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〔技術情報グループ〕

Eddy Current Testing of FBR Fuel Cladding Tubes

April,1972

SUMITOMO METAL INDUSTRIES, LTD.

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Eddy Current Testing of FBR Fuel Cladding Tubes

1. Purpose

It is purported to establish an eddy current testing technique to inspect stainless steel fuel cladding tubes.

2. The Instruments

An electric eddy current inspector; NORTEC ECS-4 (leased by Power Reactor and Nuclear Fuel Development Corporation (PNC)).

Administration No. 15201-1, Head Office;

Construction and Components:

An electric eddy current flaw detector (NDT-1)

A recorder (NDT-5220)

Oscilloscope (NDT-5601)

Driver (HS-11)

A blower

An inspection line (Made by Sumitomo Kinzoku)

3. Place of Experiment Conducted

At the Central Research Laboratories, Sumitomo Metal Ind., Amagasaki City.

4. Experiment Period

From November, 1971 to April, 1972

5. Test Specimen Materials

(1) JOYO's Stainless Steel Fuel Cladding

Dimensions:

Outer diam.:	6.3 ± 0.030mm
Inner diam.:	5.6 ± 0.025mm
Wall thickness:	0.35 ± 0.030mm
Length:	1825 ± 1.0mm

(2) MONJU's Stainless Steel Fuel Cladding

Dimensions:

Outer diam.:	6.5 ± 0.030mm
Inner diam.:	5.6 ± 0.025mm
Wall thickness:	0.35 ± 0.030mm
Length:	1825 ± 1.0mm

6. Experiment and Investigation

Items	Test Specimen	Subjects	Quantity	Remarks
1. Investigation into the correlation between eddy current signals and shape of flaws (Comparison between eddy current signals and ultrasonic signals)	JOYO stainless steel cladding tubes MONJU stainless steel cladding tubes	1. Eddy current detection	20 tubes (6000 passes)	The same specimen was subjected to 300 passes under different conditions in order to determine the optimum condition and to test the reemergence of signals
		2. Ultrasonic flaw detection	20 tubes	
		3. Destructive test (Observation of the surface and cross-section on tubes	20 tubes	
2. Investigation into the correlation between eddy current signals and the partial variations of dimensions in tubes	JOYO stainless steel cladding tubes MONJU stainless steel cladding tubes	1. Ultrasonic thickness gauge test	20 tubes	
		2. Inner diam. measurement using air micrometer	20 tubes	
		3. Measurement of surface roughness	20 tubes	
3. Mass production inspection	JOYO stainless steel cladding tubes	Eddy current detection	214 tubes 400 pass	Specimens which indicated the flaw signals were re-tested

7. Conclusion

(1) The eddy current detector can find out the flaws which are difficult to be detected by the ultrasonic flaw detector due to its shape and location.

These flaws are detectable by improving the existing ultrasonic flaw detection method and also by using the system in which the ultrasonic flaw detector is used in combination with the ultrasonic thickness gauge.

(2) The eddy current detector can precisely and accurately detect the surface caves, pits, or griding parts of surface.

(3) The eddy current detector frequently indicates signals of flaws or gives a larger background noise due to the localized wall thickness variations or inner diameter changes.

(4) A coarse surface sometimes affect and increase the background noise of the eddy current recording chart.

(5) Other than the above, in some cases, the eddy current detector gives out signals of unknown causes.

At present, ultrasonic flaw detection is being conducted on three lots of products.

Eddy Current Testing of FBR Fuel Cladding Tubes

1. Introduction

In order to inspect any defect in the clad tubing, which was applied to FBR's fuel cladding tubes of stainless steel material by use of eddy current flaw detector: MODEL ECS-4, NOREC, U.S.A. This work was undertaken in accordance with the contract which had been concluded with the Power Reactor and Nuclear Fuel Development Corporation (PNC).

2. Investigation and Schedule

2-1. Investigation Performed

The investigation was undertaken on the following three points:

(1) The correspondence between the eddy current signals and shape of the defect in comparison with the ultrasonic flaw detection. These were conducted after an eddy current flaw detection on JOYO and MONJU FBRs. had been performed.

(2) "Other than the defects", mainly the variation of dimensions in the tubes was found to be a cause for the eddy current signals.

(3) Mass production test of JOYO FBRs.

2-2. Subject Materials

(1) JOYO's Stainless Cladding Tubes

Dimensions:

Outer diam.: 6.3 ± 0.030mm

Inner diam.: 5.6 ± 0.025mm

Wall thickness: 0.35 ± 0.030mm

Length: 1825 ± 1.0mm

(2) MONJU's Stainless Cladding Tubes

Dimensions:

Outer diam.: 6.5 ± 0.030mm

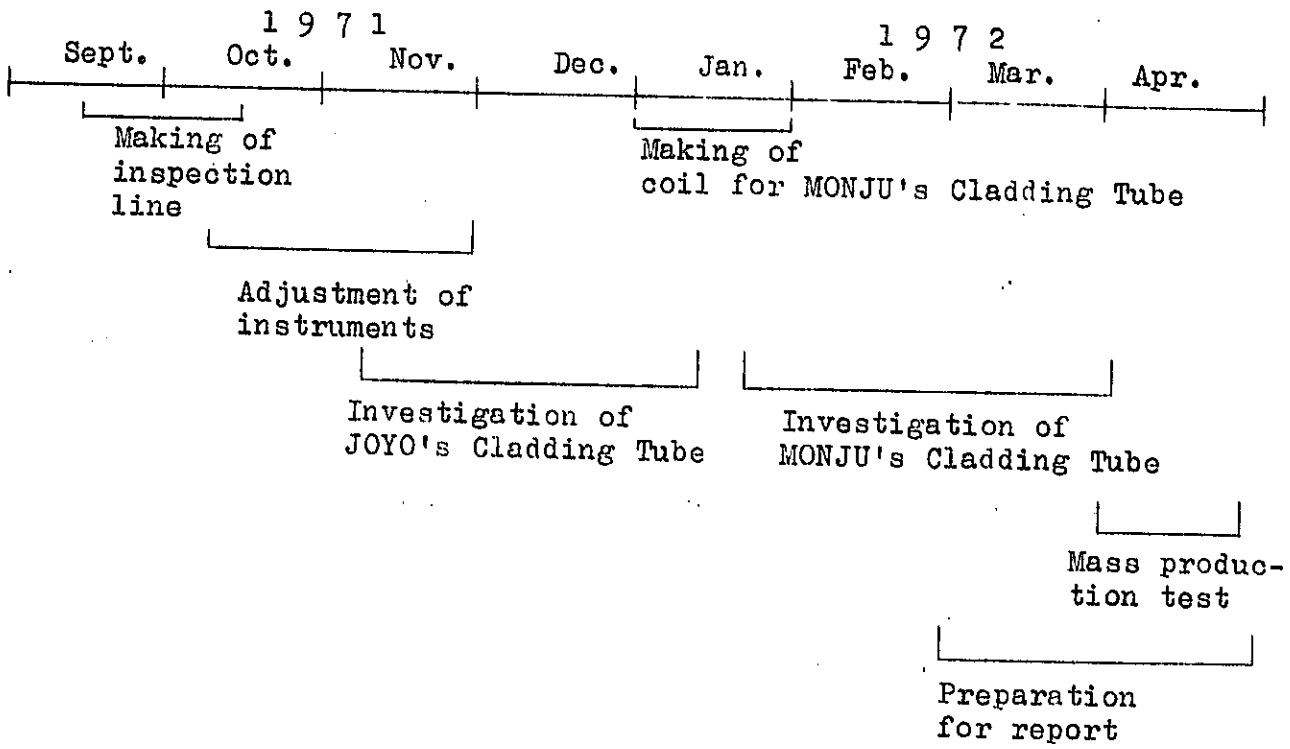
Inner diam.: 5.6 ± 0.025mm

Wall thickness: 0.35 ± 0.030mm

Length: 1825 ± 1.0mm

2-3. Schedule

The above mentioned investigation work was performed on the following schedule:



3. Instruments

3-1. Eddy Current Flaw Detector

The tubes are tested with eddy current flaw detector: NORTEC's Model ECS-4, and its specifications are as follows.

Frequency: 500kHz

Capacity: Longitudinal and circumferential flaws more than 25μ in depth and 0.75mm in length on outer and inner surfaces of the JOYO and MONJU's fuel cladding tubes are detectable.

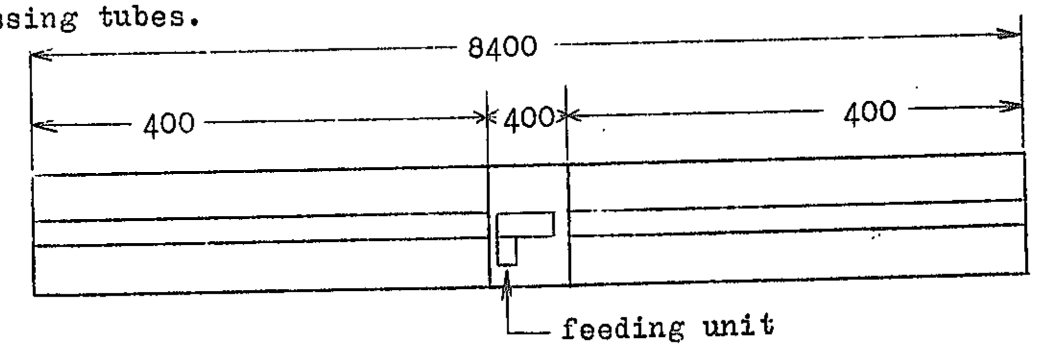
Incidental (auxiliary) units:

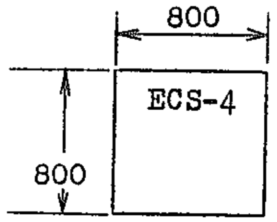
Recorder (NDT-5220)

Oscilloscope (NDT-5601)

3-2. Inspection Line

For the purpose of enabling to probe and detect a flaw in the clad tubing of 2m - 4m in length, a line using an aluminum angle of one inch in width (the same as inspection of PNC's Tokai Works) was installed. The outline of the said line is shown below. The line is applied with a polyester tape to prevent any possible scratch from being caused to the clad tubing in the process of passing tubes.





3-3. Inspection Coil

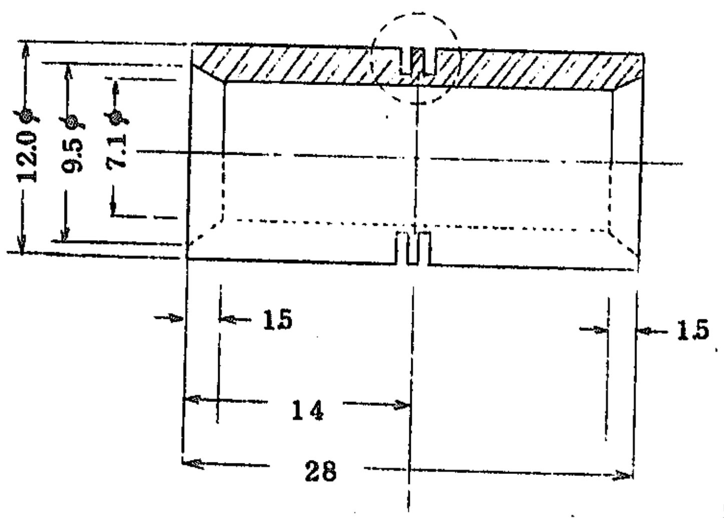
While the inspection coil for JOYO's Cladding Tubes was attached to the equipment, the coil for MONJU's Cladding Tubes was not provided. Hence it was specially made.

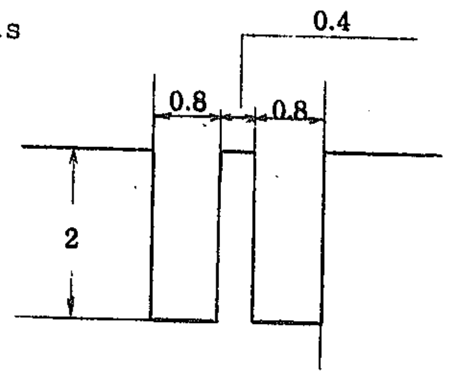
As the coil had to be matched with ECS-4's bridge, the inductance for the new coil was determined by measuring the inductance of the attached coil.

A nylon bobbin as shown in the following figure was used. The coil wire with 0.09mm in diam. was wrapped around so as to have the optimum value of inductance. The coils used for the tests were as follows.

Coil inductance: 25μH at 1kHz

Number of winding: 42 turns





4. Standard Test Specimens and adjustment of Sensitivity

4-1. Standard Test Specimens

For adjustment of sensitivity to detect the flaws in JOYO and MONJU's Cladding Tubes, the standard test specimens were used, and these standard test specimens were made for ultrasonic flaw detection tests.

4-2. Adjustment of Sensitivity

4-2.1 JOYO's Cladding Tubes

By using the standard specimens (S 3579-2) supplied by PNC, the sensitivity was set up to detect an internal flaw of 25μ in depth. The recording chart of the standard specimen under the conditions shown in Table 1 is shown in Fig. 1.

4-2.2 MONJU's Cladding Tubes

By using the standard specimen for ultrasonic flaw detection, the sensitivity was set up detect an internal flaw of 33μ in depth. The recording chart under the conditions shown in Table II is shown in Fig. 6. In the said chart, there are eddy current signals other than the standard flaws. The signals of standard flaws are indicated by arrows on the chart.

5. Comparison between the signals of Eddy Current Detection and the ones of Ultrasonic Flaw Detection.

5-1. JOYO's Cladding Tubes

Out of the cladding tubes delivered to PNC from our company, those tubes which indicated defect signals in the process of an eddy current flaw detection performed by PNC was selected as our test specimens.

These specimens are the four tubes of S3061, S3805, S2601 and S3451. The results of the eddy current flaw detection test and the ultrasonic flaw detection test are shown in Fig. 2 to Fig. 5 respectively. In the drawings, (a) represents an eddy current recording result, (b) an ultrasonic recording result, (c) a photograph of an enlarged surface view, and (d) a microscopic photograph of the traverse cross section of the part of flaws. In the drawing, the shape and the location of the defect observable on the surface of the specimen were indicated. The oblique lines or the parallel lines in the sketch of the specimens are those considered as the traces of grinding finish.

Fig. 2 represents the test result of S3061, and the signals are more in the case of an eddy current detection than the signals of an ultrasonic detection. In the central part, although there are many indications which correspond with the traces of grinding finish, there are no ultrasonic indications observed. The defect detected by a cross-sectional micrograph was proved to have about 30μ in depth. This flaw could not be detected by an eddy current detection method.

Fig. 3 is the result of S3805 specimen. On the surface of this tube, there were numerous flaws in the shape of pits or boils (eruption) which although were not detected by an ultrasonic detection, could be detected by an eddy current detection. The cross-

sectional observation result of these boil shaped defects are shown in the (d) drawing. These can be noticed on the tube's outer surface in a parallel way. This is an example indicating that those defects which were difficult to be detected by an ultrasonic detection, were able to be detected by an eddy current detection.

Fig. 4 is a result of S2601 specimen of which defects could not be detected by an ultrasonic detection but were indicated by an eddy current detection. Those signals of an eddy current detection correspond with the small coarse points or the traces of grinding finish on the outer surface of the specimen.

Fig. 5 represents the result of an eddy current flaw detection of a tube (specimen S3451) showing a cyclic signal, while an ultrasonic detection gave no defective signal. Those eddy current signals had no correspondence with the irregularities on the outer surface of this specimen.

5-2. Cladding Tubes MONJU

For the test of the MONJU's cladding tubes size, the following specimens were used:

Specimen: Tube 36-55, 22-09, and 26-43.

The results of the test, as represented by Fig. 7 to Fig. 9, show similarly as in the case of JOYO Cladding Tube sizes, the respective results of eddy current detection, ultrasonic detection, outer surface observation, cross sectional microscopic photographs, and sketch of the specimen's surface condition.

Fig. 7 represents the result of the tests carried on specimen tube 36-55, showing some eddy current signals corresponding to certain surface defects in the form of indents or pits. On this specimen tube, there were some small pits and trace of some grinding part where there was an eddy current indication. The flaws observed on this specimen are given in the following table with the description of their form, shape, size and depth:

	Form	Dimensions	Depth
1	Pits	About 0.15mmø	About 10μ
2	Pits	" 0.08 "	" 10μ
3	Pits	" 0.15 "	" 10μ
4	Slits	" 0.15mm long (longitudinal)	" 13μ
5	Pits	" 0.15mmø	" 10μ
6	Slits	" 0.6mm long (circumferential)	" 7μ

Fig. 8 represents the result of the tests carried on specimen, tube 26-09, showing some small pits and traces of grinding part where there were eddy current indications.

Fig. 9 is the result of the tests carried on specimen, tube 26-43, and indicates a circumferential flaw of more than 1mm in length and 50μ in depth on the tube's surface which was detected by either test of an eddy current or an ultrasonic flaw detection.

5-3. Summary

From the results of the tests performed on JOYO and MONJU Cladding Tubes, it has been known that an eddy current detection is able to defect more clearly on the tube's surface such traces of grinding parts, small pits and indents which an ultrasonic detection has failed to indicate, and also such an oblique defect existing along the tube's surface which is difficult to be detected by an oblique ultrasonic flaw detection. In this case, the latter is a flaw which can be sufficiently detected by the combined use of an ultrasonic flaw detector and an ultrasonic wall thickness gauge. With this test, an adequate method for product inspection has thus been confirmed.

