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COMPOSITE VITAL PARTS OPTIMISATION FOR EH 101 ROTOR HUB

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ABSTRACT

This paper is aimed to present the optimisation of the design, manufacturing and the controllability of composites loop-windings. These loop-windings are parts of the EH 101 main rotor hub. The material used for the construction of the loop-windings is graphite-epoxy composite material. The target of the program was to optimize the manufacturing process, minimize defects and choose the graphite-epoxy material with the charateristics more compatible at this application. To obtain this target manufacturing and structural tests were carried out, correlations with analytical models and the structural tests were performed. Research for the non destructive tests were done in order to assume the quality of the loop-windings.

1. INTRODUCTION

The EH 101 is a multi-purpose helicopter originating from the requirement to replace the Sea-Kings and the SH-in service with the Royal Navy and the Italian Navy.

The helicopter is located within the 14.000 kg gross weight class (Fig. 1).

The main rotor head is fully articulated with elastomeric bearings carrying blade tension loads while allowing flap, lag and pitch movements (Fig. 2 and 3).

In flight the shear loads are transferred directly into the metallic core which is fitted at 20 the most. The centrifugal force passing through the elastomeric bearing is carried by the composite structure.

Therefore the composite structure in flight is subjected mainly to centrifugal static loads while the metallic core is designed for fatigue loads on the safe-life basis.

Furthermore on ground the static loads given by the blades are supported also by the composite part of the hub. For this reason the part should meet specific requirements of stiffness.

Also the composite part of the hub is able to carry the flight loads in the case of failure of the centre arm.

The main structural parts of the hub fig. (4 and 5) are the metallic core with the spline to be fitted with the mast, twelve graphite-epoxy composite material loop-windings and the glass-epoxy composite material cases.

The research presented in this paper is the optimisation of design, manufacturing and the controllability of the loop-windings of the hub.

2. RESEARCH FOCAL POINTS

2.1 MANUFACTURING OPTIMISATION

The items are to be manufactured by winding a tape or roving around a die that has the same shape of the internal form of the loop winding.

The problem to be solved becomes more complex since two of the loop-windings are not in plane, but are complex space forms, (fig. 6,7,8 and 9)

The first one, outer lower loop-winding lies on a cone surface but changes its distance five times in a round, therefore we have a double contour on the shape.

The second one, internal lower loop-winding lies at the same cone surface as the other loop-winding but is limited at one fifth of the cone surface, this one changes also its cross-section the two other loop-windings upper external and upper internal are plane and of course simpler.

At this point there are two ways to proceed, first one with tape wide as much as the loop-windings and roving.

Of course the tape has a lot of advantages but the main concern was its capability of following a double contour in a space. The advantages naturally are less winding, more constant properties of the raw material and better detectability of the defects.

At the other side the advantages of the roving are its capability of following complex shapes in the space and that one defect on the raw material gives less extented impact on the cross-section.

Therefore we followed the decision to optimize the manufacturing process for loop-windings generated by tape leaving the roving alternative in the case of impossibilities to produce high quality loop-windings by tape due to complex space contour.

For both applications other tecnological problems were to be solved such as:

- tension of the material during winding
- radial pressure during winding
- need of preheating of the raw material
- geometrical definition of the dies in order to take account of their thermal expansion during cure
- special features for the winding of non-plane loop-windings

2.2 MATERIAL CHOICE OPTIMISATION

The choice of the material has been done in progression with the development of the manufacturing experience and the acquisition of data.

The focal point of this part of the research was to identify which material parameter would better characterize the behaviour of the items, choose the raw materials that complies better with these characteristics and test it.

2.3 NON DESTRUCTIVE TESTS OPTIMISATION

Main objective of this part of the research was to evaluate the best way to perform the inspection of the loop windings by x-rays, to determine the detectability of the defects and to build the optimum parameters for identifying them.

The non-destructive tests have been used therefore as a research sensor aimed as feed-back for the optimisation of manufacturing process and the material used.

2.4 ANALYSIS

In order to support the research also an analytical approach is required to correlate the experimental data and to prepare the basis of the methods of analytical evaluation of defects and damages on the spar parts, that would occur in the future and the evaluation of the impact at the complete structure.

