fm: BUREAU VERITAS, Hamburg (TRANSLATED)

to: Lloyd Werft Bremerhaven GmbH,
Bremerhaven

B.V. ref. TB 1954/FA/ba Hamburg, Dec. 2nd, 1985

Sect. No. 21 E 762
Boilers CH 12/9

Dear Sirs,

S/S "NORWAY" - Main Boilers
Cracks in Welds

Reverting to a visit of your Mr. Satow to our office in Hamburg on Oct. 21, 1985, we would once more thank you for handing over to us both your papers and Babcock boiler information.

The appropriate department of our society has evaluated those reports and hereby comments as follows.

1. There is urgent need to test all boiler upper and lower drums (boilers 1-4) to the ORP method (magnetic particle penetration test). The lengths of welds to be tested should be selected to incorporate also such areas where cracks had been discovered once before. (Please also refer to Babcock inspection report page 2).

2. The material thickness left should be ascertained by ultrasonic testing and be compared with those minimum figures as previously given to you by us.

3. Providing owner's general agreement, all weld repair procedure is to be submitted to Bureau Veritas for review and approval (all documentation should be provided in four-fold).

4. Particular attention should be paid here to the basic material of the drums which is known to an insufficient degree only (i.e. chemical composition & physical properties). Therefore, most precise analysis will have to be done to enable final method for weld repair to be determined.

We hope that this information will be helpful to you.

Yours faithfully,

for BUREAU VERITAS
(German Central Office)

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E-0176

VETCO SERVICES
COMBUSTION ENGINEERING, INC.

PRÜFBERICHT

Oberflächenrißprüfung

Nr.: _____

Blatt _____ von _____

Auftraggeber: Lloyd Werft	Auftrag-Nr.: MB 1699/87
Ort der Prüfung: M.S. „NORWAY"	Prüfzeitraum: 12.09.87
Prüfobjekt: Längs- und Rundnähte	Prüfung vor/nach Wärmebehandlung
Kennzeichnung: Kessel 21 Obertrommel	Prüfumfang: 100 %
Werkstoff:	
Prüfvorschrift: HP 5/3	

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAM 5
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 · 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒ trocken ☐ Untergrundfarbe
fluoreszierend ☒ schwarz ☐ _____

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☒
Prüfstücktemperatur: ___ °C

Prüfergebnis: Fehler beschliffen, nicht wegbekommen

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1])	Fehlerlänge mm	Fehlerlage[2])	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Wanddicke Bemerkungen Anzeige	Wanddicke Bemerkungen Grundmaterial
RN1	/	/	/	Bagdahn	X				
RN2	4260	L 25	S	"				52,4	56,2
"	4530	L 20	S	"				54,3	56,8
"	4580	L 10	S	"				54,0	57,1
"	4960	L 15	S	"				46,7	55,6
LN1	2760	L 15	S	"				54,7	57,2
LN2	/	/	/	"					
	v. LN1	v. R1 nach RN2							
v. hinten gesehen	780	280 mm Breite MP geprüft			X				
	280								

[1]) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
[2]) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

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Magdeburger Str. 5 – Postfach 42
3100 Celle/Germany
Tel. (05141) 8 20 31

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13.09.87			

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Oberflächenrißprüfung

Nr.: _____

Blatt _____ von _____

Auftraggeber: Lloyd Werft	Auftrag-Nr.: MB 1699187
Ort der Prüfung: M.S. „NORWAY"	Prüfzeitraum: 13.09.87
Prüfobjekt: Längs- und Rundnähte	Prüfung ~~vor~~/nach Wärmebehandlung
Kennzeichnung: Kessel 21 Untertrommel	Prüfumfang: 100%
Werkstoff:	
Prüfvorschrift: HP 5/3	

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAM 5
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 · 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒ trocken ☐ Untergrundfarbe _____
fluoreszierend ☒ schwarz ☐

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☐
Prüfstücktemperatur: ___ °C

Prüfergebnis:

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1]	Fehlerlänge mm	Fehlerlage[2]	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Bemerkungen
RN 1	/	/	/	Berg	x			
RN 2	/	/	/	"	x			
LN 1	/	/	/	"	x			
LN 2	/	/	/	"	x			

[1]) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
[2]) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

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Oberflächenrißprüfung

Nr.: _____

Blatt 1 von 2

Auftraggeber:	Lloyd Werft	Auftrag-Nr.:	MB1699/87
Ort der Prüfung:	M.S. „NORWAY"	Prüfzeitraum:	14.09.87
Prüfobjekt:	Längs- und Rundnahte	Prüfung ~~vor~~/nach Wärmebehandlung	
Kennzeichnung:	Kessel 21 Seitentrommel	Prüfumfang:	100%
Werkstoff:			
Prüfvorschrift:	HP 5/3		

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAM 5
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 · 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒ trocken ☐ Untergrundfarbe
fluoreszierend ☒ schwarz ☐ _____

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☒
Prüfstücktemperatur: ___ °C