6. Dimensional Variation and Eddy Current Flaw Detection Signals

6-1. Wall Thickness Variation

Those tubes which indicated some defect signals at the time of the eddy current flaw detection test were subjected to an ultrasonic wall thickness gauge test (vidigauge 14H). There were certain eddy current signals at such an area where the wall thickness variation is extremely localized. Fig. 10 and 11 represent such phenomena of test results.

The eddy current signals corresponding with wall thickness variations are shown with arrows. The wall thickness variation observed on the surface of the specimen is about 0.01mm which is about 3.5% variation of the wall thickness of the tube. Fig. 14

to 16 represent the similar test result on MONJU Cladding Tubes.

Those flaws of considerable depth on the outer surface were detected as the signal variation of wall thickness. These records maintained the extent of the gate (extent of measurement) within 0.44mm and 0.47mm, and those which showed extremely large signals mean the smaller value of wall thickness exceeding the said extent of gate, that is, the abrupt variation of wall thickness.

6-2. Variation of Internal Diameter

Fig. 12 and 13 represent respectively the result of an intrnal diameter measured by air micrometer, which signals are compared with those of eddy current detection.

Fig. 12 shows that the tubes with a large variation of internal diameter detected by an eddy current testing have comparatively a larger background noise. Tube No. 1 has an maximum inner diameter variation of 0.018mm, which is larger than that of No. 2 specimen. The mean value of its background noise is 11mm at the height on the recording chart, which is larger than the 7.6mm of No. 2 specimen.

Fig. 13 shows an example of cyclic eddy current signals corresponding with the localized internal diameter variation. The maximum variation of the internal diameter is 0.005mm and the result is shown in (b) which corresponds with eddy current signals as shown in (a).

6-3. Summary

It has been proved that eddy current testing signals appear due to an abrupt localized variation of wall thickness or internal diameter, and that a larger internal diameter variation gives a larger background noise on a recording chart of eddy current testing. Further, it also have been confirmed that even a small microscopic reduction of wall thickness in the defective area can be detected by measuring the wall thickness.

7. Effect of Coarse Surface

It has been found out as a result of the test, that even the traces of grinding finish can sometimes produce a substantial amount of eddy current signals. A grinding trace signal test was conducted to see the size of signals by applying a sand paper to polish the area where no eddy current flaw signal was indicated.

Fig. 10 (a) shows the eddy current flaw signals on the place where polishing over 5mm in width on tubes was applied for 10 seconds with the use of three types of sand paper of No. 800, No. 1000 and No. 1200 respectively. Fig. 10 (b) indicates the variation of eddy current flaw detection signals at different polishing times with the use of No. 800 paper. As a result, it was found out that the eddy current flaw detection signal was larger when the surface was more coarse and rough during the same polishing time and that longer the polishing time, larger the eddy current signal. Thus it was confirmed that a slight polishing would result in an enlarged eddy current signal.

Other than the above described eddy current signals, there were tubes which indicated a signal of extreme characteristics, as shown in Fig. 18. The tube in question was examined, but no conspicuous correspondence with the outer surface condition or the dimensional variation could be observed.

As obvious from this drawing, it was considered that there might be some differences between the two sections separated from the middle part of the tube, the outer surface coarseness was measured, and it was proved that at the area where signals of eddy current detection showed the abnormal high background noise, surface was more coarse with the value of surface coarseness; Rt = 4μ (Rrms = 0.33μ), while on the opposite area where background noise is not so high but was less coarse with Rt = 22μ (Rrms = 0.22μ). The inner surface had several lines of scratch traces, almost in the parallel way, and it is considered that these inner surface scratch lines might have been the cause of the background noise. Thus, it was found out that even these surface roughness could be a factor to cause an eddy current signal.

8. Mass Production Inspection

An eddy current flaw detection was conducted with respect to the three lots of JOYO cladding tubes delivered to PNC. These test specimen tubes are shown in the following table:

Lot No.	Type of Steel	Dimensions	Quantity	Weight
		(mm)		(kg)
TTQ9052 (11)	SUS32TP	6.3x0.35x1825	67	6
TTQ9052 (13)	SUS32TP	6.3x0.35x1825	72	7
TTQ9052 (15)	SUS32TP	6.3x0.35x1825	75	7

The eddy current detection on the cladding tubes was conducted under the conditions as shown in Table 1, and the tubes which had indicated eddy current signals were classified as follows:

1. Classification of Tubes According to Extent of Eddy Current Signals

These tubes were classified in the order of the signal size on the eddy current recording chart and they are classified as follows: (1) Under 16mm, (2) from 16mm to 20mm, (3) from 20mm to 24mm, and (4) above 24mm.

The artificial flaw made on the outer surface to a depth of 15μ showed an eddy current indication with an amplitude of 12mm on the recording paper, while the artificial flaw made on the outer surface to a depth of 25μ recorded an amplitude of 32mm on the recording paper.

2. Classification According to Types of Eddy Current Signals

Out of the tubes indicating above 16mm amplitude in the eddy current detection chart, the classification of tubes was made in the following order: (1) A tube which indicated a sudden single pulse,

(2) a tube which indicated an overall high background noise, and (3) a tube of which pulse signal indicated in a form of a group signal.

The typical eddy current detection charts of (1), (2), and (3) are shown in Fig. 19. Fig. 19 (a) is the chart having no eddy current flaw signal, while (b), (c) and (d) respectively represent the actual examples of (1), (2) and (3).

The classification under the above numbers 1 and 2 are given in the following tables respectively:

Table 1. Classification by the extent of Eddy Current Signals

Unit: Pieces

Lot No.	Less than 16mm	16 upto 20mm	20 upto 24mm	24mm and above	Total
TTQ9052 (11)	41	9	5	12	67
TTQ9052 (13)	27	11	14	20	72
TTQ9052 (15)	47	13	4	11	75
Total	115	33	23	43	214

Table 2. Classification by Types of Eddy Current Signals

Unit: Pieces

Lot No.	Sudden single pulse	Overall high noise	Pulse in a group	Total
TTQ9052 (11)	21	3	2	26
TTQ9052 (13)	28	13	4	45
TTQ9052 (15)	16	1	11	28
Total	65	17	17	99

The tubes which indicated eddy current signals of more than 16mm amplitude on the recording paper were about 39% of the total of lot number (11), about 63% of lot number (13) and about 37% of lot number (15). Among these tubes which indicated eddy current signals of more than 16mm amplitude, the tubes which showed single pulse signal were about 66% of them, and it is considered that among these tubes there might be some which have certain independent defects.

The tubes which showed an overall high background noise were about 17% of them, and the tubes which have indicated single pulse in a group was about 17%. It is considered among these tubes, there might be a certain number of tubes which have dimensional variation or unsatisfactory surface condition. These, however, will be made more certain or clarified in the future by a comparative study with the results of ultrasonic flaw detection tests.

9. Conclusion

As the results of various investigations and experiments performed with respect to the eddy current detection test on FBR cladding tubes of stainless materials, the following items have been found out:

(1) The eddy current detector can find out the flaws which are difficult to be detected by the ultrasonic flaw detector due to its shape and location.

These flaws are detectable by improving the existing ultrasonic flaw detection method and also by using the system in which the ultrasonic flaw detector is used in combination with the ultrasonic thickness gauge.

(2) The eddy current detector can precisely and accurately detect the surface caves, pits, or griding parts of surface.

(3) The eddy current detector frequently indicates signals of flaws or gives a larger background noise due to the localized wall thickness variations or inner diameter changes.

(4) A coarse surface, sometimes affect and increase the background noise of the eddy current recording chart.

(5) Other than above, in some cases, the eddy current detection gives out signals of unknown causes.

Through these experiment, the following results have been acquired, which will be a helpful guidance for the future work, and by which the hitherto used and followed processing technique has been greatly improved and thus, the product quality and performance guaranty have been substantially raised.

In the application of the eddy current detection method:

(1) It must be tested prior to a grinding finish (in the case of an intermediary inspection).

(2) It must be applied as a prior process in advance of the ultrasonic flaw detection (in the case of product inspection). Further, in relation to the ultrasonic detection process:

(3) The ultrasonic flaw detection should be applied in combination with an ultrasonic wall thickness gauge.

However, in the application of the eddy current detection method, there are some unknown signals, therefore, it is necessary that it should have a high reliability similar to that of ultrasonic detection method, while it may be yet dependent on a further detailed investigation.

Acknowledgements

Our sincere appreciation is hereby expressed to all the persons concerned in the PNC's Tokai Works, particularly, to Mr. Toshimasa Aoki, Inspection Chief, and Mr. Yoshitoku Takeishi, Inspection Supervisor, for their asstance and cooperation in leasing and making available to us the eddy current detector and other instruments.

Table 1 Testing Condition

Feeding Speed	1.5 m / min
Chart Speed	5 mm / sec
Sensitivity I.D.	10mV / div
Sensitivity O.D.	10mV / div
Rotation	30
Gain	60

Table 2 Testing Condition

Feeding Speed	1.5 m/mis
Chart Speed	1 mm/sec 5 mm/sec
Sensitivity I.D.	10mV/div
Sensitivity O.D.	10mV/div
Rotation	15
Gain	20

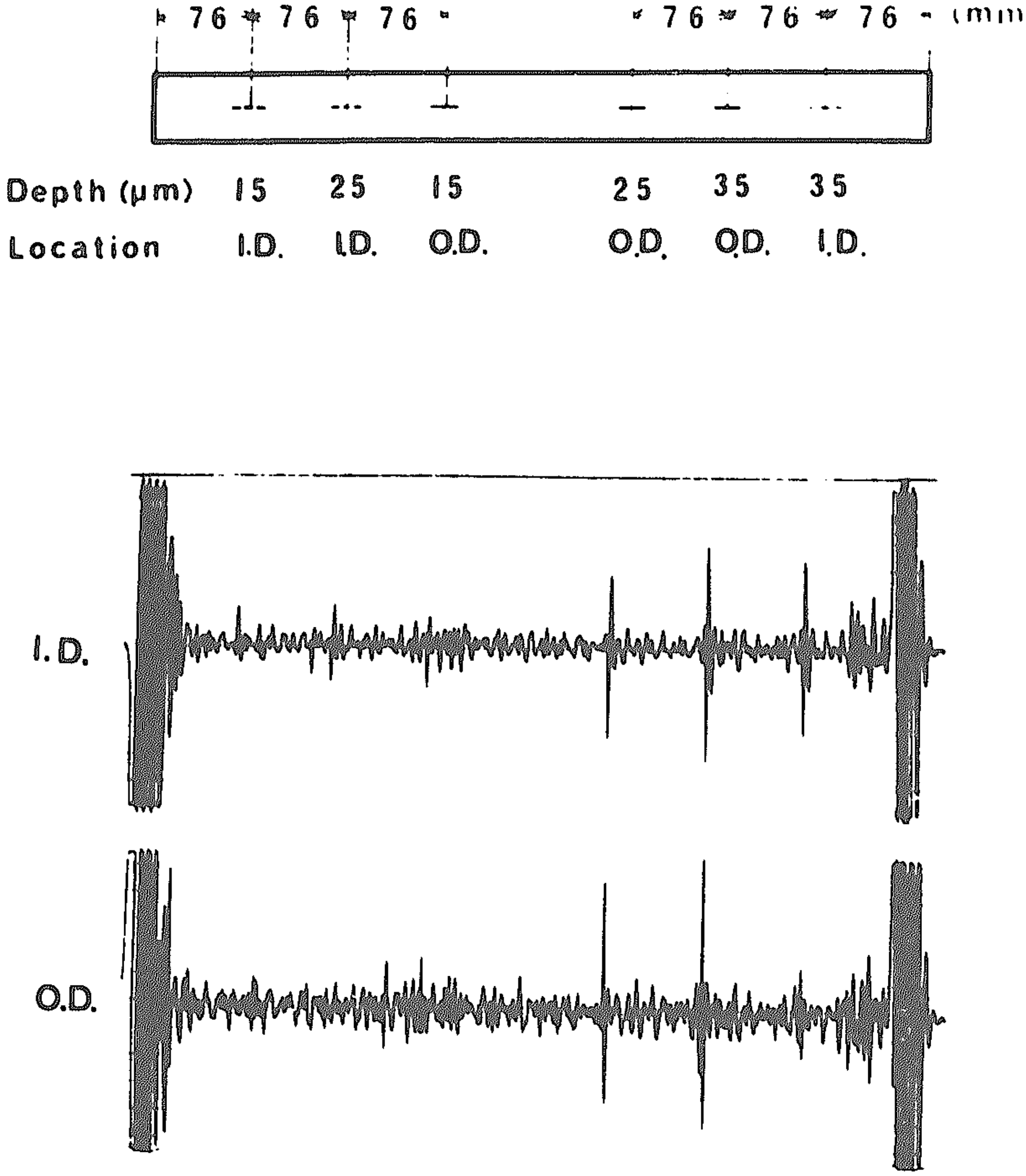
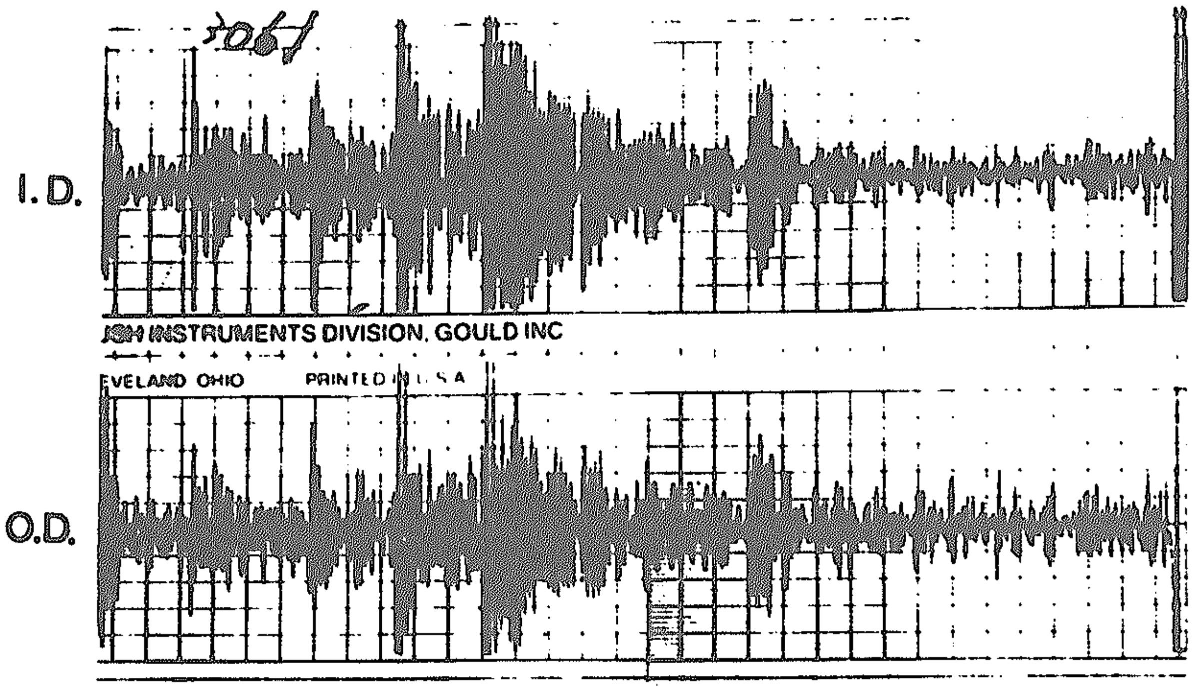
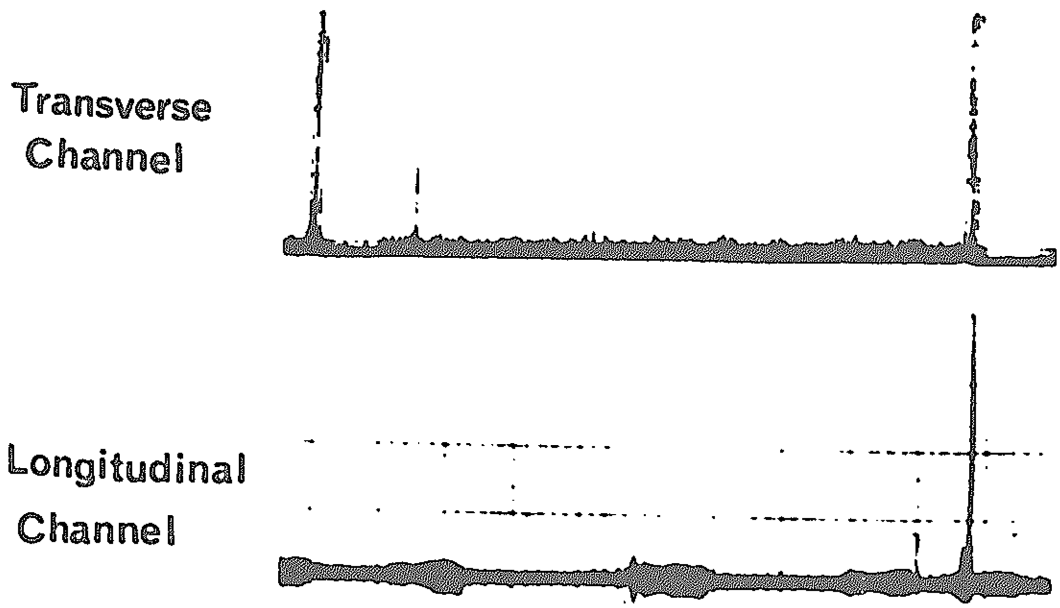