2.5 TESTS

Included in the EH 101 program are tests of structural elements especially dedicated at the optimisation of the manufacturing processes, the choice of the materials and the investigation of defect and damage tollerance characteristics.

The test planned on the loop-windings were tension and flexural tests.

The first one simulates approximately the application of the centrifugal force and the other one simulates the vertical force, typical of ground load cases.

Also the leading tests performed on a glass epoxy loop-winding (fig. 10) and the four-arm scale hub (fig. 11 e 12) are considered since they gave very significant informations for the optimisation of the loop-windings.

3. PRESENT SITUATION OF THE RESEARCH AND ITS IMPLICATIONS IN THE DEVELOPMENT PHASE

3.1 TESTS PERFORMED ANALYTICAL METHOD TO SUPPORT THEM AND CORRELATION BETWEEN THEM

The first loop-winding (fig. 10) to be produced was a glass-epoxy loop-winding with a cross-ply case (leading test TP1).

The loop-winding was manufactured by winding of tape wide as high as the loop-winding. No particular problems were found during manufacturing. The item after the curing of the cross-ply case on the core was controlled by x-rays. No defects were found and that was confirmed by destructive tests performed after the end of the structural tests.

The structural tests performed were only static tests with only axial load (fig 1) in order to evaluate if a closed structure like a loop-winding can carry this type of load and to correlate the analytical models with the experimental results.

The structural analysis was performed by use of two different methods both by the use of finite element programs.

The first method uses monodimensional elements (fig 14) the second one uses tridimensional elements (fig 15).

For both of the two methods it was necessary to produce special procedures in order to support the traditional finite elements codes since they are not able to perform a complete structural analysis of composite structures of this type. The flow chart of these two methods are shown (fig 16 and 17).

The experimental data was survied by photoelastic coating (fig 18) and displacement measurements. The correlation between analytical results and experimental data was very good. Fig 19 shows the max displacements correlation and the typical strain correlation in a section is shown (fig. 20).

After, the manufacturing of the loop-windings for the four arm hubs (fig. 11 and 12) was begun , scaled down from the hub of the EH-101 helicopter (leading test TP2).

The manufacturing of these loop-windings gave a lot of information used for the manufacturing of the real ones.

Also the structural tests of the four arm hubs gave information about the state of strains and stresses of the loop-winding in the hub and the type of failure.

The loop-windings produced for the four arm hubs are manufactured by glass-epoxy for the first specimen and graphite-epoxy for all the others.

This because during the manufacturing of the hubs the ground cases of the EH 101 helicopter were evaluated and found to request additional stiffness for the hub, especially during the folding of the blades.

The hubs performed static and fatigue tests. Correlation between the experimental data and the analytical results was performed with very good results. These tests have cleared out that the critical stress for the loop- windings are the interlaminal stresses out of the plane of lamination.

The structural tests were performed only at one type of the little loop-windings the internal upper one. The choice was done in order to minimize the colateral effects due to the out plane form of the other two loop-windings and to reduce the test machine volume in respect to the fourth one.

The structural tests performed were a simple in-plane tension test and a flexural test simulating the out of plane ground loads (fig 21 ane 22).

The correlation with the analytical models similar with those of the glass loop-winding was very good within the limits already presented for the glass loop-windings.

Since a lot of defects were included at those loop-windings we tried to simulate these defects with the analytical models but the results are not yet satisfactory.

The most important information from these tests were those optained from the failure of these defected loop-windings.

The failure of these loop-windings with the inplane load began at the middle of the section (fig 23) more distant from the line of action of the applied force.

The analytical models confirmed that at this point we have the maximum tension trasverse stress (fig 24). The failure analysis confirm that the failures were interlaminar failures.

The failures at the loop-windings with defects at this area were very earlier and of course that is a confirmation of the hypothesis.

After that the tests with the loop-windings for the hub of the EH 101 helicopter began. Also only the upper internal loop-windings were tested here.