Prüfergebnis:

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1]	Fehlerlänge mm	Fehlerlage[2]	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Bemerkungen: Wandelliche Anzeige	Bemerkungen: Wandelliche Grundmaterial
LN 1	1940	L 2x 5mm	S	Bagdahn				22,4	23,2
"	2000	L 3 x 10	S	"				22,1	22,9
"	2040	L 3 x 6	S	"				22,3	22,8
"	2310	L 1 x 15 L 5 x 5	S	"				22,2	23,1
"	3350	L 1 x 10	S	"				21,9	23,1
"	3570	L 1 x 10	S	"				21,4	23,4
"	3690	L 3 x 5	S	"				21,8	23,2
"	3730	L 1 x 12	S	"				22,4	22,8
"	4030	L 1 x 8	S	"				22,6	23,4
"	4710	Q 5 x 5	S	"				22,8	23,5

[1]) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
[2]) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

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PRÜFBERICHT

Oberflächenrißprüfung

Nr.: _____

Blatt 2 von 2

Auftraggeber: Lloyd Werft	Auftrag-Nr.: MB 1699/87
Ort der Prüfung: M.S. „NORWAY"	Prüfzeitraum: 14.09.87
Prüfobjekt: Längs- und Rundnähte	Prüfung ~~vor~~/nach Wärmebehandlung
Kennzeichnung: Kessel 21 Seitentrommel	Prüfumfang: 100 %
Werkstoff:	
Prüfvorschrift: HP 5/3	

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAM 5
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 - 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒, trocken ☐ Untergrundfarbe
fluoreszierend ☒, schwarz ☐ _____

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☒
Prüfstücktemperatur: ___ °C

Prüfergebnis:

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1])	Fehlerlänge mm	Fehlerlage[2])	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Wandlicke Bemerkungen Anzeige	Wandlicke Bemerkungen Grundmaterial
LN 2	3130	–	–	Bagdahn		X		23,1	23,6
4	4230	–	–	4		X		23,2	23,7
RN 1	–	–	–	4	X				
RN 2	–	–	–	4	X				

[1]) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
[2]) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

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Oberflächenrißprüfung

Nr.: _____

Blatt 1 von 1

Auftraggeber:	Lloyd Werft	Auftrag-Nr.:	MB 1699/87
Ort der Prüfung:	M.S. „NORWAY"	Prüfzeitraum:	17.09.87
Prüfobjekt:	Längs- und Rundnähte	Prüfung vor/nach Wärmebehandlung	
Kennzeichnung:	Kessel 21 Obertrommel	Prüfumfang:	100 %
Werkstoff:			
Prüfvorschrift:	HP 5/3		

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAM 5
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 - 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒ trocken ☐ Untergrundfarbe
fluoreszierend ☒ schwarz ☐ _____

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☒
Prüfstücktemperatur: ___ °C

Prüfergebnis:

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1])	Fehlerlänge mm	Fehlerlage[2])	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Bemerkungen (Wanddicke: Anzeige / Grundwerkstoff)
RN1	/	/	/	Bagdahn	X			
RN2	4260	-	-	"		X		50,8 56,2
	4530	-	-	"		X		52,4 56,8
	4580	/	/	"		X		50,5 57,1
	* 4960	L 15	S	"				46,7 55,6
LN1	2760	/	/	"		X		54,0 57,2
LN2	/	/	/	"	X			* Fehlertiefe
v.h. geschen	RN1 780 von LN1 nach LN2							0,5mm +-20%
	280 mm Breite MP geprüft				X			Gerät: X-RT 804
	280							Krautkrämer

1) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
2) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

Datum	Beurteilung	Beurteilung/Abnahme	
Bahn 18.09.87			

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Oberflächenrißprüfung

Nr.: _____

Blatt 1 von 2

Auftraggeber:	Lloyd Werft	Auftrag-Nr.:	MB 1699/87
Ort der Prüfung:	M.S. „NORWAY"	Prüfzeitraum:	17.09.87
Prüfobjekt:	Längs- und Rundnähte	Prüfung ~~vor/~~nach Wärmebehandlung	
Kennzeichnung:	Kessel 21 Seitentrommel	Prüfumfang:	100 %
Werkstoff:			
Prüfvorschrift:	HP 5/3		

Prüftechnische Angaben:

Magnetpulverprüfung:
Prüfgerät: HAMS
Felderzeugung (Kurzzeichen nach DIN 54121)
Feldstärke 20 · 65 kA/m ☒
_____ kA/m ☐
_____ ☐
Prüfmittel: naß ☒, trocken ☐ Untergrundfarbe
fluoreszierend ☒, schwarz ☐ _____

Farbeindringprüfung:
Hersteller:
Eindringmittel:
Einwirkdauer:
Reiniger:
Entwickler:
Entwicklungsdauer:

Oberflächenbeschaffenheit:
geschliffen ☐
unbearbeitet ☐
blecheben ☒
Prüfstücktemperatur: ___ °C