Fig.1 Eddy Current Recording Chart of Standard Tube

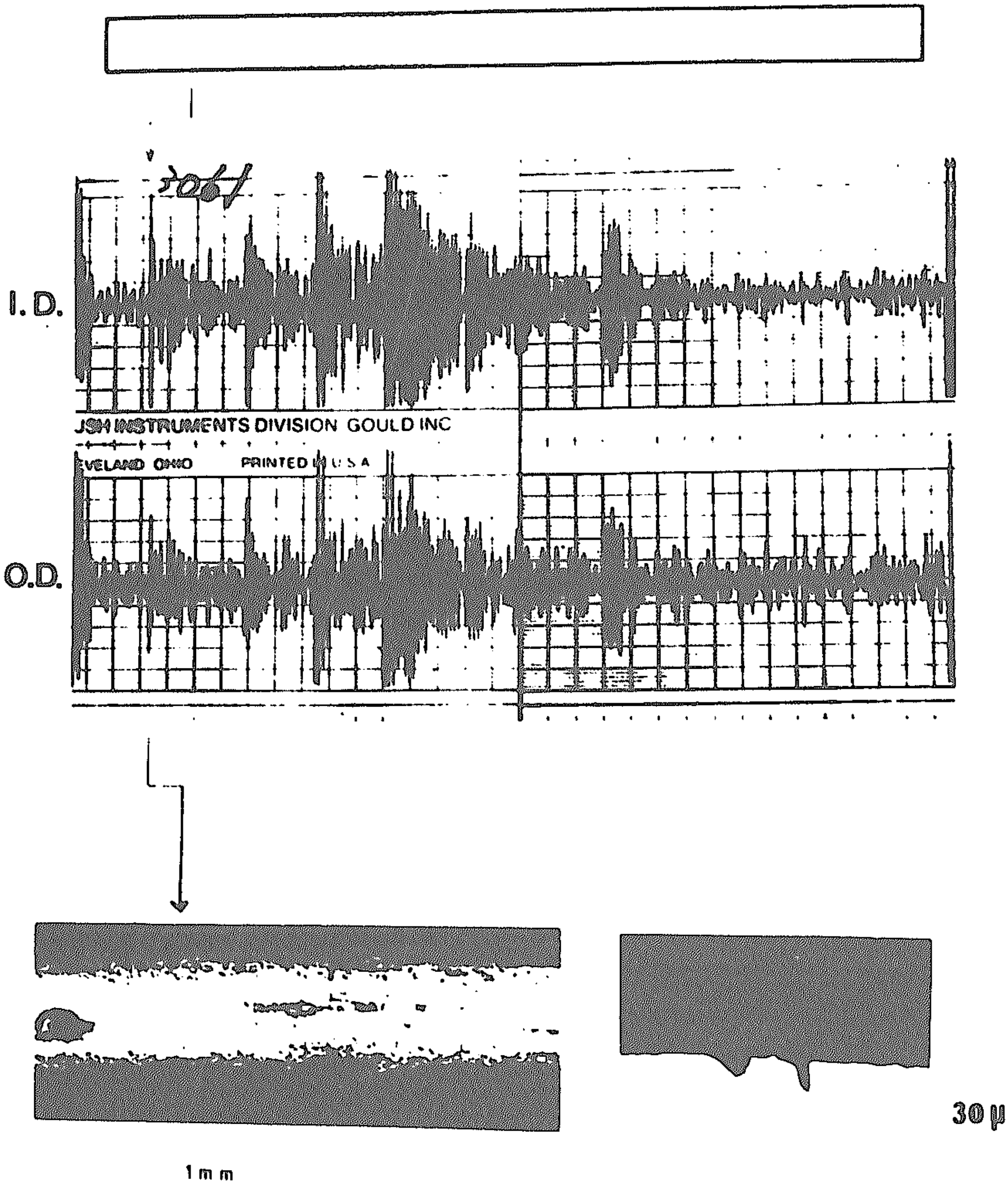


(a) Eddy Current Recording Chart



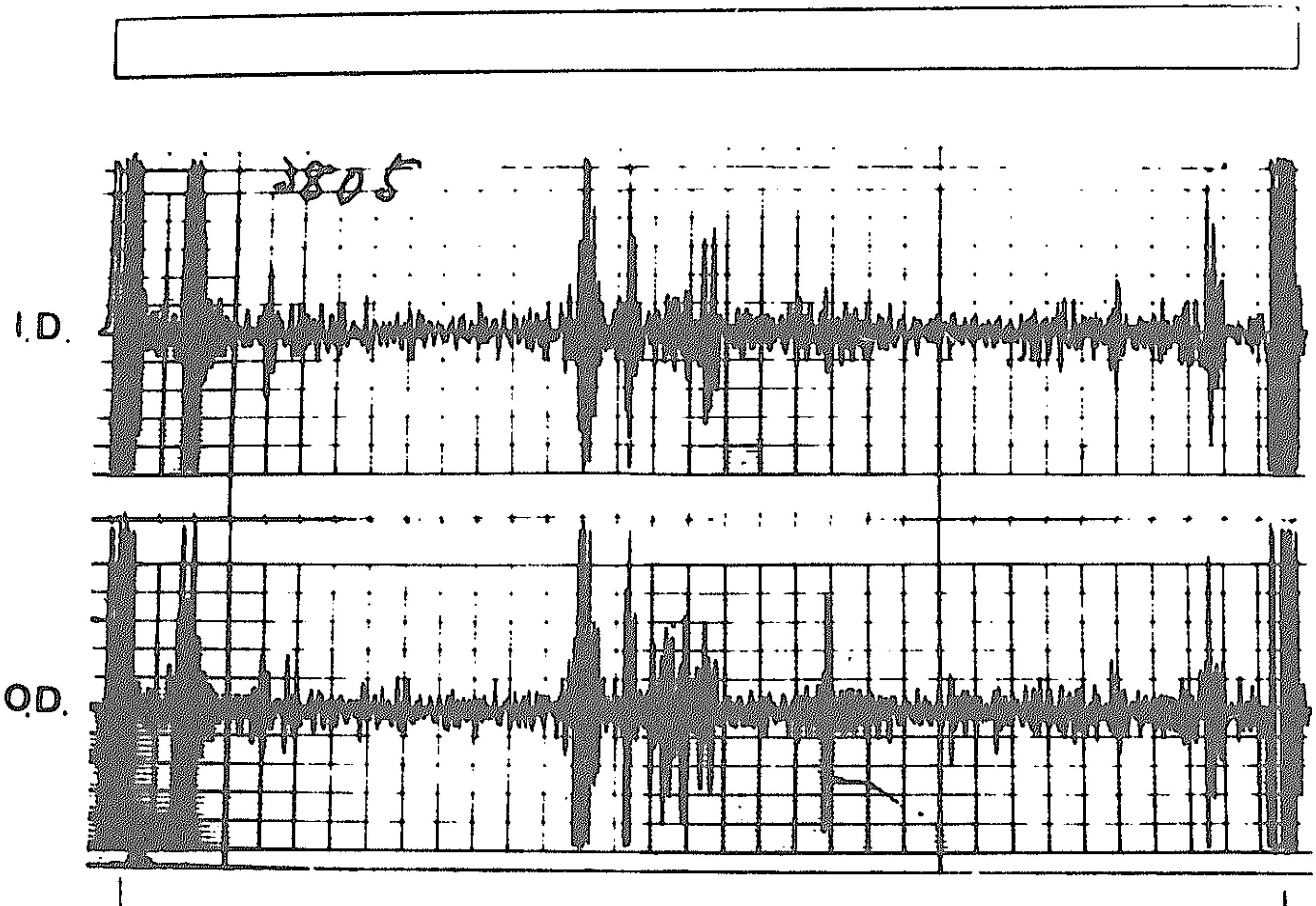
(b) Ultrasonic Recording Chart

Fig. 2 Tube S 3061

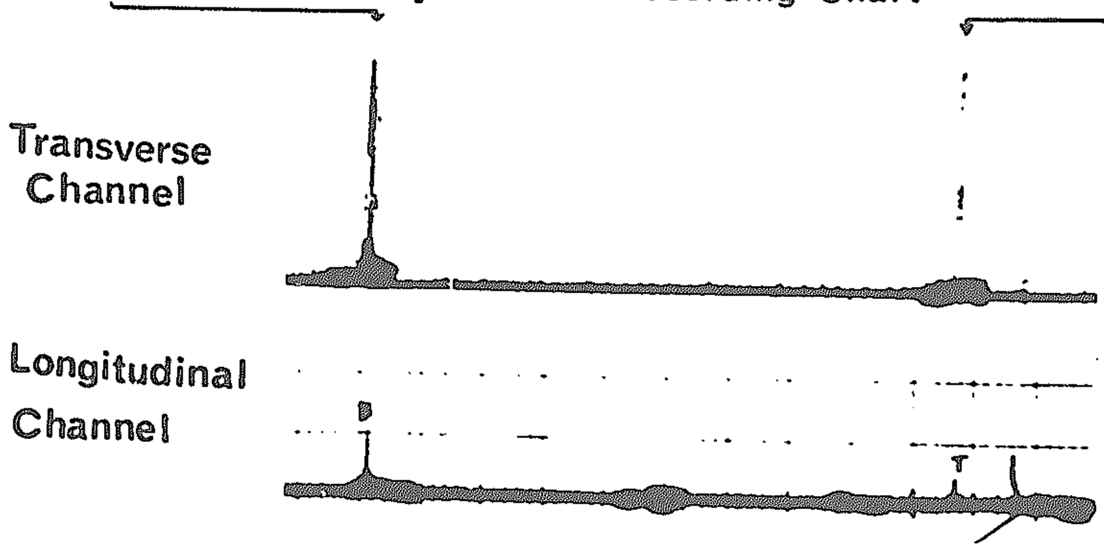


(c) Surface View (d) Transverse Cross-section

Fig.2 Tube S3061

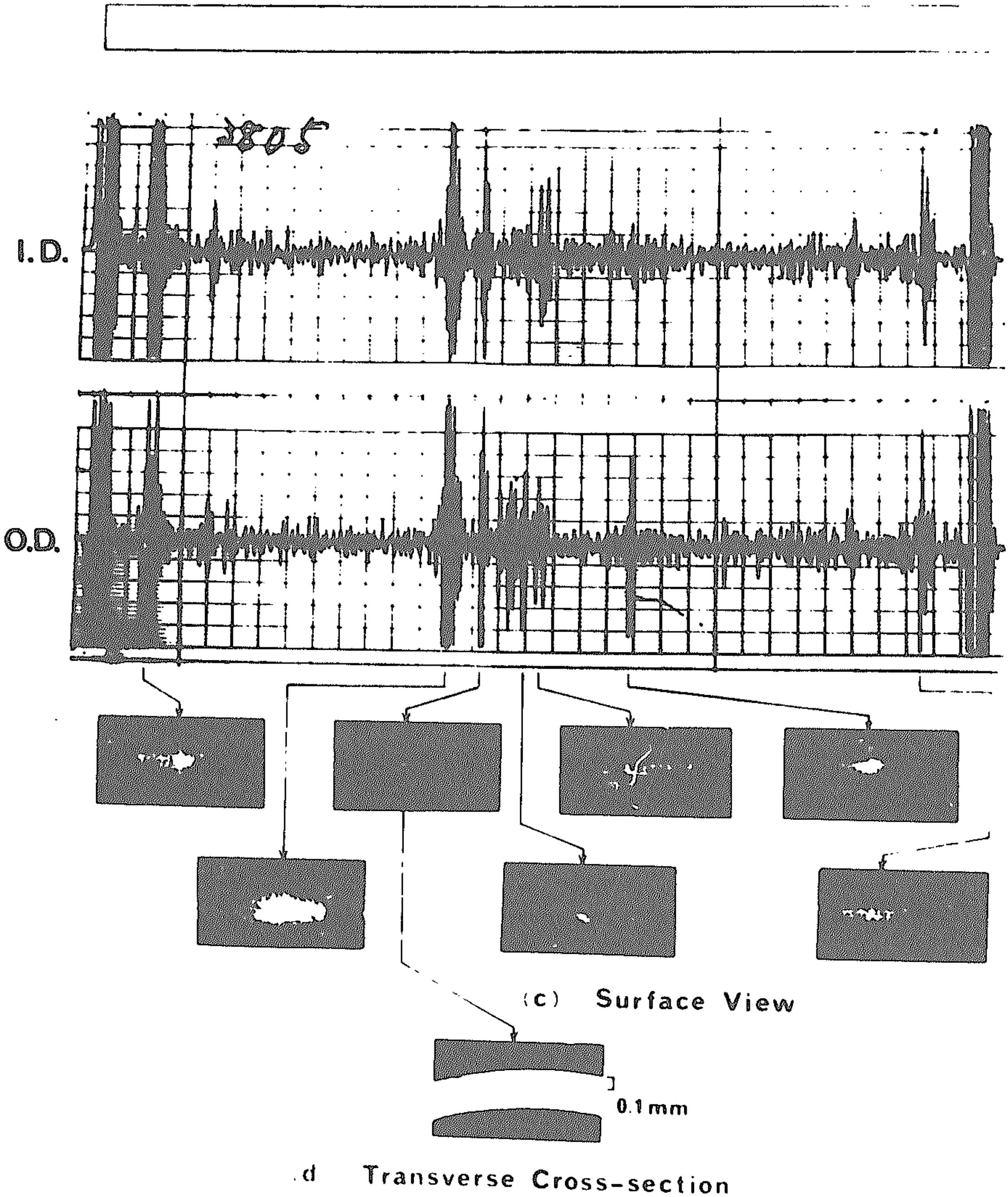


(a) Eddy Current Recording Chart



(b) Ultrasonic Recording Chart

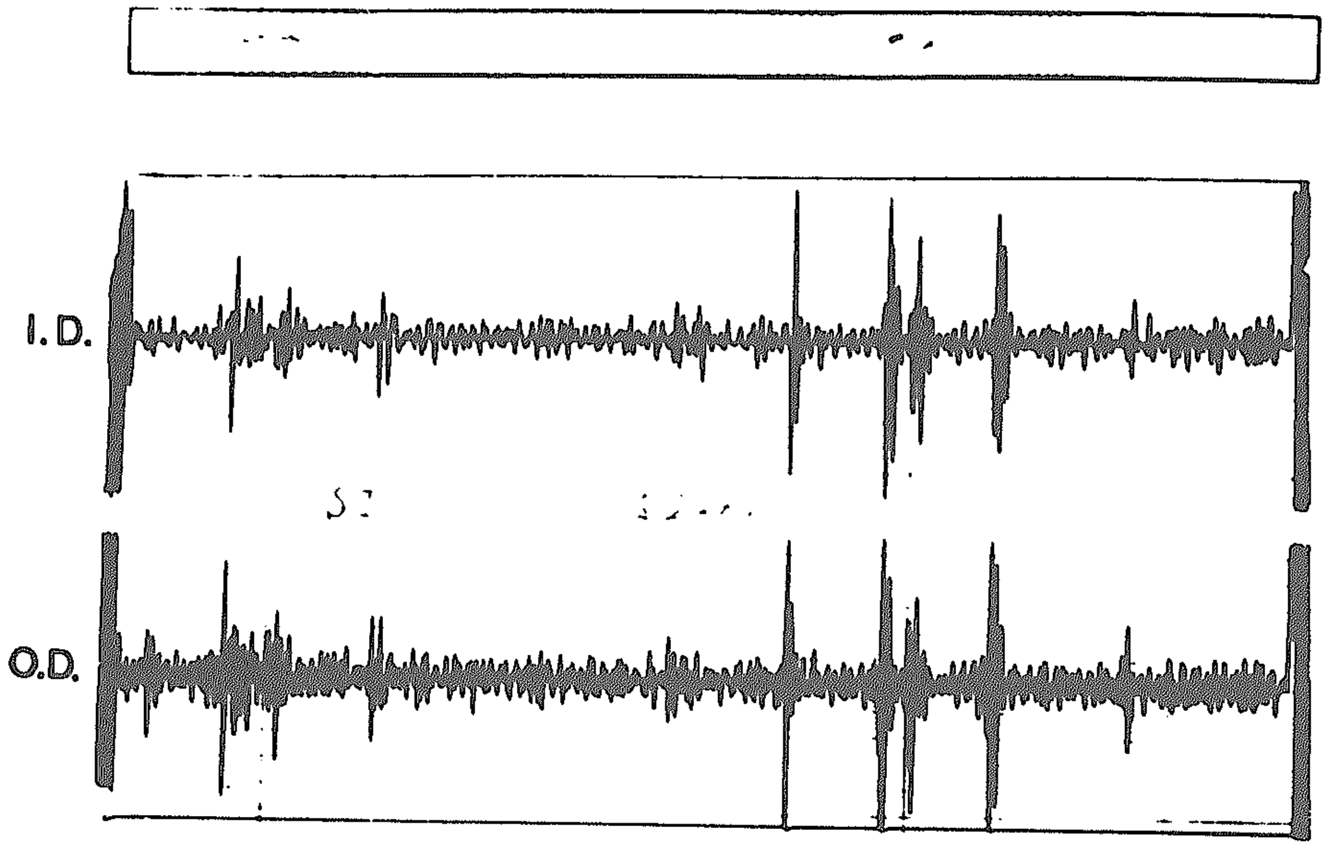
Fig.3 Tube S3805



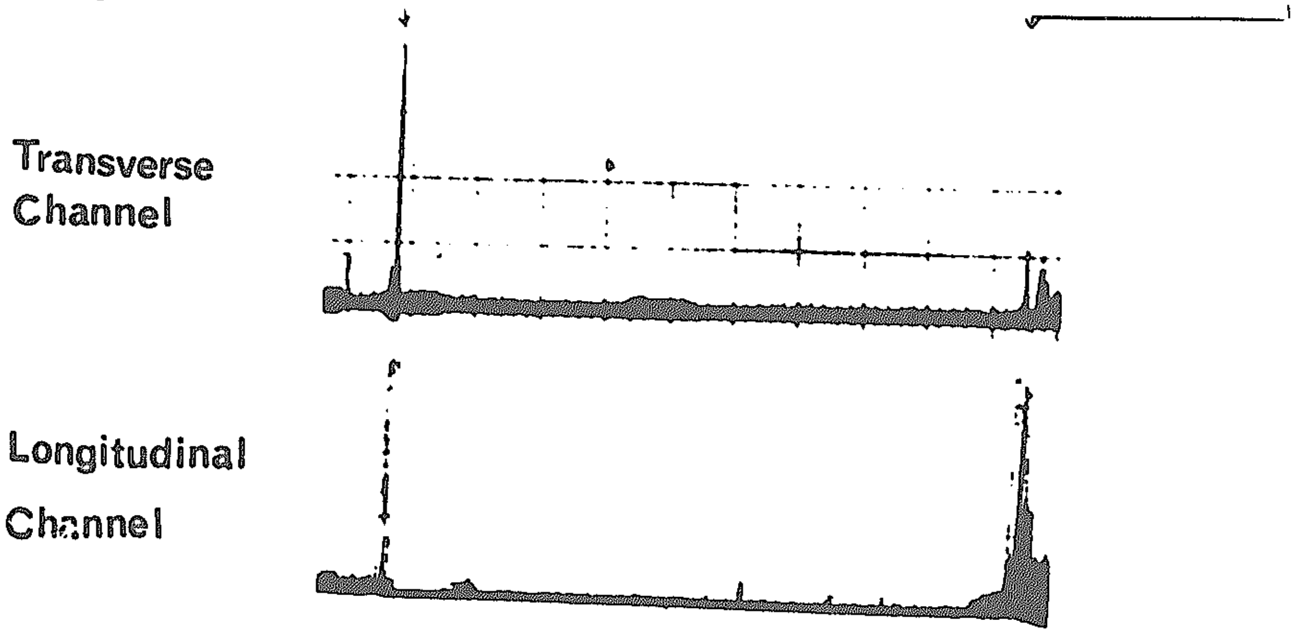