The structural test performed was the simple tension test (fig 25) with two different application of the load and the costrain, one concentrates and one distributes. The sixteen loop-windings tested manufactured from four different materials. On table 1 the materials and their results are reported. Also table 2 reports the ratio between flexural modulus, tension modulus and the medium values of the displacement of the loop- windings. The only material out of these ratio is the one with the high modulus fiber.

The most important information of these tests was that since the two roving loop-windings and the two high modulus loop-windings have the typical interlaminar failure, the two intermediate modulus loop-winding had a failure for pressure at the point of application of load at a higher level of load of others.

3.2 NON DESTRUCTIVE TESTS DEVELOPMENT

The role of Non Destructive Evaluation in the development of a projected structure and the set up of the proper technology that allow to realize a good and reliable component, is very important.

Infact the Non Destructive tests allow to save money and time, finding a lot of important informations and leaving the sample available for any kind of further investigation, furthermore N.D. Evaluation supply information that can help the comprehension of the behaviour of tested samples and simplify the stress analysis.

In the philosophy of integrated development of any component, especially when new materials and/or technologies are involved, it is very important to follow a guideline in which production, design and inspection people have to work very strictly, from the beginning of the development, in order to short the time lost between questions and answers.

In this chapter we report the activity performed in the field of N.D.E. during the development of the component and we show the results obtained.

We want to emphasize that in this activity, the N.D. Investigation works like a "service" supporting the engineering of such a composite structure, nevertheless all the work carried out creates the basis of the future Quality Control procedure for the real flying component.

From the shape and the geometry of the structure, a radiographic technique was preferred, particularly we choose the XERORADIOGRAPHIC method in order to have high quality (high resolution, high contrast) images, easy to read in the daylight and easy to handle even in the test shop enviroment.

At first some samples, realized using different winding techniques, were inspected by xeroradiography and then dissected in order to determine the typical defect and their radiographic images.

In this phase there was a usefull feed-back from the radiographic inspection to the production technique and in a quite short time it was possible to set up all the winding parameters and to find reliable methods to produce internal and external rings.

Then, some little specimens, cut out from a defective ring, were submitted to mechanical tests, in order to evaluate, roughly, the influence of flaws on mechanical properties, and mainly, to produce some failures due to well known defects ~~situazione~~, and controlled applied load.

Some significant pictures of N.D.I. are presented. For instance in (Fig 26) some tridimensional marcel are included in a roving made loop-winding. A typical delamination is shown in (fig 27) for a tape loop-winding. A bad compactation is shown in (fig 28). Flat and tilted projection of a Xeroradiographic image of a significant sample is shown in (fig 29), delamination resin/air bags and marcel in the external part can be shown.

Next are presented some photographic views of defects defected by N.D.I. and then sectioned (fig. 30 and 31).

A photographic view (10X) (fig 32) of the transverse cross section of a typical failure surface. From the separating lines between different transverse planes; it is easy to see that the failure mode is mainly driven by the reduced interlaminar shear properties of the defected laminate.

At the end in (fig 33) both sides of the interlaminar failure of a specimen are shown.

The Xeroradiographic was the method used during the research but since the Quality Control of the manufacturing plans uses the normal X-ray inspection also trains between the two methods was done and we arise also by the normal X-ray inspection high standard.

3.3 MATERIAL AND MANUFACTURING EVALUATION

The first graphite loop-windings (scaled) were produced in order to save time with the graphite-epoxy material already available for other programs.

There were produced loop-windings by tape as high as the width of the loop-winding (12.8 mm) by a graphite epoxy material with high modulus fiber at a volume fraction of 50%.

With this material, tension of the tape and a radial pressure were carefully chosen, but the results especially for the no-plane loop windings were very bad. The typical defects were delaminations. This is due to the high percentage (÷20%) of damaged tape during cutting.

For the loop-windings produced by roving, a graphite-epoxy material with moderate modulus, moderate strain fiber at a volume fraction of 60%, was used.

The problem with this material was the low resin content and the high percentage of voids in the loop windings.

The part requested for the production of the four arm hubs were manufactured but with scraps of about 75% of the parts produced.

From the experience of the manufacturing of the scale loop-windings the informations obtained from the structural tests and of course from the design requirements, the choice of the raw material has to be done.