Prüfergebnis:

Prüfbereich	Abstand Anzeigen vom Bezugspunkt[1])	Fehlerlänge mm	Fehlerlage[2])	Prüfer	Beurteilung anzeigenfrei bzw. belaßbar	Beurteilung belaßbar nach Nacharbeit	Beurteilung ausbessern	Wanddicke Anzeige	Wanddicke Grundwerkstoff	Bemerkungen
LN1	1950	L 10	S	Bagdahn				21,9	23,2	
"	2005	L 5	S	"				21,6	22,9	
"	* 2280	L 10,12 L 5,7	S	"				21,7	23,1	
"	3400	L 10	S	"				21,0	23,1	
V	3555	L 12	S	"				21,6	23,4	
VI	3700	L 8	S	"				21,8	23,2	
II	4030	L 15	S	"				21,6	23,4	
II	4700	Q 3,4	S	"				21,9	23,5	
	* Rißtiefe	0,5 mm	+- 20%	Abweichung						
	Gerät	X-RT	804	Kraut Krämer						

[1]) Bezugspunkt und Abwicklungsrichtung _____ gekennzeichnet.
[2]) G = Grundwerkstoff, Ü = Übergangszone, S = Schweißgut

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18.09.87			
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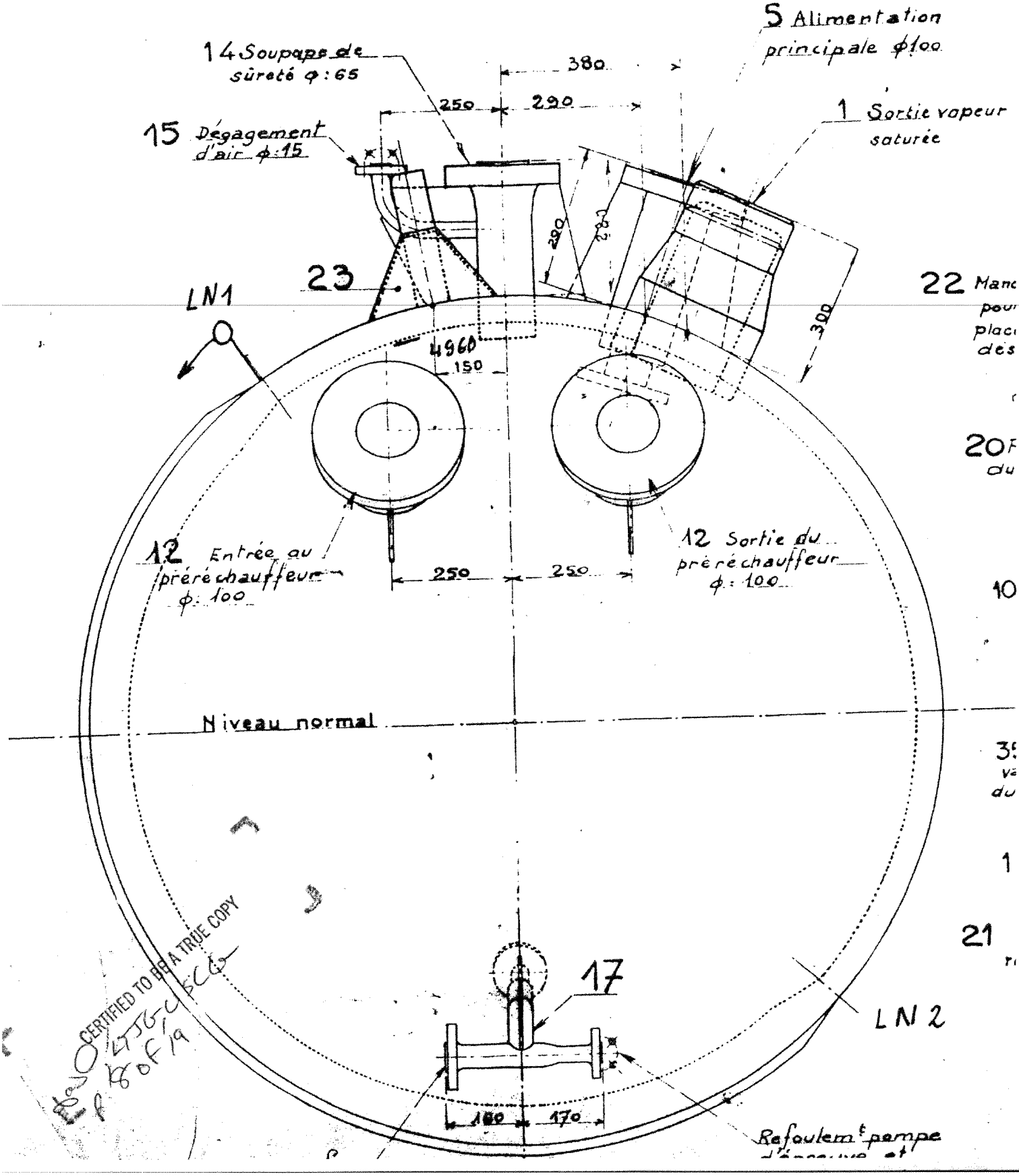
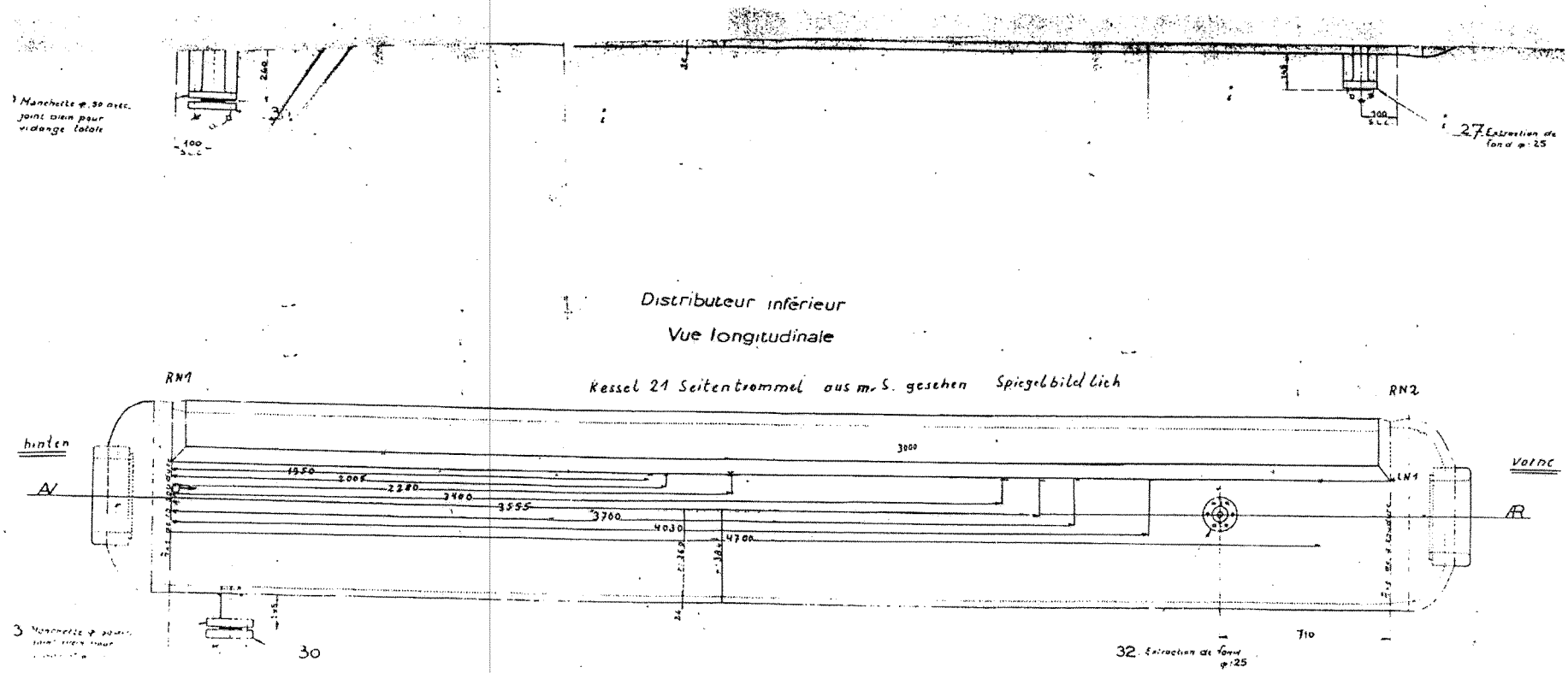
Kessel 21 Obertrommel spiegelbildlich





Report Boiler 21 Prints from Ship file! Cracks

Examination of Linear Indications in Magnetic Particle Tests on Two Boilers of the SS "Norway"

Part 1

1.0 Upper Drum /Boiler 21

In the area of the circumferential weld three magnetic particle indications were detected in the top half of the boiler. The boiler was made of a steel corresponding to the German material 19Mn5. One indication was ground down to the allowable minimum wall thickness. In this condition, the indication was examined, among other things, by a replica technique in accordance with DIN 54 150.

1.1 Macroetching

To determine the flaw location macroetching was carried out. The 7 mm long linear indication is located about 14 mm distant from the fusion line in the plate. The crack length was measured on the replica.

1.2 Structure Replica

Brief description of the technique used: After fine-grinding, the area under inspection was polished electrolytically and subsequently manually etched with 10 percent alcoholic HNO_3. An about 0.1 mm thick film wetted with a solvent was pressed on this surface. After a contact time of approximately five minutes, an image of the structure and possible defects was produced on the film. As the basic diagram in Fig. 1 shows, the crack images stand out in relief on the film. In simple cases, interpretation is possible on site using a portable microscope. Complex phenomena however normally require an examination under a reflected light microscope at a mangnifcation up to 1000 x or under a scanning electron microscope which means an examination in the laboratory.