(c) Surface View

(d) Transverse Cross-section

Fig.3 Tube S3805

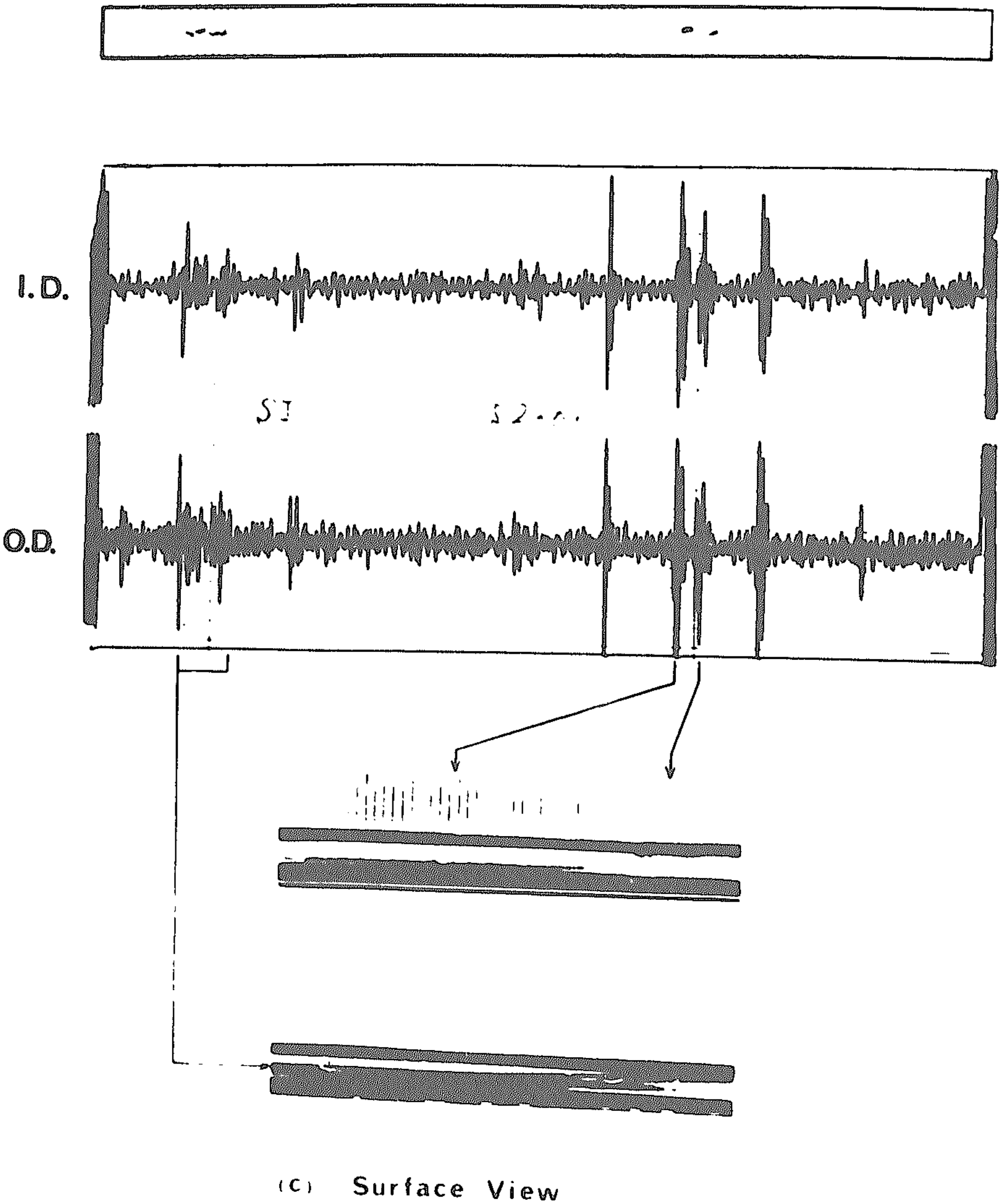


(a) Eddy Current Recording Chart



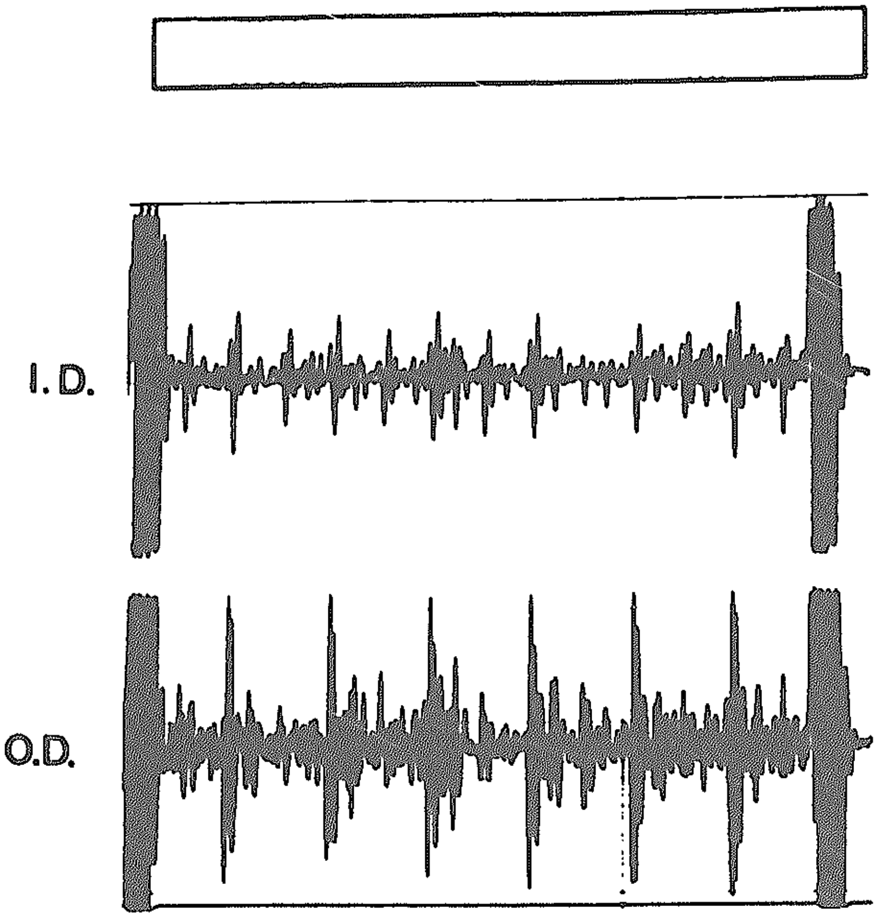
(b) Ultrasonic Recording Chart

Fig.4 Tube S2601

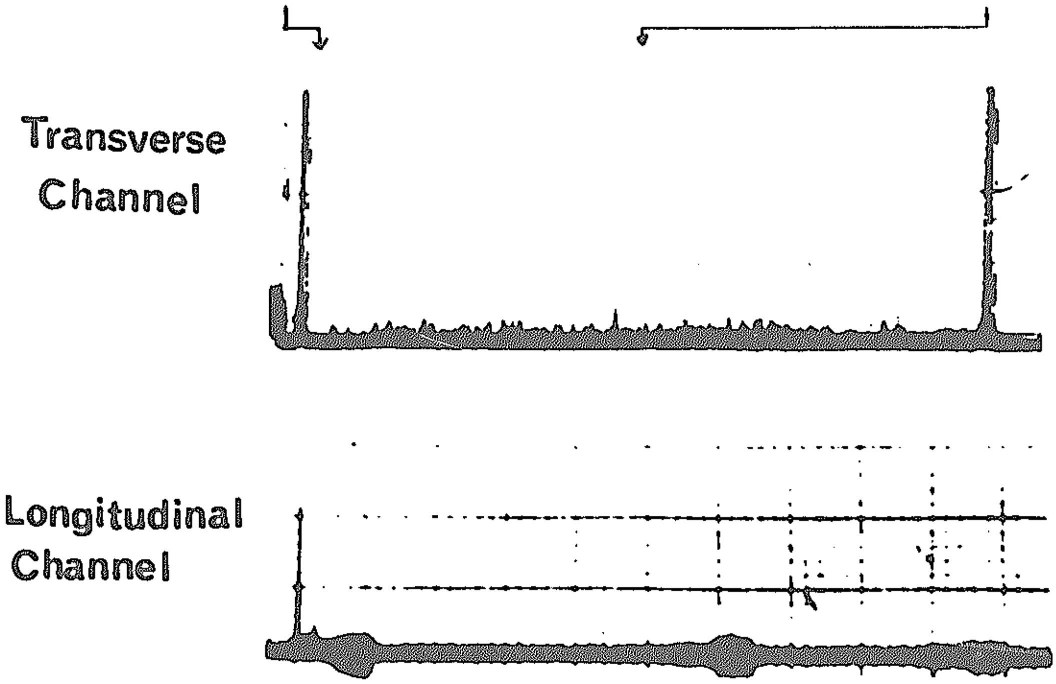


(C) Surface View

Fig. 4 Tube S2601



(a) Eddy Current Recording Chart



(b) Ultrasonic Recording Chart

Fig.5 Tube S3451

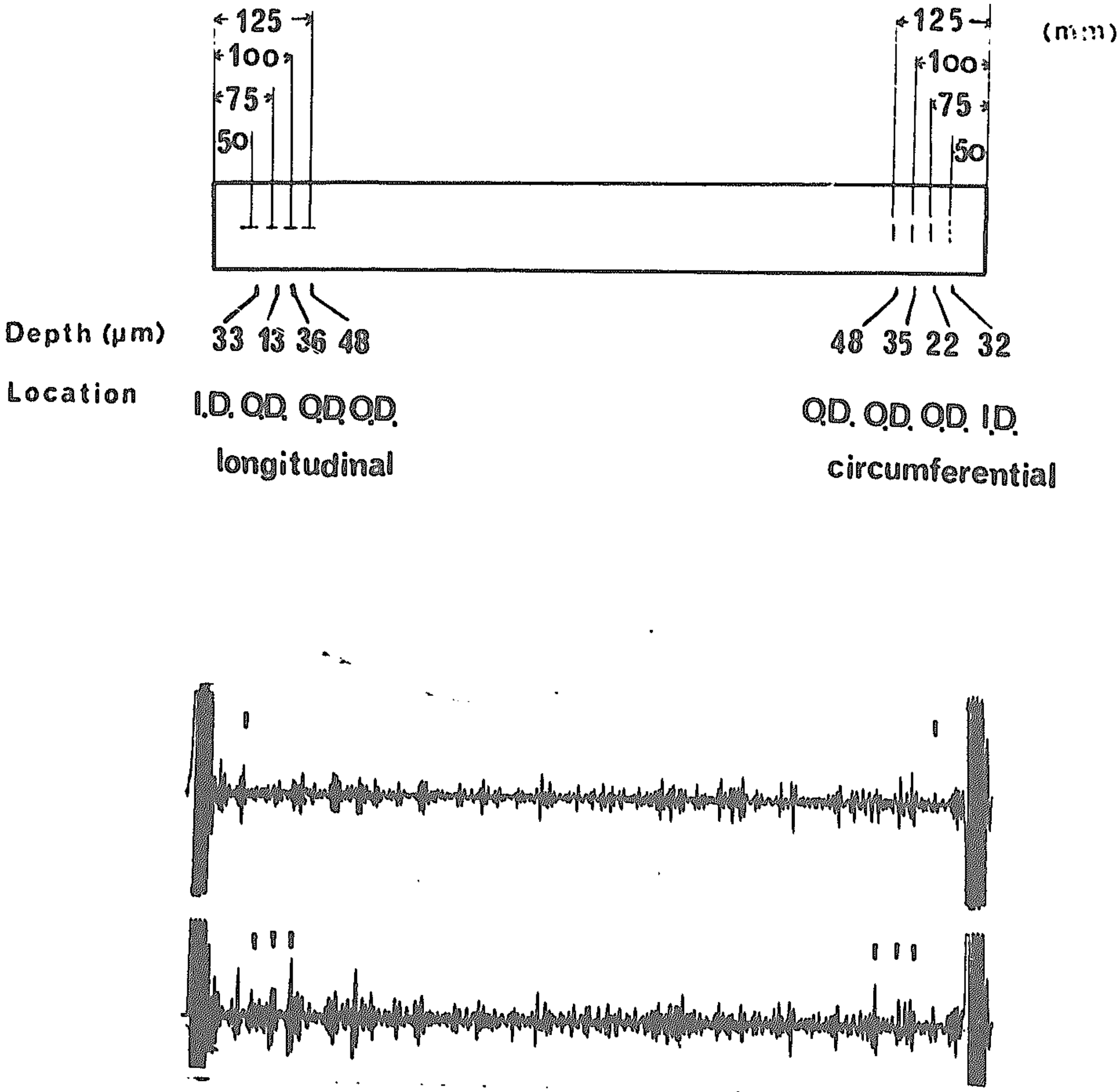
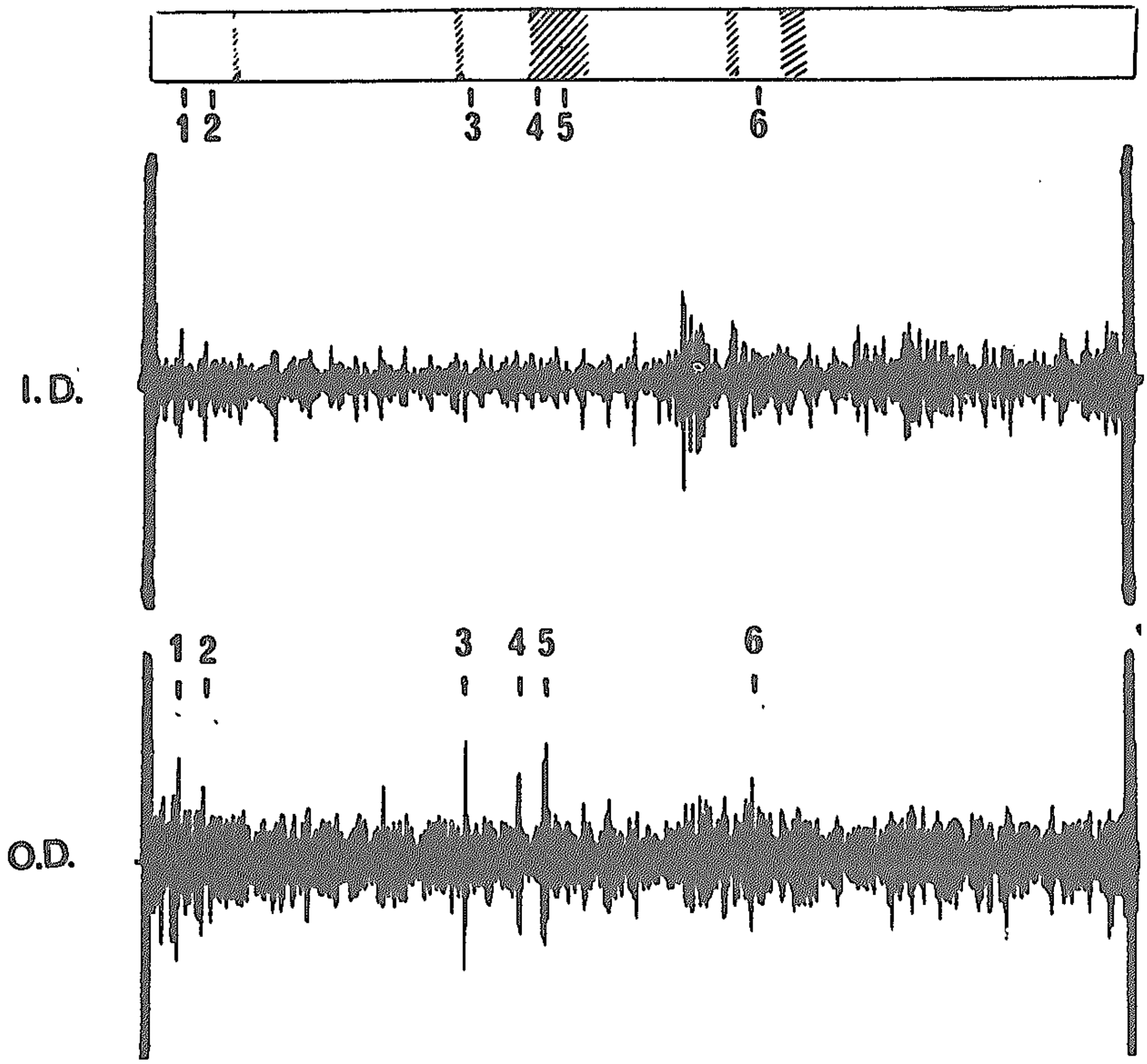
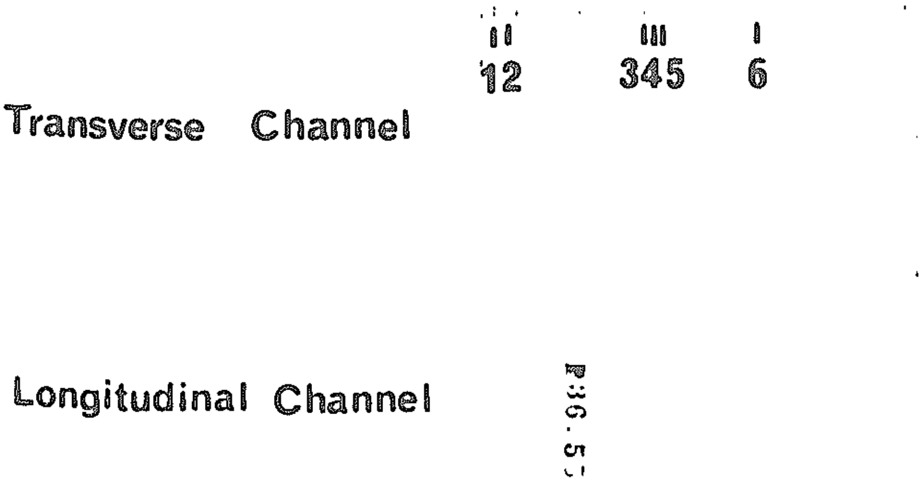