From this data it was decided to choose a raw material with interlaminal properties as high as possible. This material is the graphite-epoxy tape with intermediate modulus high strain graphite fibers 50% in volume.

A roving material with the same graphite fibers 46% in volume and tape with moderate modulus fibers was considered as an alternative.

With the chosen material the results were soon very good especially for the two planes loop-windings (table 3) also for the other two loop-windings after the definition of the manufacturing procedure the results were acceptable.

Furthermore after the results of the structural tests, where the results of the intermediate modulus graphite epoxy tape were very good, it was clear that this was the right choice.

In table 4 the results of the prototype production is shown. In table 5 the total preliminary production and prototype is shown. It is clear that the result is very good but some work is to be done for the no plane loop-windings

CONCLUSIONS

The targets of the first part of the optimization program of the composite loop-windings for the EH-101 Helicopter hub have been reached.

The main manufacturing problems were solved , the raw material was chosen and the controllability by non destructive methods was demostrated.

Also the fundamentals for the defect and damage analysis of these loop-windings have been developed.

REFERENCES

1. R.E. ROWLANDS — "Application of photoelastic coatings to composites". *Developments in composite* material -2 pag. 101

2. V. GIAVOTTO and others — "Evaluation of section properties for hollow composite beams" Fifth european rotorcraft and pow powered lift aircraft forum.

3. R. TONES — "Mechanics of composite materials"

4. S. TSAI H.T. HASIN — "Introduction to composite material

5. C. DESAI J. ABEL — "Introduction to the finite element method"

6. H. SCHAFER — "MSC/NASTRAN static a normal model analysis"

7. C. ROTONDI — "Analisi strutturale di un elemento anulare in materiale composito" (thesis".

8. A. TEMPESTA — "Valutazione analitica e sperimentale della influenza di difetti di costruzione in elementi semplic costituenti strutture elicotterist che (thesis)".

9. E. ANAMATEROS,F. BARANI — "Analytical evaluation of a composite loop-winding by the use of mono and tridimensional element models and correlation with experimental data (MSC/NASTRA EUROPEAN USERS CONFERENCE Munich April 1985.

10. J.L. CAMAHORT,D.CARVER, R.PFEIL and B.J. MULROYJr — Process Control N.D.E. Procedure for Advanced Composite Structure S.A.M.P.E. 1978 pages 337-389

11. D.HAGEMAIER and R.FASSBENDER — Non Destructive Testing of Adhesive Bonded Structure S.A.M.P.E. Quarterly,July1978 pages 368.

12. D.HAGEMAIER,J.J.McFAUL and D. MOON — Non Destructive Testing of Graphite Fiber Composite Structures. National Aeronautic and Space Engineering and Manufacturing Meeting, LosAngeles 5-9 October 1970.

13. V.WAGNER,G.SAMANNI,E.PORRO, L.ROTA,C.PELUFFO — Xeroradiography: High Quality Radiography for Glass Reinforced Composites. S.A.M.P.E. European Chapter I, Cannes, Intercontinental Conference,12-14 January 1981.

14. G.LUZZATI and MORASI — La xeroradiografia- Presentazione del metodo e basi fisiche, La Radiologia Medica Vol. 60 n.9 pag 721-736 Sett. 1974.

15. G.BORASI and G.TOSI — Le caratteristiche dell'immagine xeroradiografica: La Radiologia Medica Vol. 60 n. 9 pag. 737-749 Sett. 1974

16. Rank Xerox Corp. data sheet on 125 Model

17. Rank Xerox Corp. Technical application, Bulleting N.1

18. R.C. McMASTER and H.L. HOYT — Xeroradiography in the 1970's Material Evaluation Vol. XXIX n.12 Pages 265-274 (By courtesy of Rank Xerox Corp.)

19. A.BURGER,C.VIEWEG and L.BAUER — Rontgenprufung von Gusstucken mittels Xeroradiograpghic. Rank Xerox GmbH Munchen. (By courtesy of Rank Xerox Corp.)