Replicas were made of the crack, crack surroundings, base material, heat-affected zone and the weld. The very fine-grained ferritic-pearlitic base material is shown in Fig. 2. Fig. 3 shows the structure in the middle of the weld. Both the base material structure and the weld structure with ferrite and portions of transition-stage structure are unobjectionable.

The scanning electron microscopic photograph of the crack is shown in Fig. 4. Figs. 5 and 6 show one photomicrograph of a crack tip each taken under a scanning electron microscope and a reflected light microscope. Pores arranged like pearls on a string are located immediately before the crack tip. Cracks result from the coalescence of these pores and the probability is that the 7 mm long crack will grow in this direction.

The structure of the crack face away from the weld is, like that of the base material, of the ferritic-pearlitic type (Fig. 8). In the area of the crack face near the weld the structure has rehardened and shows a high portion of transformation-stage structure.

In the area of the heat affected zone small pores were found at the grain boundaries in some places. The pores are of such a size that they can only be detected at a mangification of 400X. At some few points the pores have grown to such an extent that they coalesced to form microcracks. Figs. 10 - 12 show reflected light microscopic photographs of these areas. To rule out any misinterpretation this area was examined under the scanning electron microscope. Due to the considerably greater depth of definiiton of the SEM the micropores appear more plastic as raised areas at the grain boundaries. Figs. 13 - 15 show areas in which the micropores have not yet coalesced. According to Figs. 10 - 13 the micropores seem to form at the primary grain boundaries.

Note on the Structure Replication:
In the area of the structure replica the surface was ground hollow. Preparation of a plane replication surface would have required the removal of a larger amount of material in the adjacent areas so that this was dispensed with. This in turn impaired the replication quality which resulted in the fact that an optimum image of the crack edges was in our opinion not produced. The dark-grey zone below the crack in Fig. 6 does not represent a change in structure, but was caused by the a high local contact pressure applied to obtain full contact with all areas. The conditions prevailing in the boiler were very unfavourable for performing metallographic work so that especially in the micrographs of low magnification also images of dirt particles were produced.

1.3 Low Load Hardness Test

Hardness tests were conducted in the area under inspection using a portable low-load hardness tester, type Microdur. The test method applied was the diamond pyramid hardness test at 1-kg test load.

Area under test	Result
Middle of weld	224 - 232 DPH at 1-kg load
HAZ (about 1 mm from the fusion line)	188 - 200 DPH at 1-kg load
Base material - plate	180 - 182 DPH at 1-kg load
crack face area - near the weld	270 - 320 DPH at 1-kg load
carck face area - away from the weld	180 - 188 DPH at 1-kg load

The hardness tester was checked on a heardness reference plate of 255 DPH at 1-kg load in the boiler with regard to the reproducibility of the measuring results directly before and after the test. The hardness values of the crack face area near the weld are particularly confirmed results.

1.4 Overall Result - Upper Drum / Boiler 21

The 7 mm long crack is according to the examinations carried out a discontinuity essentially governed by the formation of micropores due to long-term thermal stressing. Such cracks are caused by the coalescence of pores forming at the grain boundaries. In Figs. 5 - 7, pores arranged like pearls on a string will be noted in the extension of the crack tips. Apart from the documented ones, no other pores were detected in the vicinity of the crack.

In the heat affected zone, pores were detected at various points. In two documented areas pores had likewise coalesced to form microcracks (Figs. 10 - 12). These microcracks are 0.025 and 0.009 mm, respectively, in length.

Obviously, micropores occur in the present case in the heat affected zone only. It seems to be a contradiction that in the hardness test lower hardness values were determined in the heat affected zone than in the zone of the crack face away from the weld. On the basis of the normal method of vessel manufacture it cannot be explained that areas away from the weld have a higher heardness than the area next to the fusion line.

In the upper area of the boiler three major indications were found outside the weld. The author assumes that after final heat treatment of the boiler auxiliary welds were made in the interior. After these welds had become unnecessary they were ground down - however, not again subjected to a heat treatment for obvious reasons. This hypothesis could explain the different hardness values and the varying sizes of the discontinuities. While micropores formed in the HAZ of the properly produced weld due to long-term thermal stressing and coalesced to form microcracks, a macrocrack occurred in an area which suggests an impermissible heat influence.

Part 2

2.0 Lateral Drum / Boiler 21

In the lateral drum, indications of the magnetic particle test on a longitudinal weld were to be inspected visually.

2.1 Visual Inspection

The plates and longitudinal weld had been subject to corrosion. On the plate the corrosion attack manifested itself by a pitted appearance. In the weld, the attack is considerably more severe with regard to frequency and depth of the corrosion pits. The differences are to such an extent that the width of the weld could be estimated by the differing corrosion attack. From the corrosion point of view, the weld metal is obviously electro-mechically less noble than the plate.