Fig.6 Eddy Current Recording Chart of Standard Tube

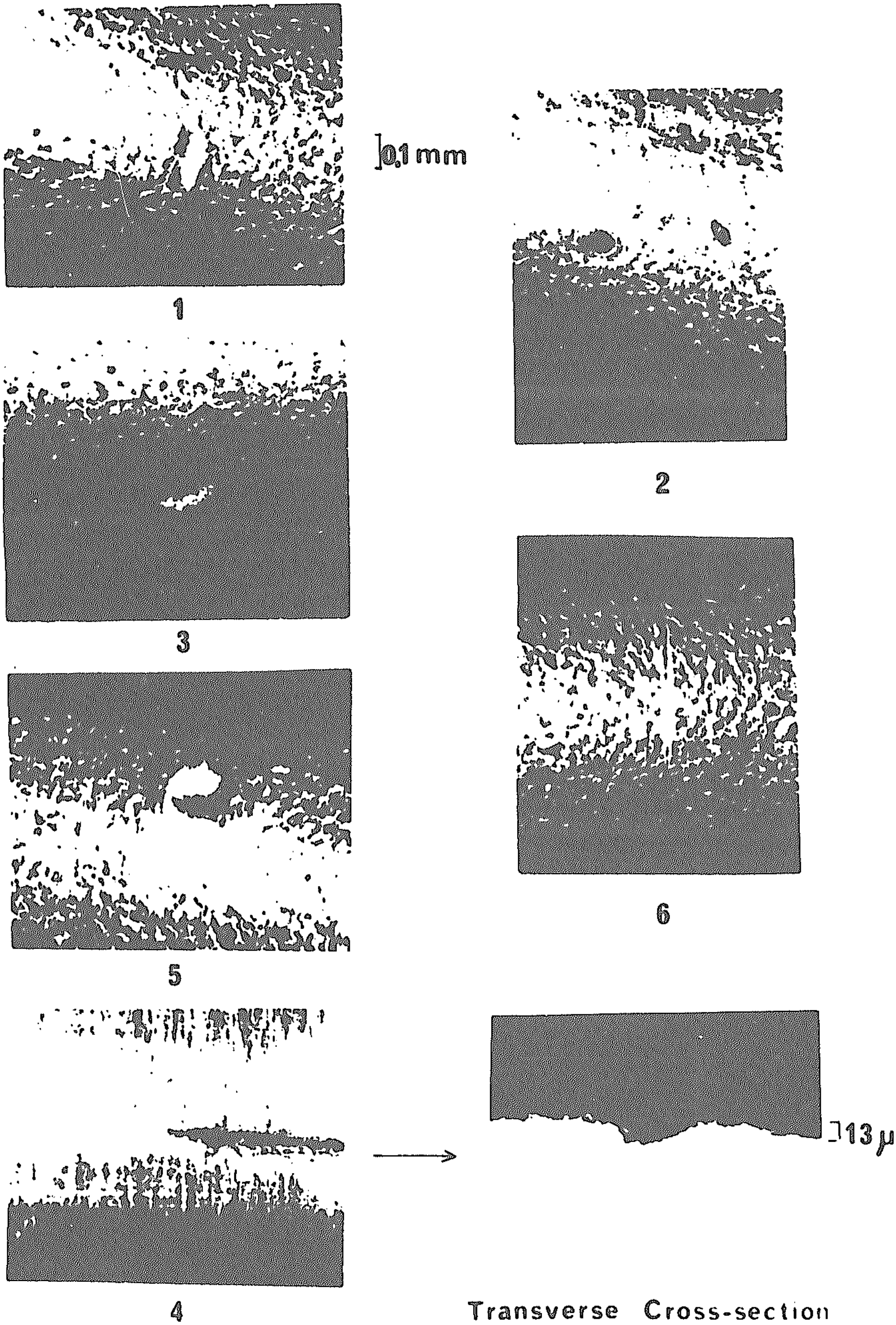


(a) Eddy Current Recording Chart

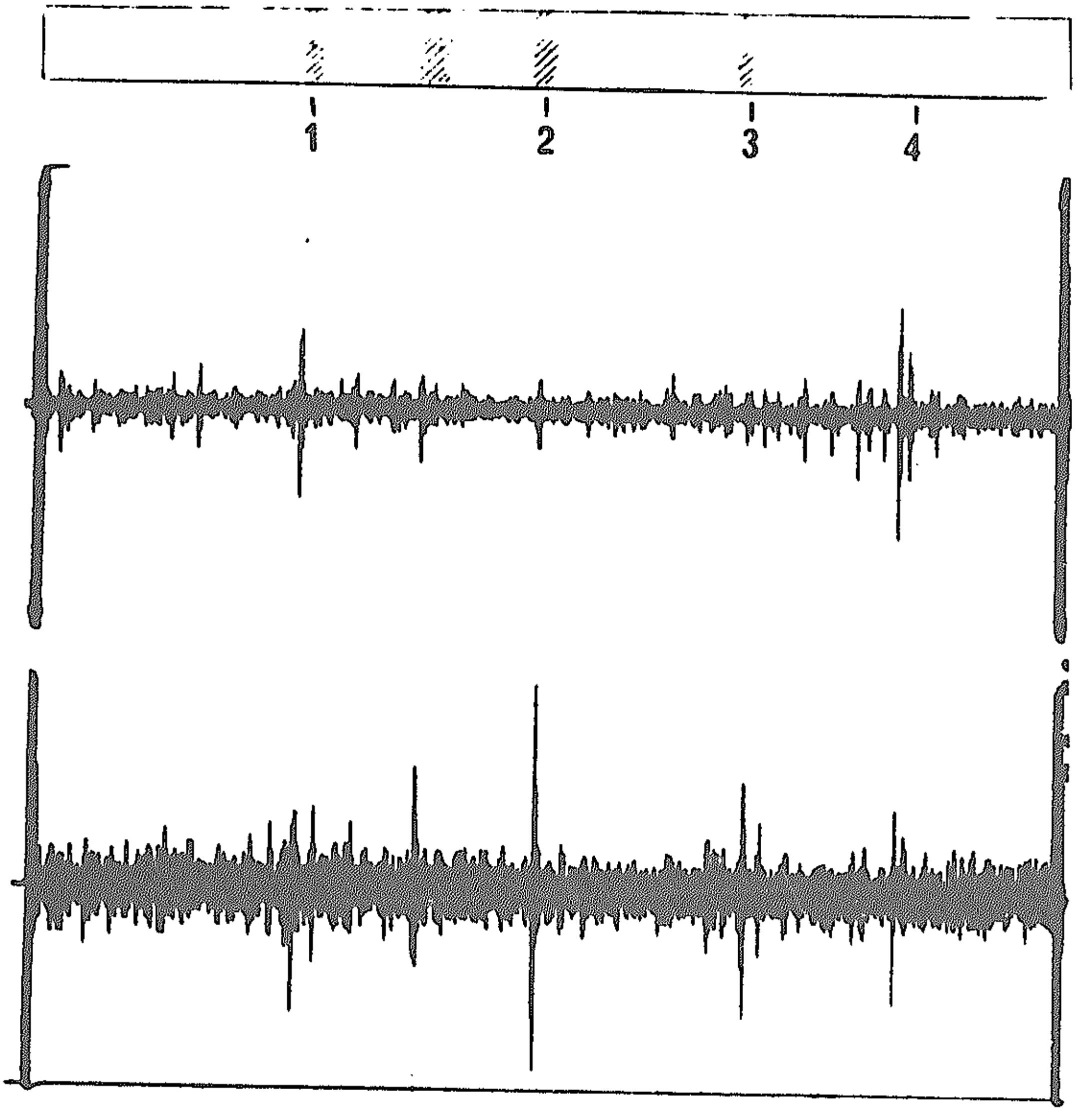


(b) Ultrasonic Recording Chart

Fig.7 Tube 36 5 5



(C) Micrograph Of The Defect



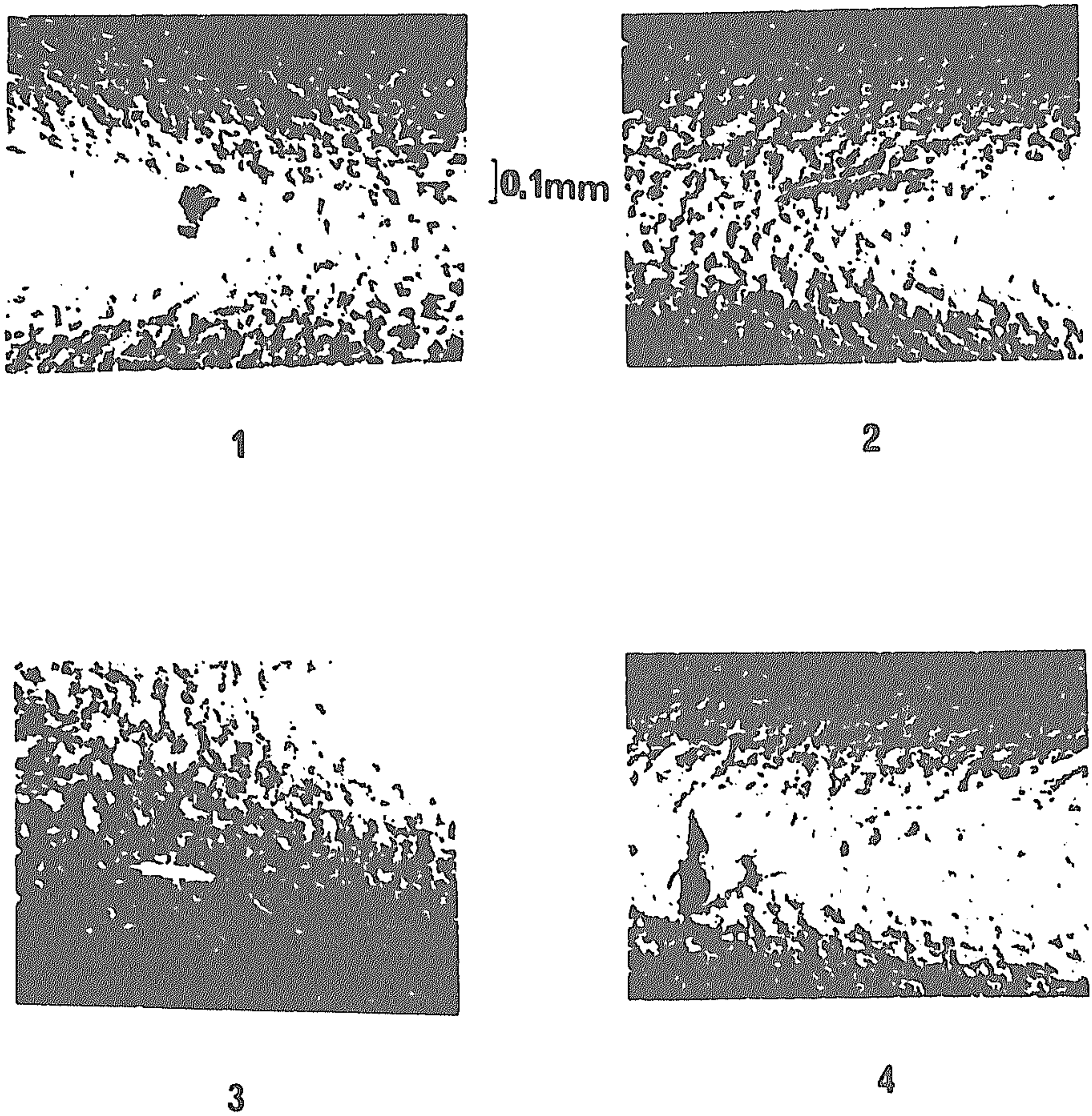
(a) Eddy Current Recording Chart

Transverse Channel

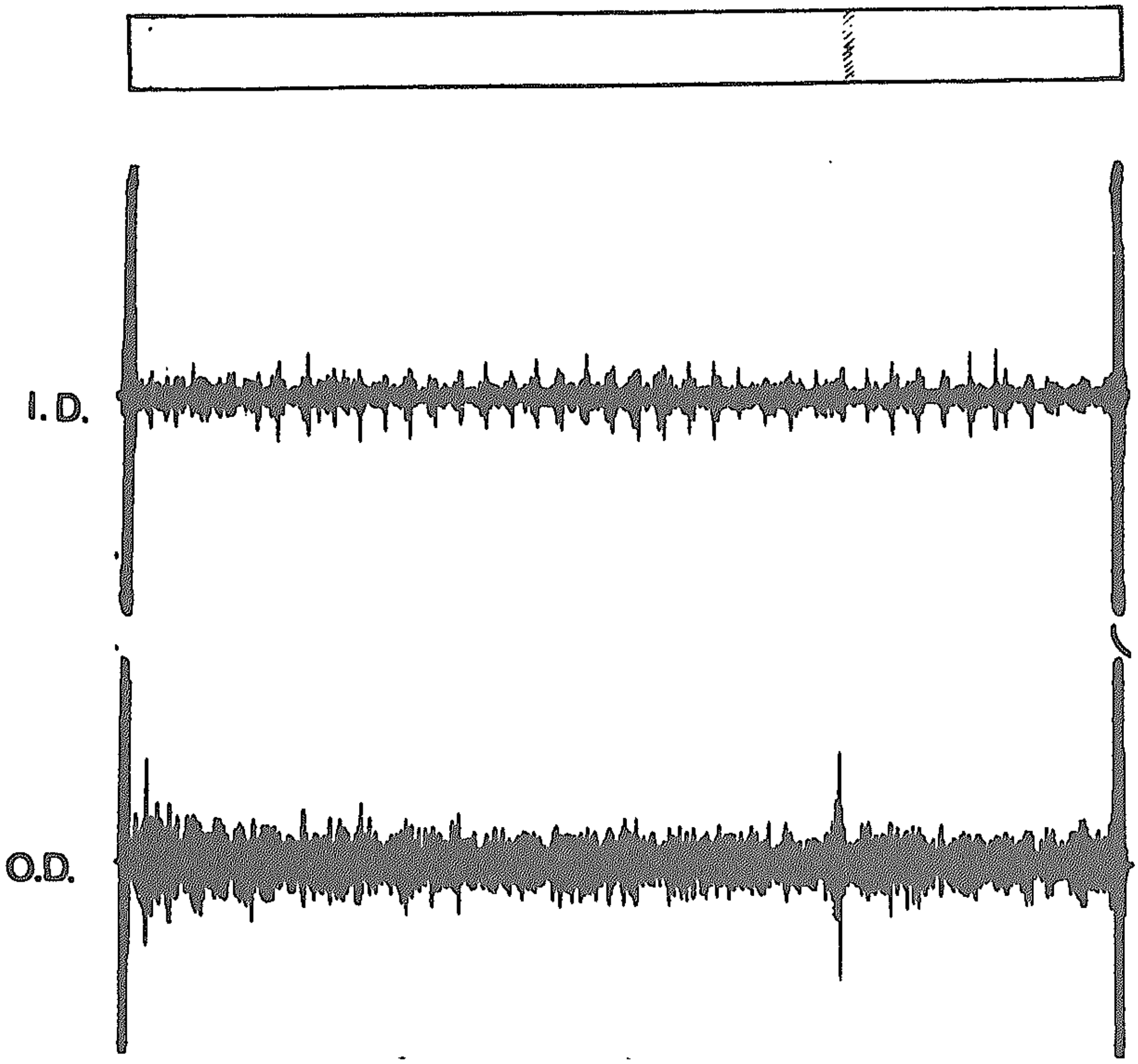
Longitudinal Channel

b. Ultrasonic Recording Chart

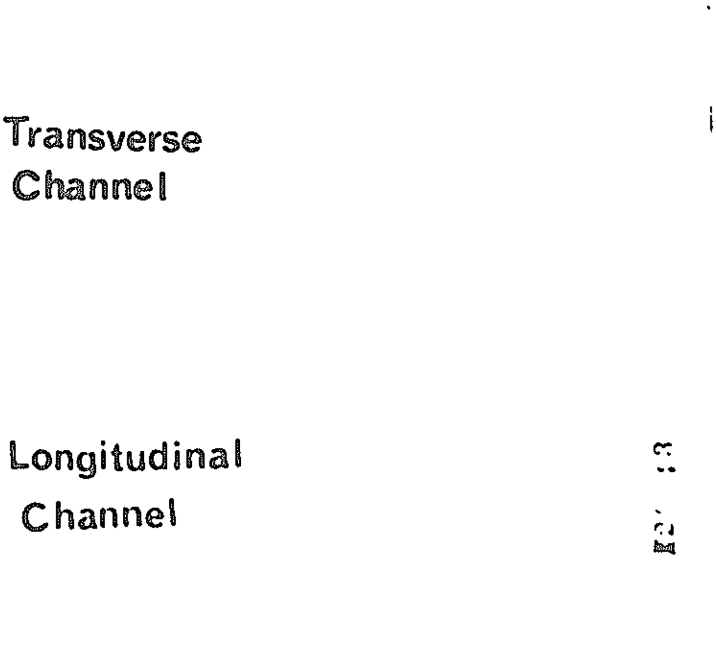
Fig. 8 Tube 26 09



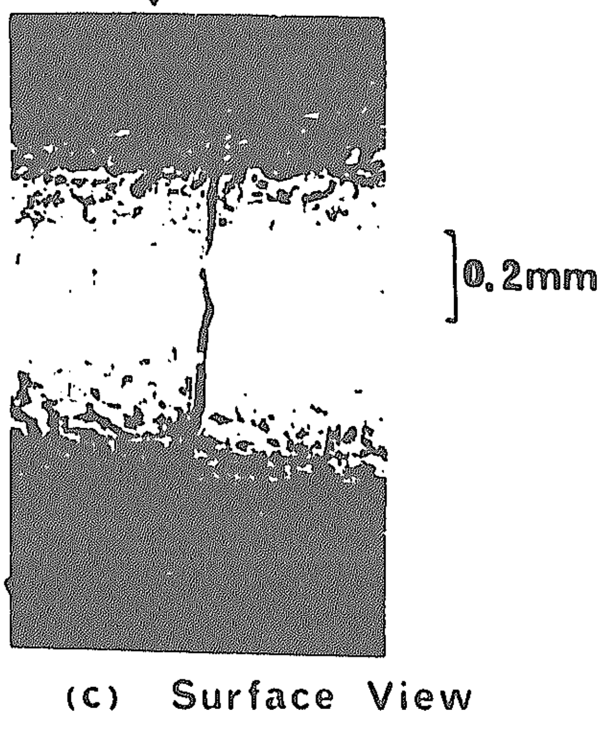
(C) Micrograph Of The Defect



(a) Eddy Current Recording Chart

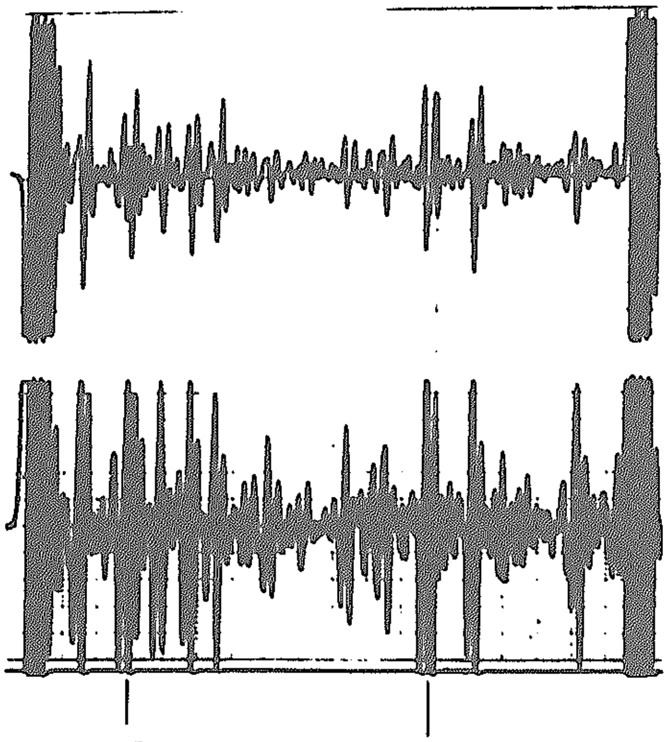


(b) Ultrasonic Recording Chart