20. M.FARIOLI,F.PORRO,G.SAMANNI V.WAGNER — Advanced N.D. Techniques for composite primari structures. Agard-Panel meeting spring 1983, London (U.K.)

da "Materials Evaluation", 43 May8

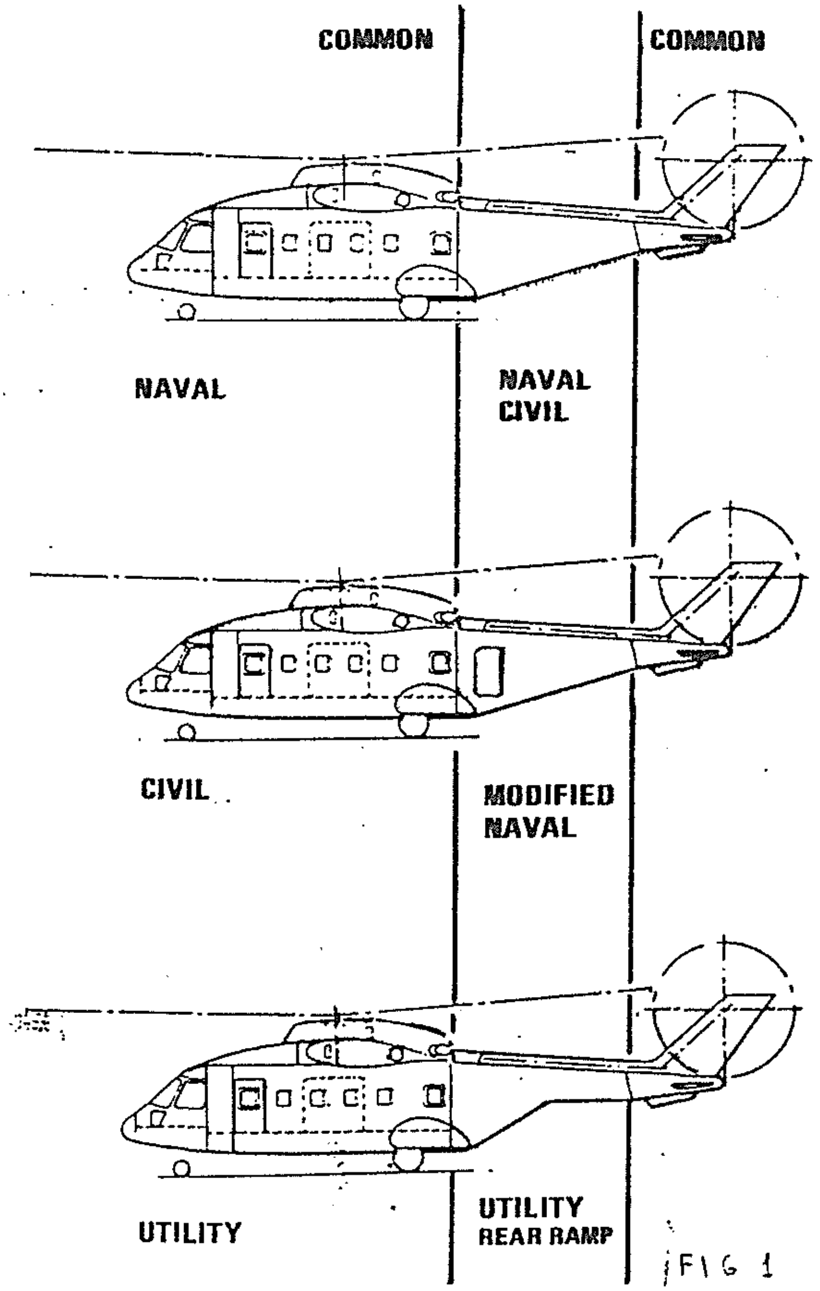
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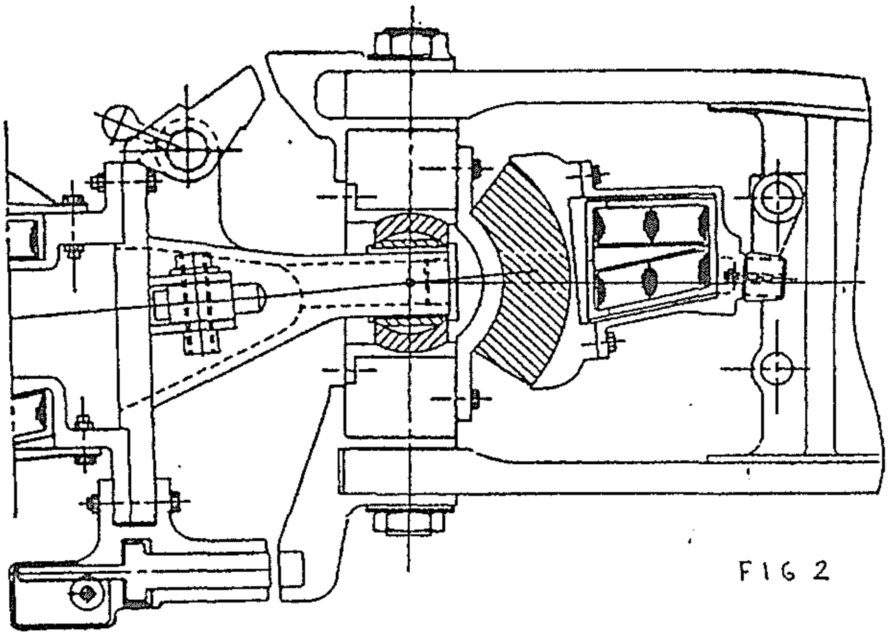
FIG 1