2.2 Macroetching

An area ground down to minimum wall thickness was examined in which an about 10 mm long indication and several other ones considerably shorter in length were visible with the unaided eye. A macroetching showed that the long indication was approximately 3 - 4 mm outside the fusion line in the plate of the upper drum half. The short indications are located in the weld center.

2.3 Interpretation of the Indications

All indications are considerably rounded at their ends. In proportion to their length, the indications are disproportionately wide - measured against normal crack length/width ratios.

The indications are apparently the not ground-down starting points of the described corrosion attack. The about 10 mm long indication is likewise apparently not a stress, hardness or corrosion crack. The ends of the indication are quite rounded, the length/width ratio is too wide for a non-gaping crack. This indication, too, seems to be due to corrosion attack.

It is possible, i.e. it cannot be ruled out with certainty, that this is an old crack which was later rounded out by corrosion. The danger of "crack" propagation seems to be most unlikely.

2.4 Low Load Hardness Test

In various areas the diamond pyramid hardness at 1-kg load was determined - as previously on the upper drum.

Area under test	Result
Weld	132 - 154 DPH at 1-kg load
HAZ	206 - 238 DPH at 1-kg load
base material, upper plate	190 - 236 DPH at 1-kg load
1st side of the 10 mm indication	216 - 240 DPH at 1-kg load
2nd side of the 10 mm indication	200 - 228 DPH at 1-kg load

No impermissible or critical hardness values were detected.

2.5 Note on the Magnetic Particle Test on the Lateral Drum - Longitudinal Weld

For magnetic particle testing the surfaces under test should be prepared so that indications stand out clearly from the background. This condition was not fulfilled for the longitudinal weld. This would have meant that the longitudinal weld would have to be ground smooth. Owing to the corrosion attack which shows a greater depth than the pitting on the plate surface relatively frequent magnetic

particle indications would in our experience be detected. The points where indications were registered by the testers in September 1987 are probably especially intense indications. Other testers would at the present time of testing record indications without any changes in the material having occurred. These statements do not constitute a criticism of the personnel performing the material tests, but seem to be appropriate for relativizing the MT results and any test results determined in future. The initiators of the test considered cleaning of the area under test as sufficient.

Recording of indications is not identical with the recording of cracks. Only indications which result in concentrations of magnetic particles on the surface due to permeability factors are recorded by the testers. The causes of these indications can be multi-faceted and therefore fall within the competence of other specialists qualified in this respect.