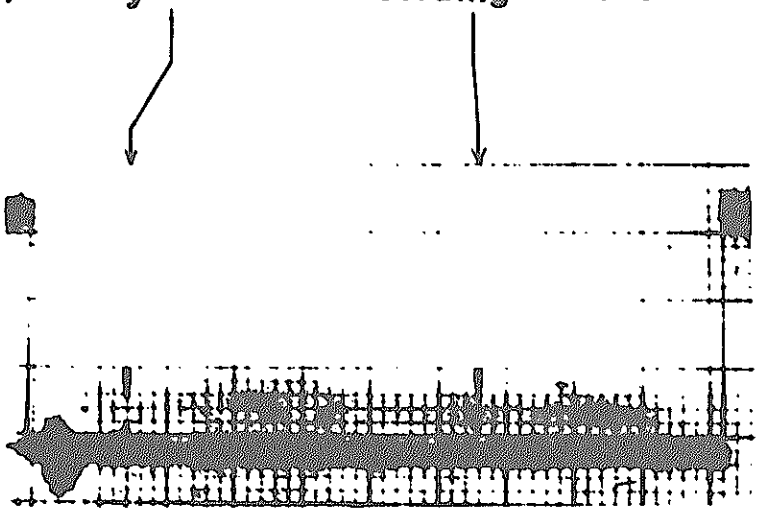


(c) Surface View

Fig.9 Tube 26 43

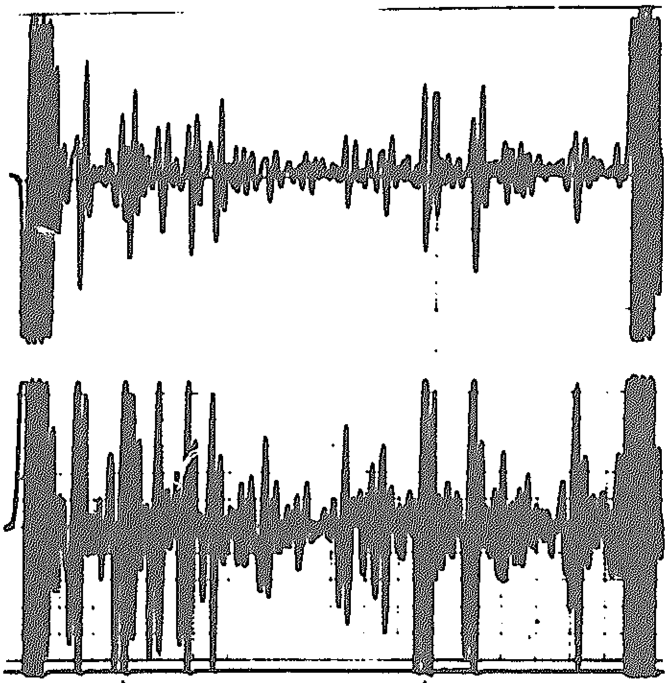


(a) Eddy Current Recording Chart

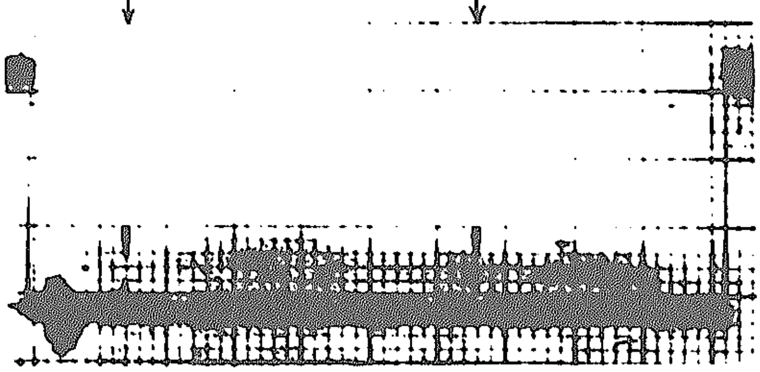


(b) Wall Thickness Shown By Ultrasonic Wall Thickness Gauge

Fig.11 Comparison Between Variation of Wall Thickness and Eddy Current Signals

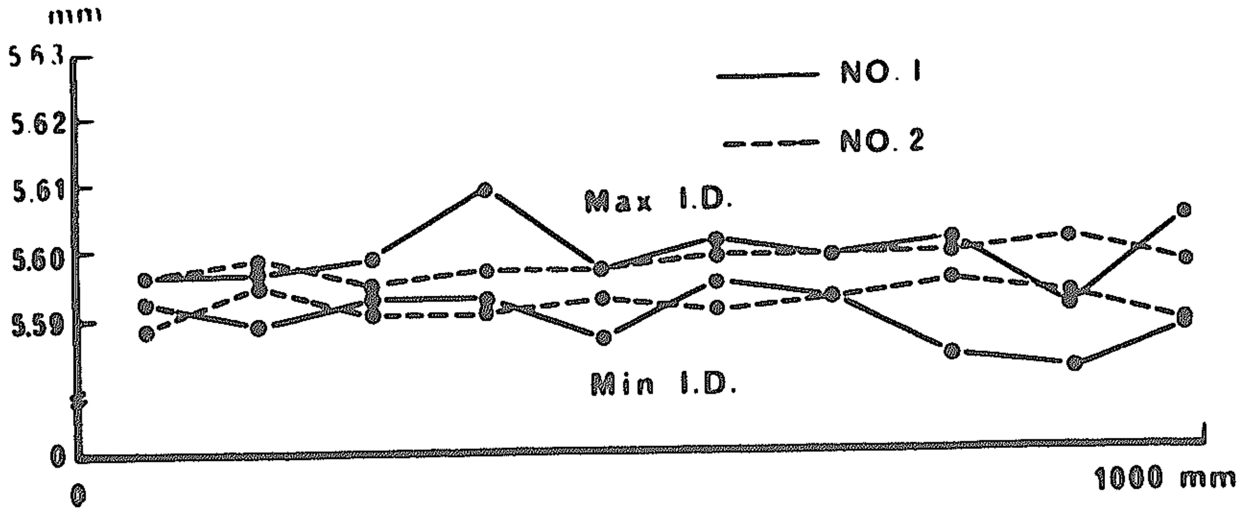


(a) Eddy Current Recording Chart

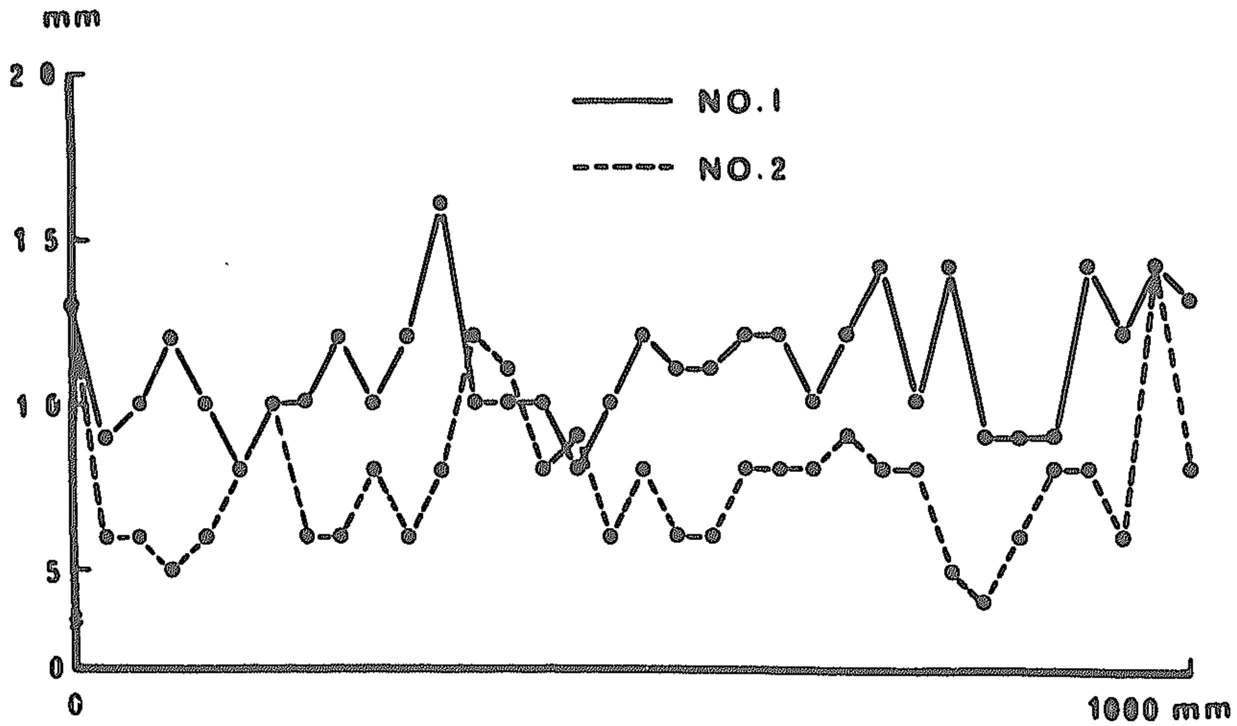


(b) Wall Thickness Shown By Ultrasonic Wall Thickness Gauge

Fig.11 Comparison Between Variation of Wall Thickness and Eddy Current Signals

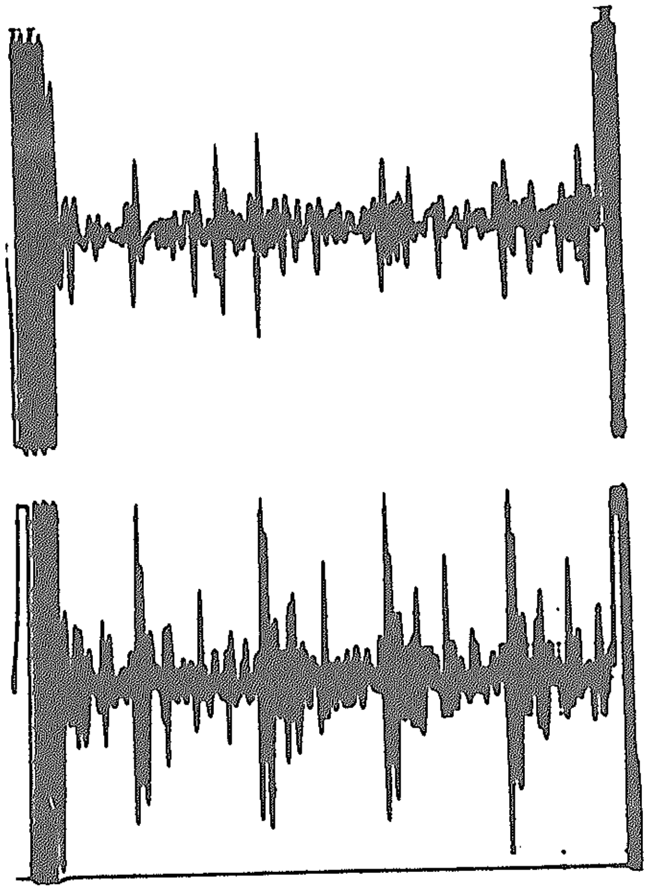


(a) Inner Diameter

