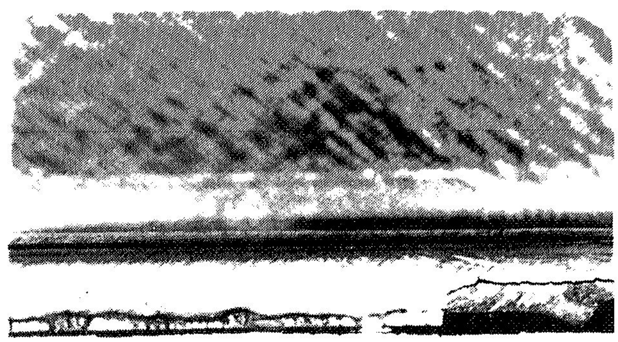

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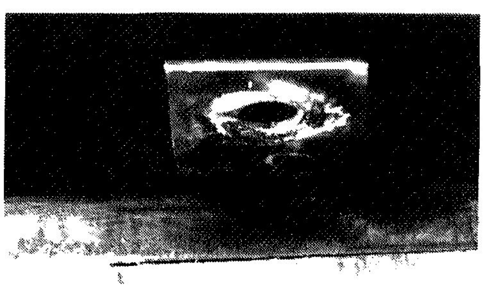

Figure 13.

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