Bremen, September 25, 1987

sgd. Burek

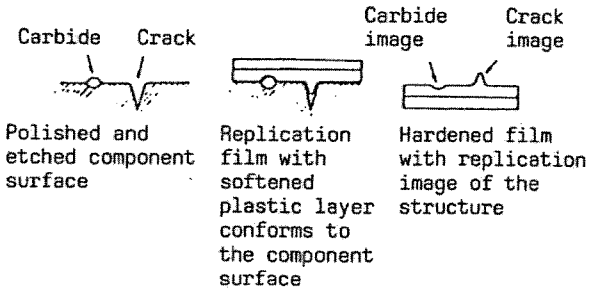


Fig. 1
Principle of replication technique

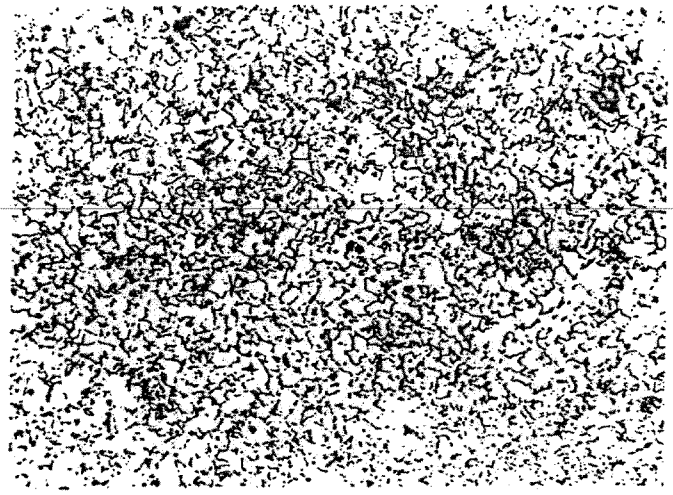


Fig. 2

Base material structure replica

Etched in HNO_3

180 - 182 DPH, 1-kg load

Magnification: 200 : 1

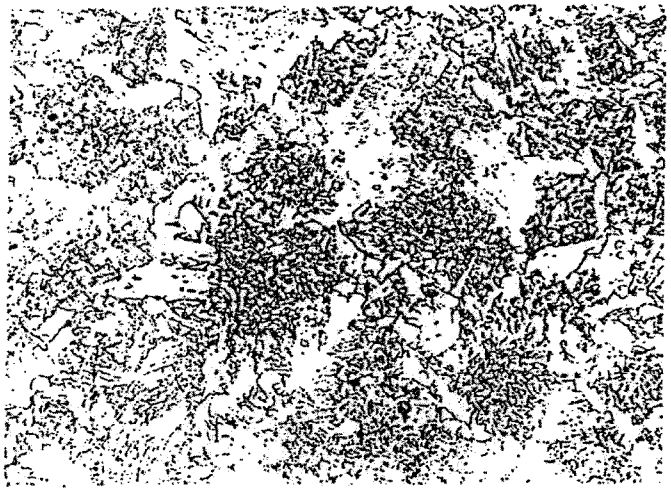


Fig. 3

Weld structure replica

Etched in HNO_3

224 - 232 DPH, 1-kg load

Magnification: 200 : 1

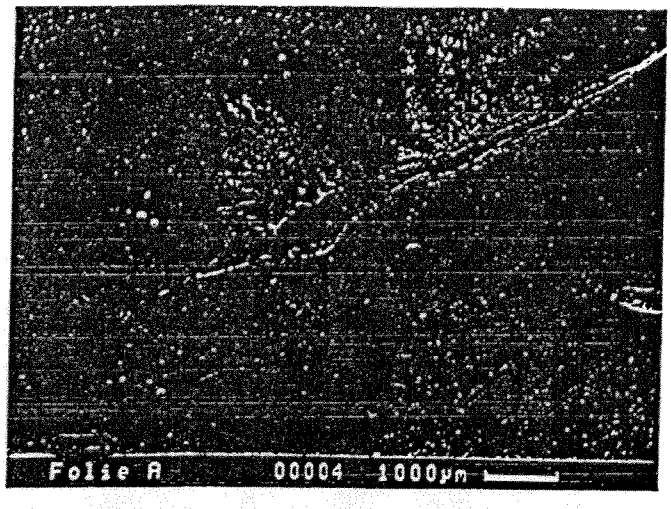


Fig. 4
Crack
SEM photograph

Replication image A

Magnification 14 : 1

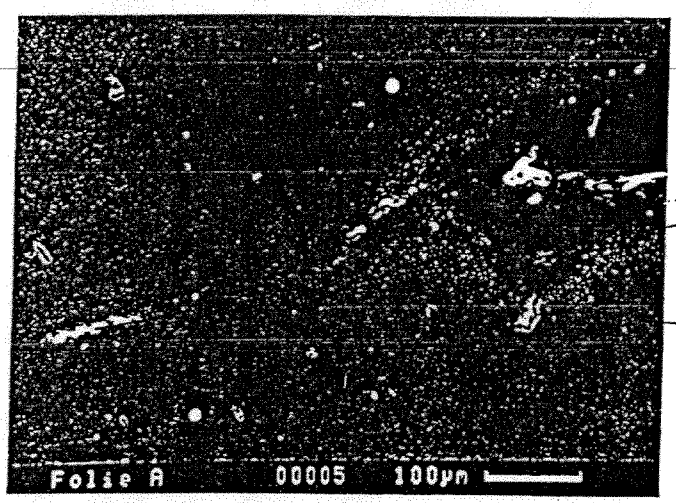


Fig. 5

1st crack tip with pore strings located directly in front

SEM

Film defect

Magnification 180 : 1

Fig. 6
as above

Reflected light microscopic photograph

Magnification 100 : 1

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Fig. 7

2nd crack tip

Reflected light microscopic photograph

Magnification 100 : 1