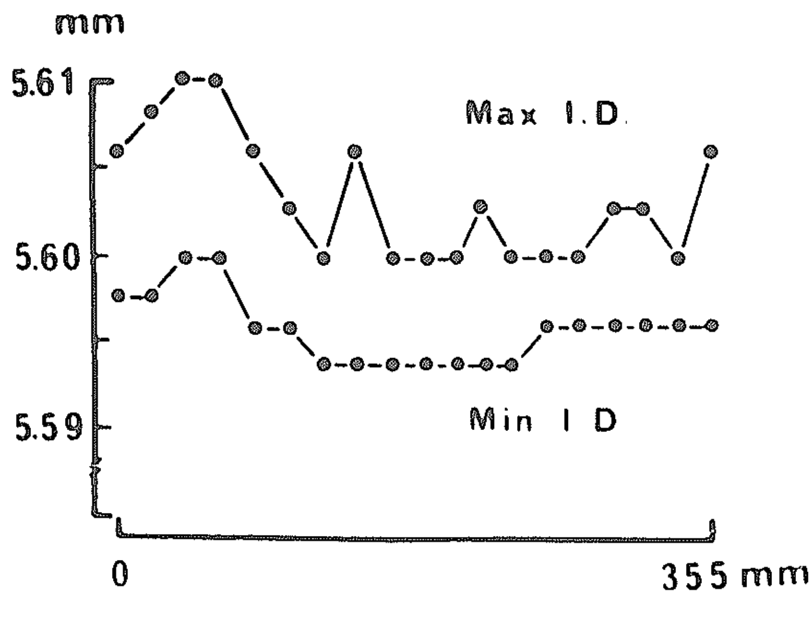


(b) Background Noise

Fig12 Comparison between Variation of Inner Diameter and Background Noise

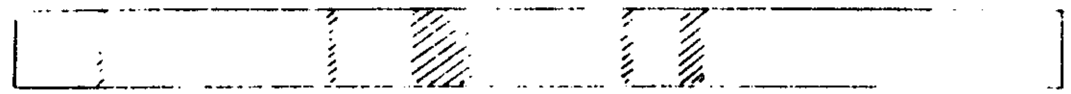


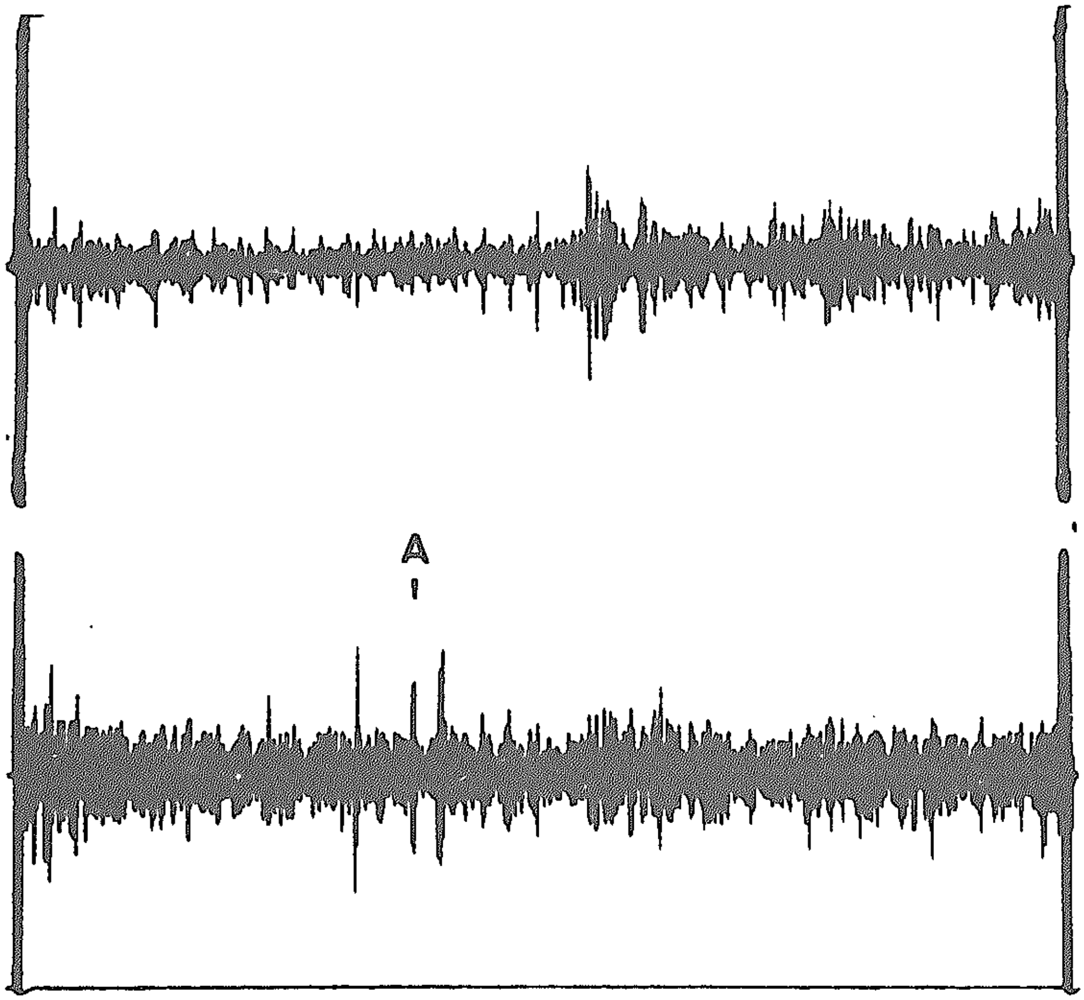
(a) Eddy Current Recording Chart



(b) Inner Diameter

Fig.13 Comparison Between Variation of Inner Diameter and Eddy Current Signals

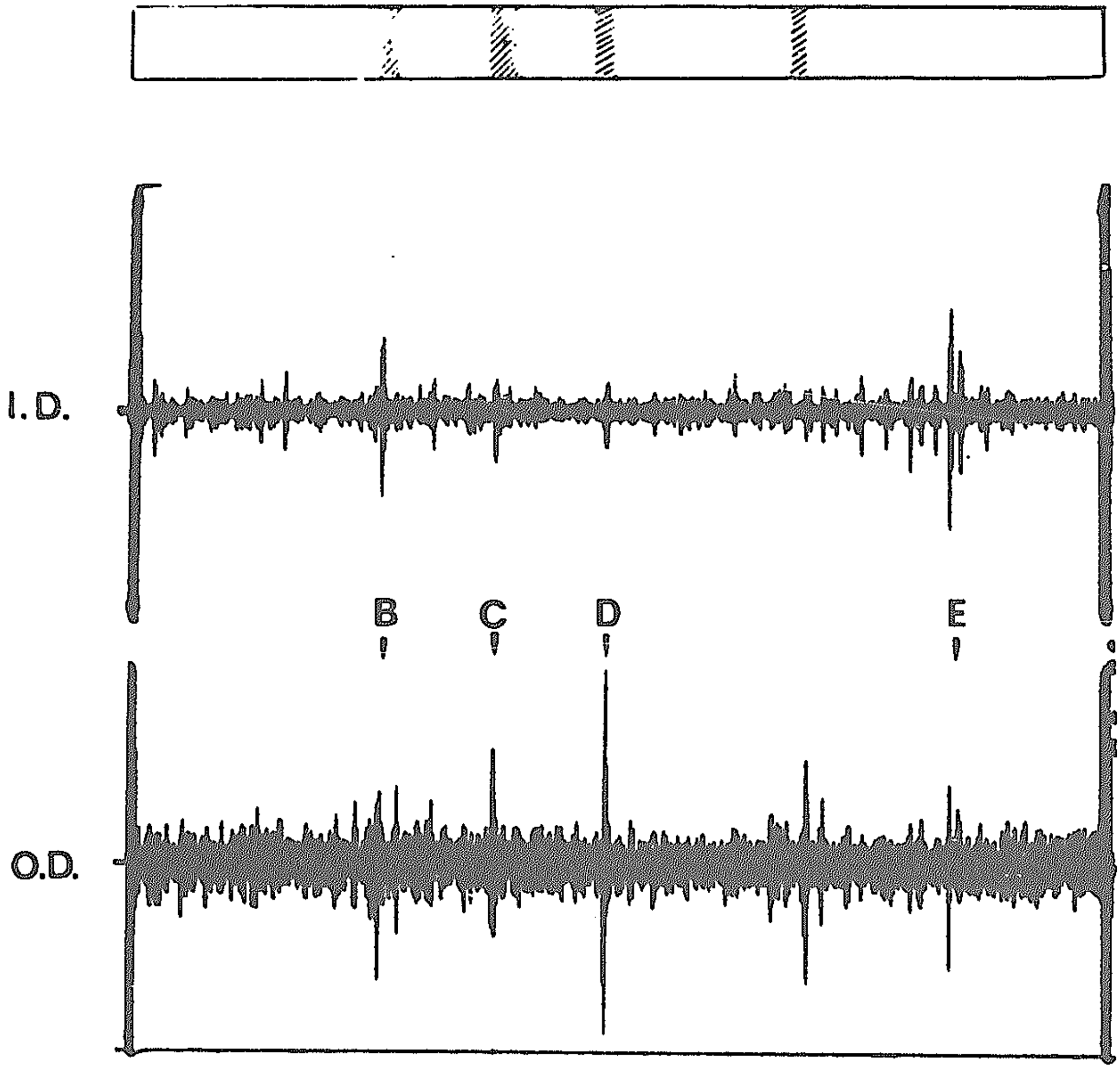




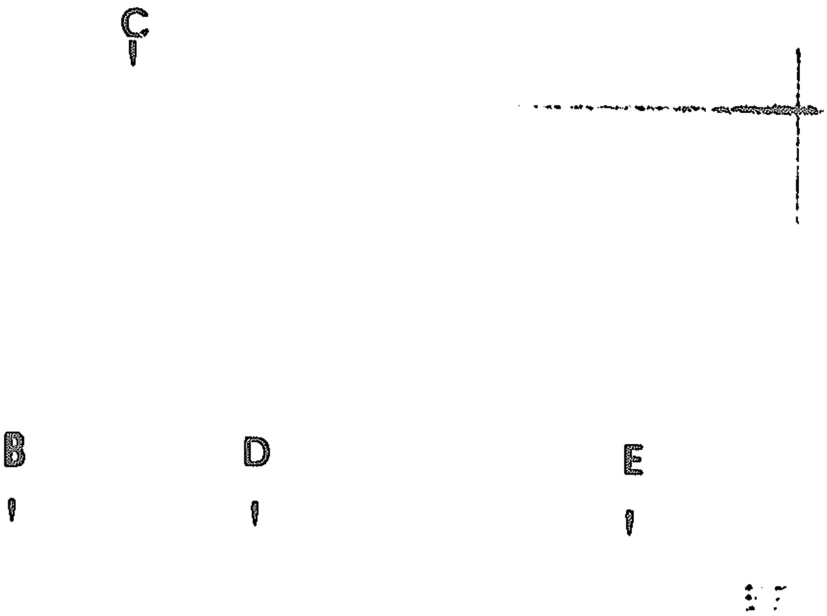
(a) Eddy Current Recording Chart

(b) Wall Thickness

Fig. 14 Comparison Between Variation Of Wall Thickness And Eddy Current Signals

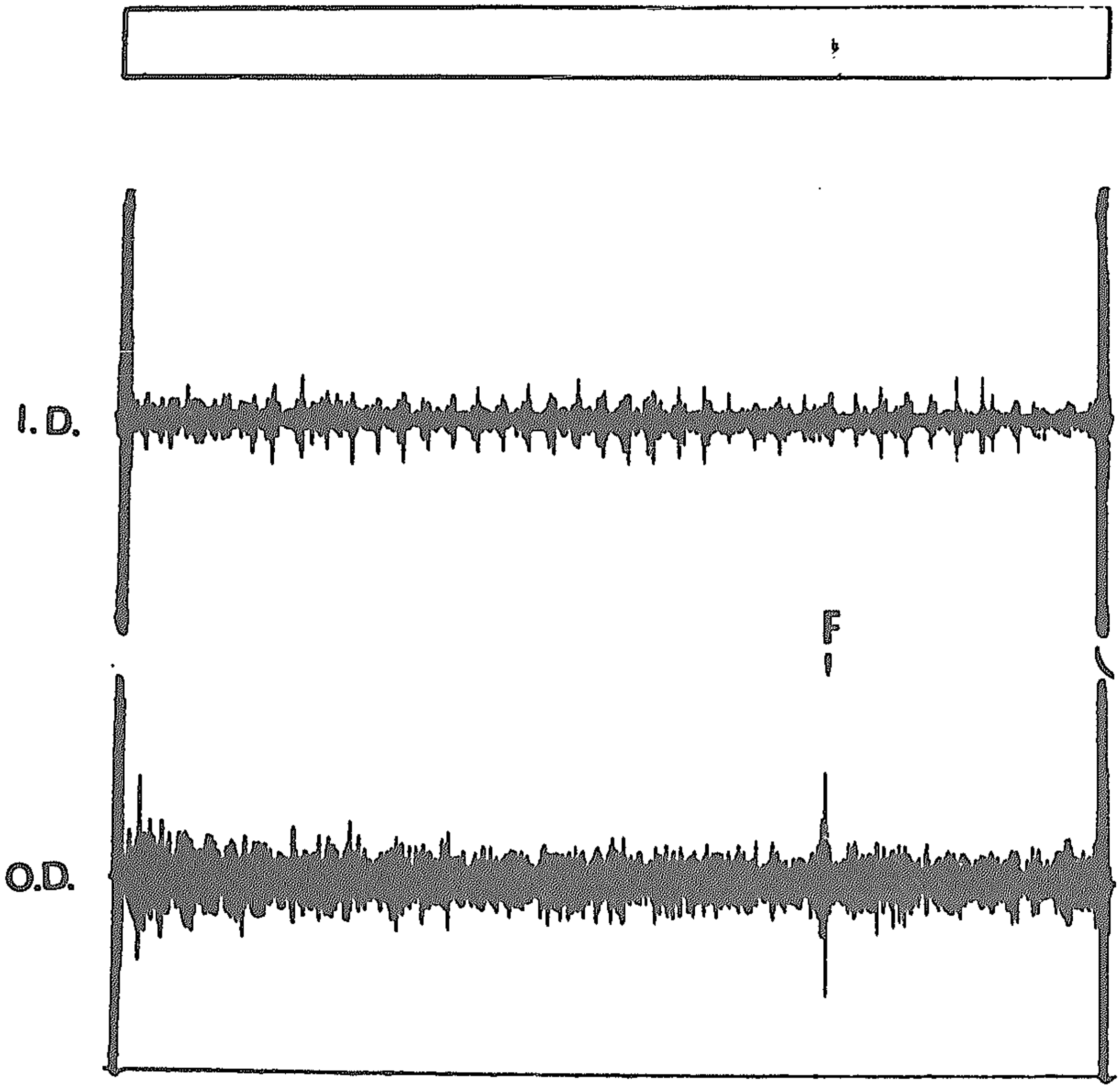


(a) Eddy Current Recording Chart



(b) Wall Thickness