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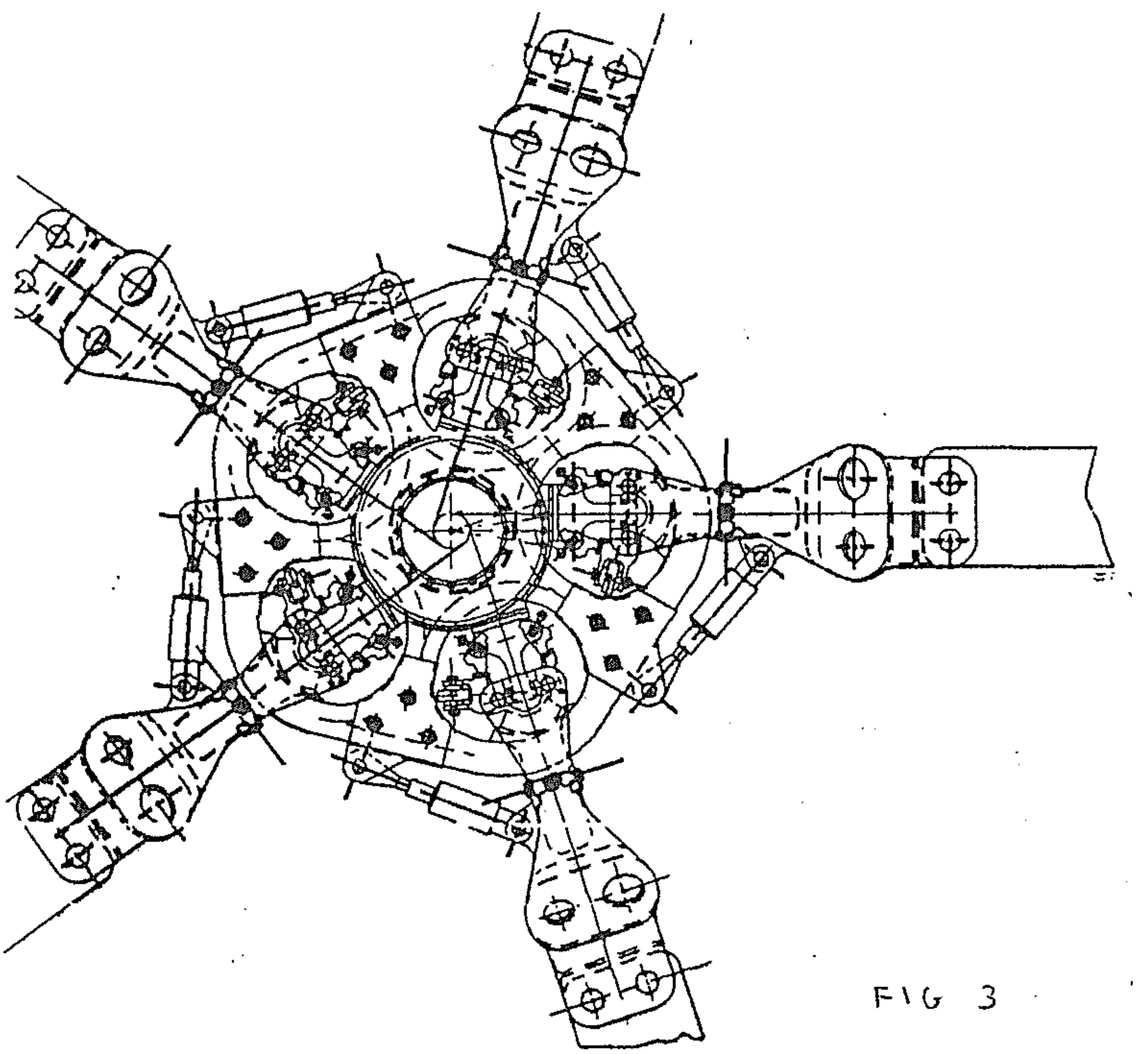