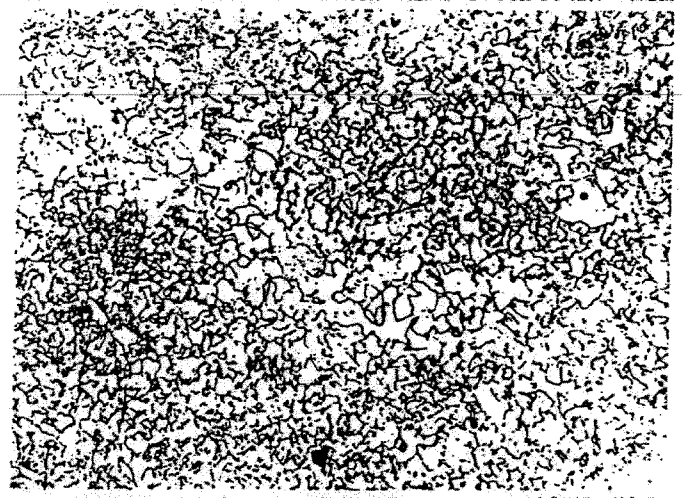

Fig. 8

Base material structure, about 1 mm beside the crack face, away from the weld

188 - 200 DPH, 1-kg load

Magnification 200 : 1

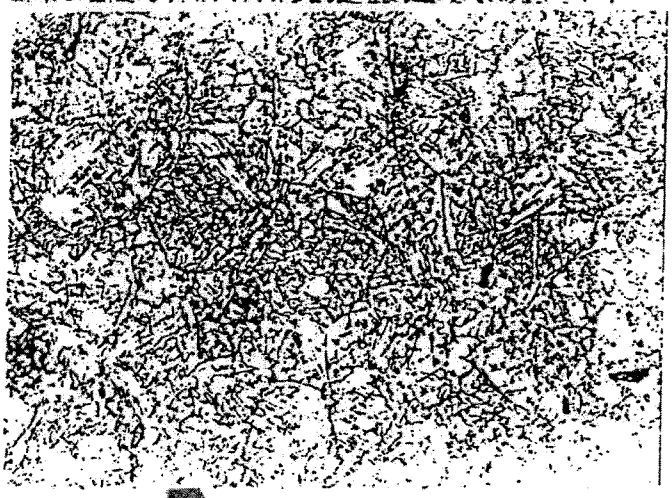

Fig. 9

Rehardened structure, opposite side of the crack face, near the weld

270 - 320 DPH, 1-kg load

Magnification 200 : 1

Fig. 10

Heat-affected zone

Micropores at grain boundary and incipient crack formation

Magnification 400: 1

Fig. 11

as above

Magnification 1000 : 1

Fig. 12

Heat-affected zone

Micropores at grain boundary with incipient crack formation

Magnification 1000 : 1

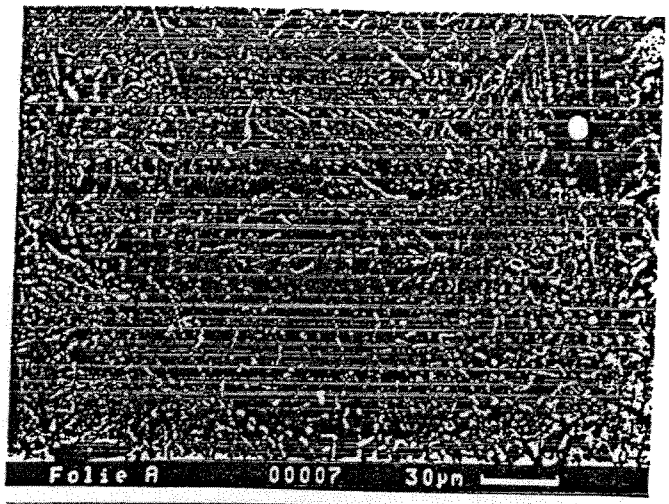

Fig. 13

Micropores at grain boundaries in the heat-affected zone

SEM

Magnification about 500 : 1

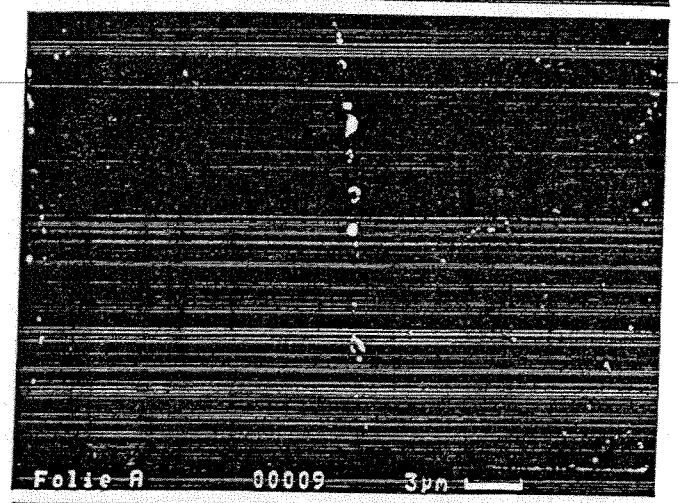

Fig. 14

as above

Magnification about 3300 : 1

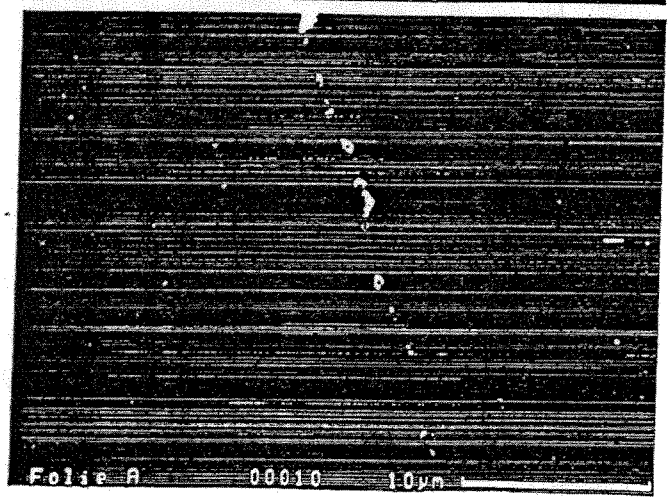

Fig. 15

as above

Magnification about 3500 : 1