Fig.15 Comparison Between Variation of Wall Thickness and Eddy Current Signals



(a) Eddy Current Recording Chart

F

(b) Wall Thickness

Fig.16 Comparison Between Variation of Wall Thickness and Eddy Current Signals

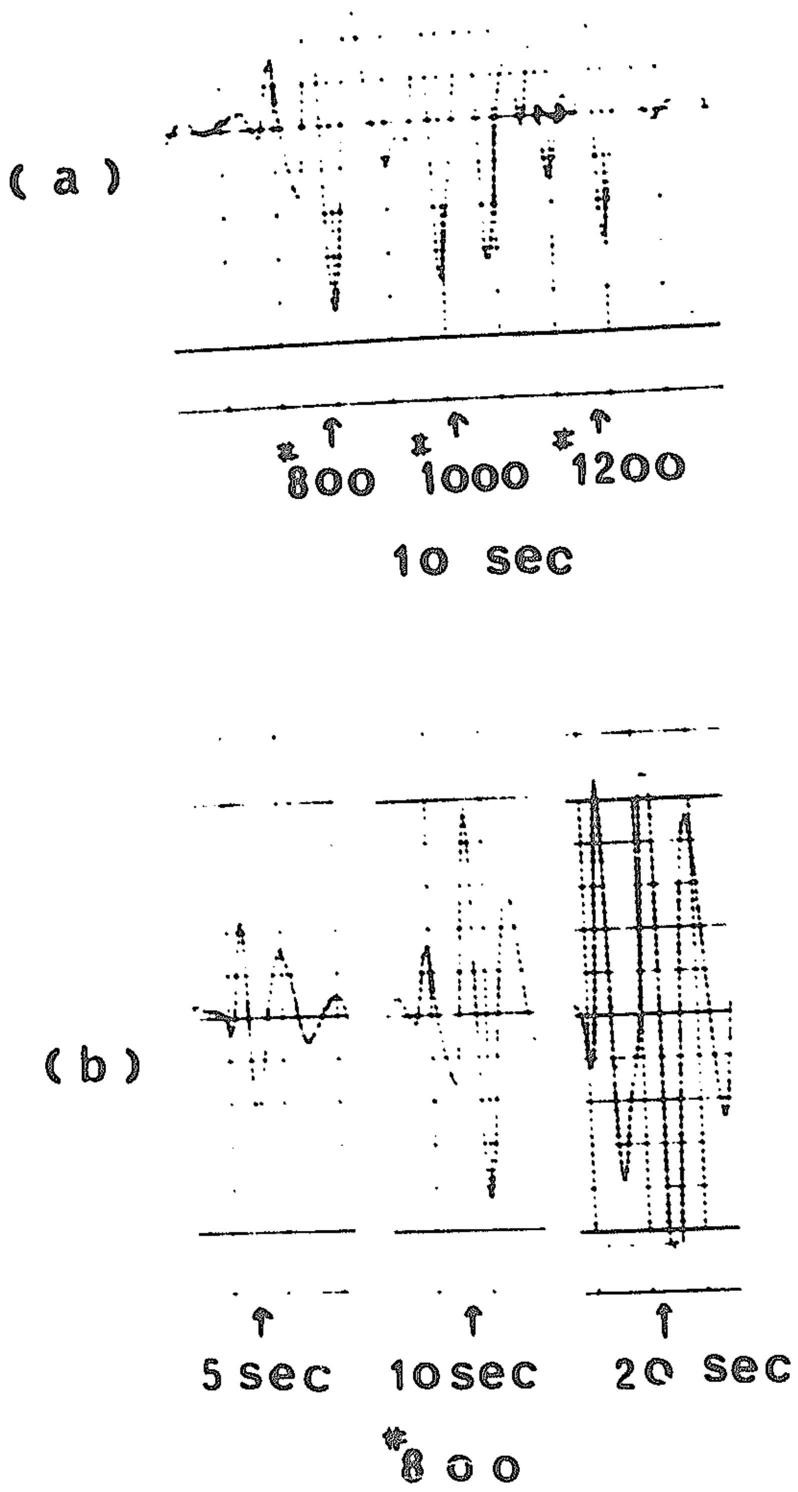
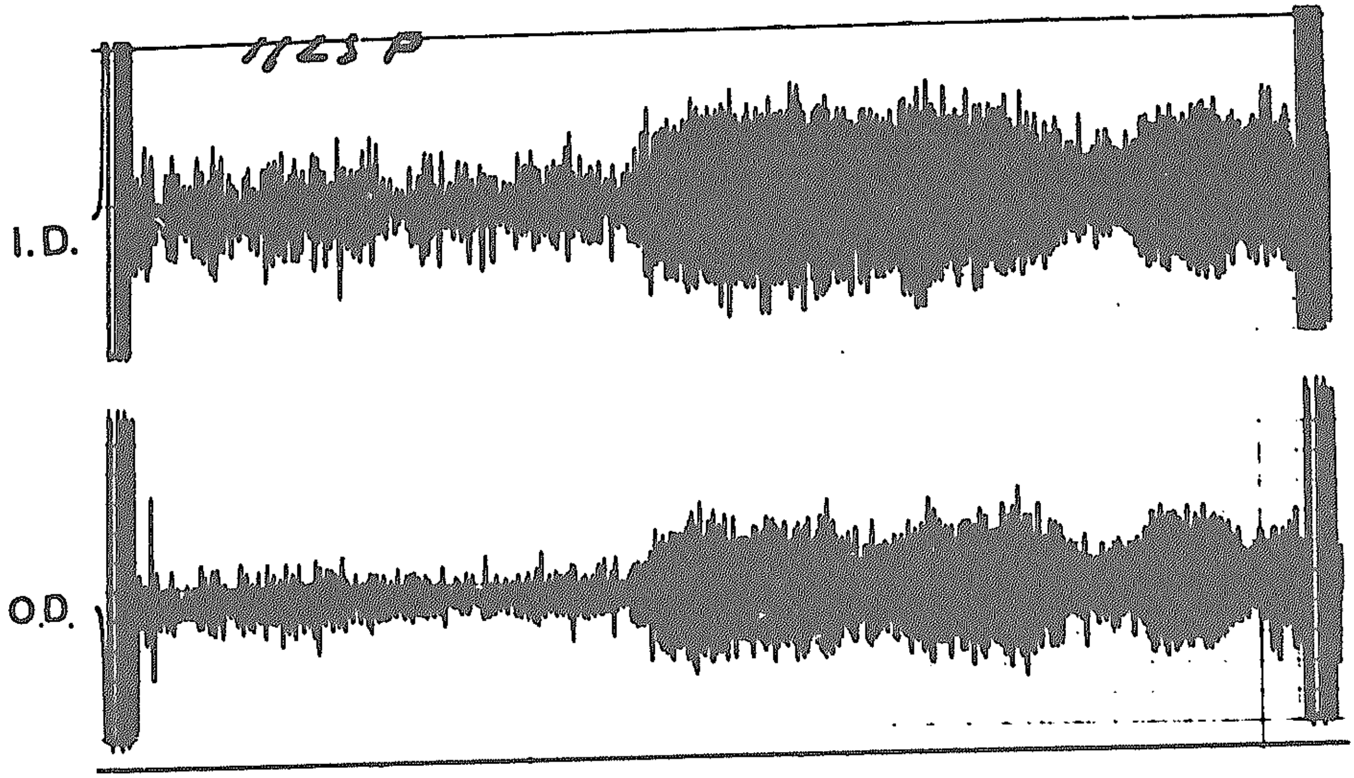
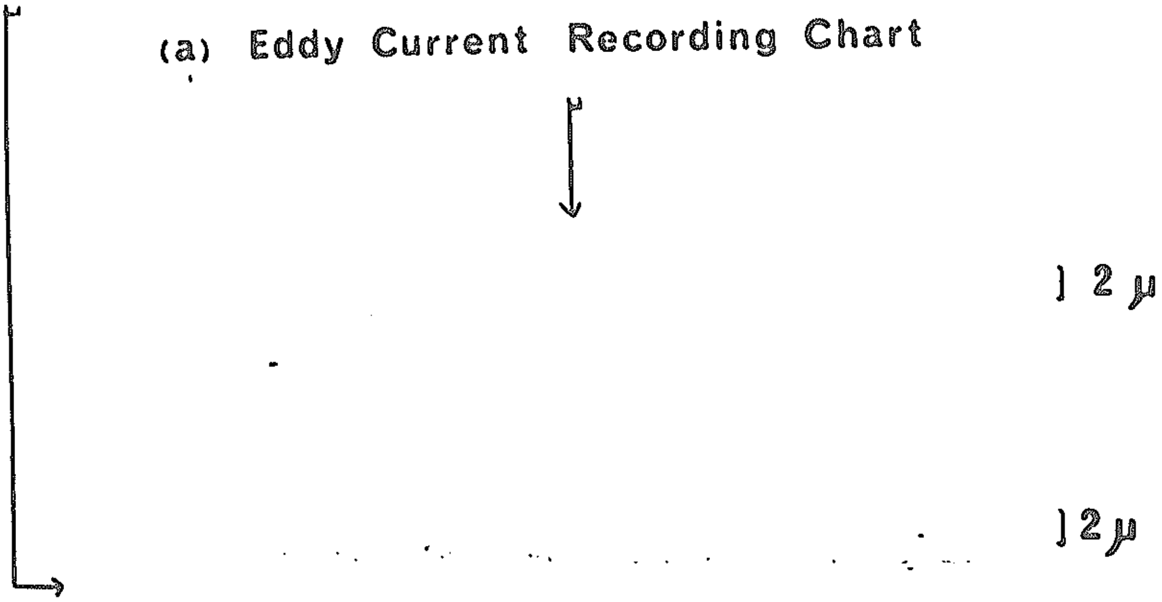


Fig. 17 Indication Of Grinding Surface

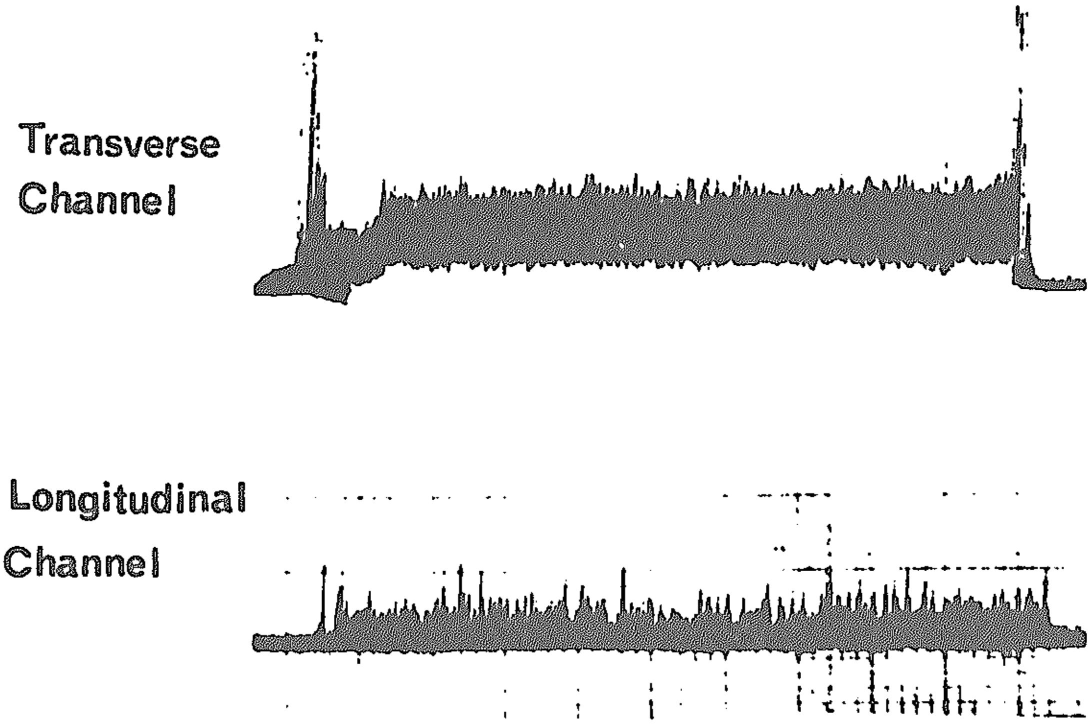


(a) Eddy Current Recording Chart

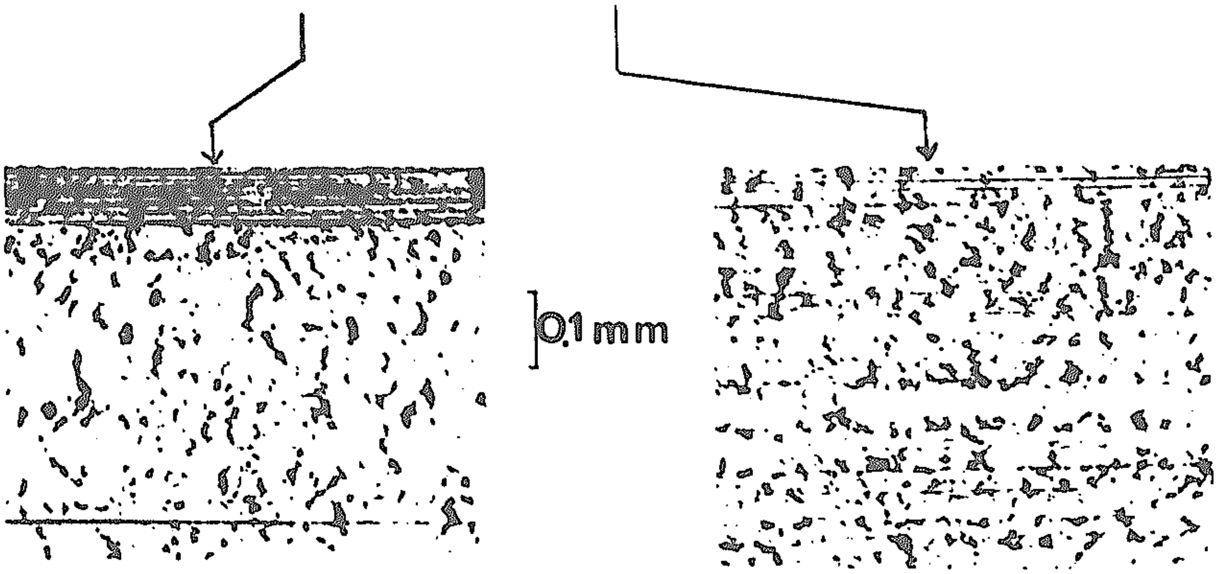


(b) Surface Roughness

Fig.18 Surface Roughness Of Tube 1125B



(c) Ultrasonic Recording Chart



(d) Inner Surface

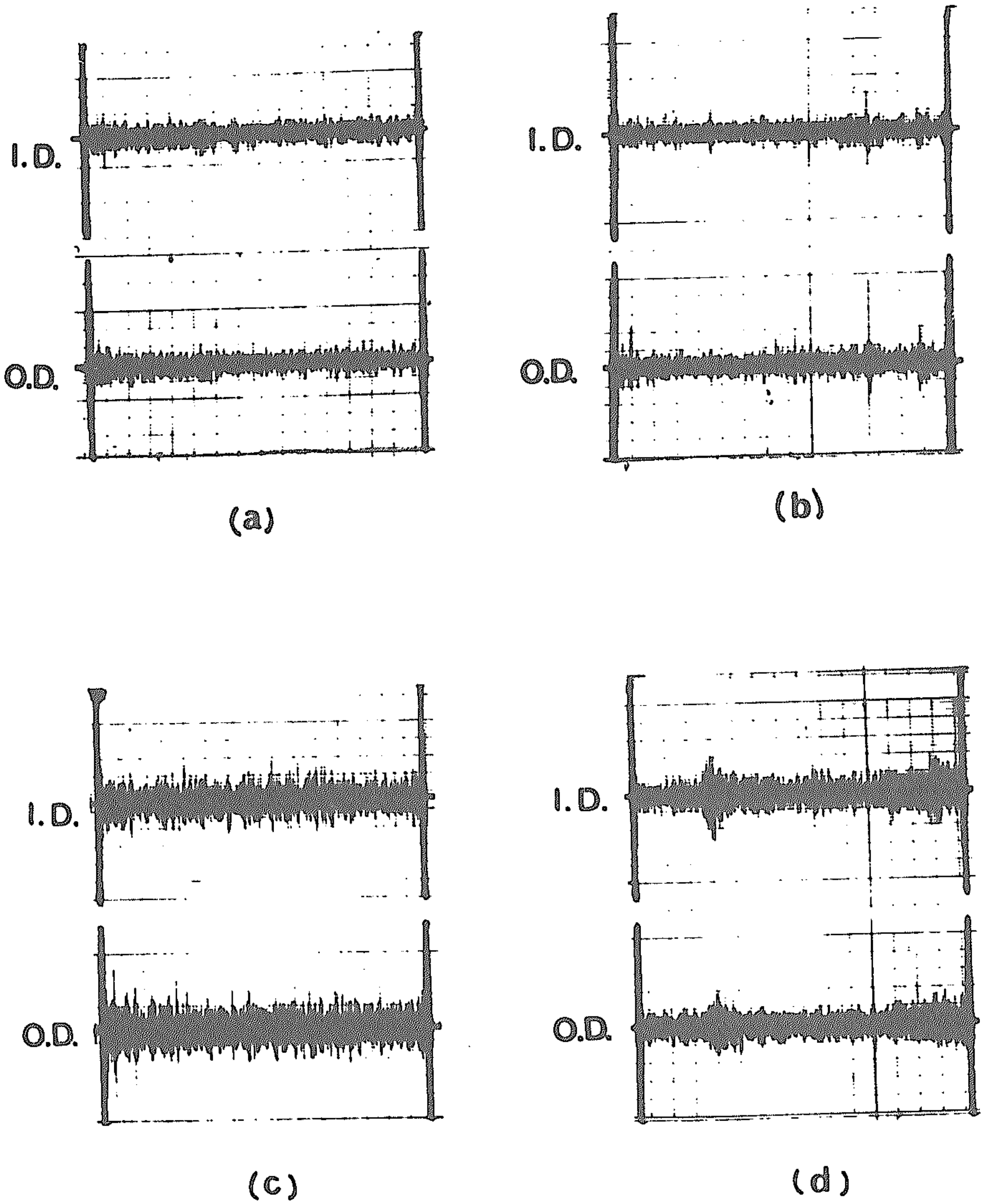


Fig.19 Eddy Current Recording Chart