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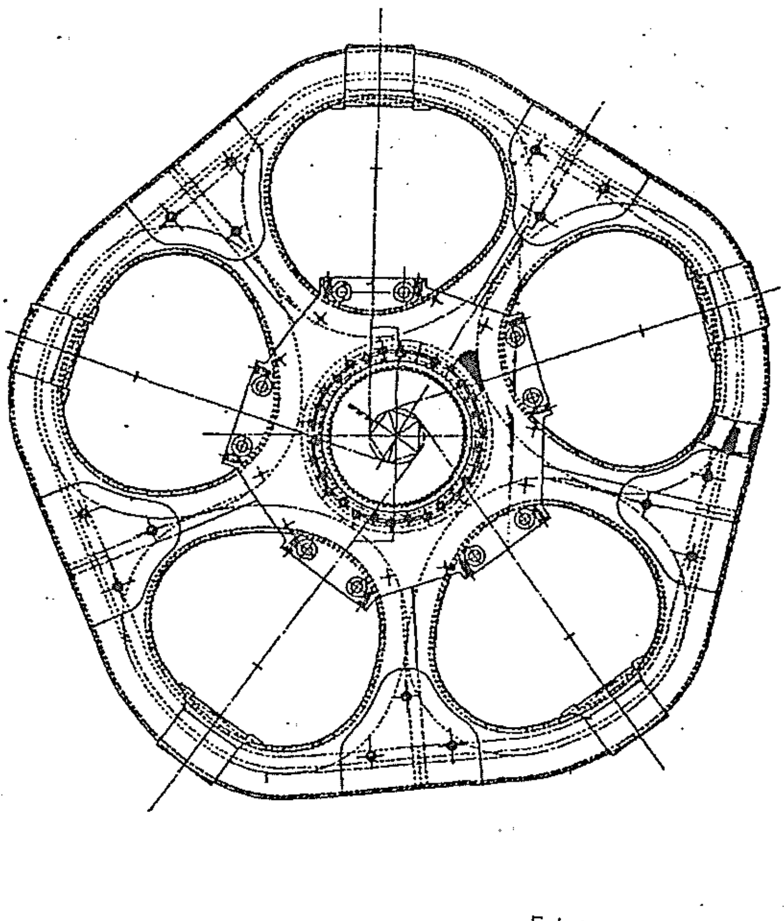

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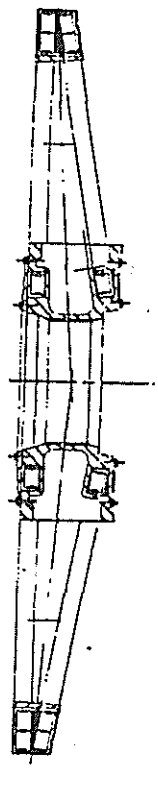

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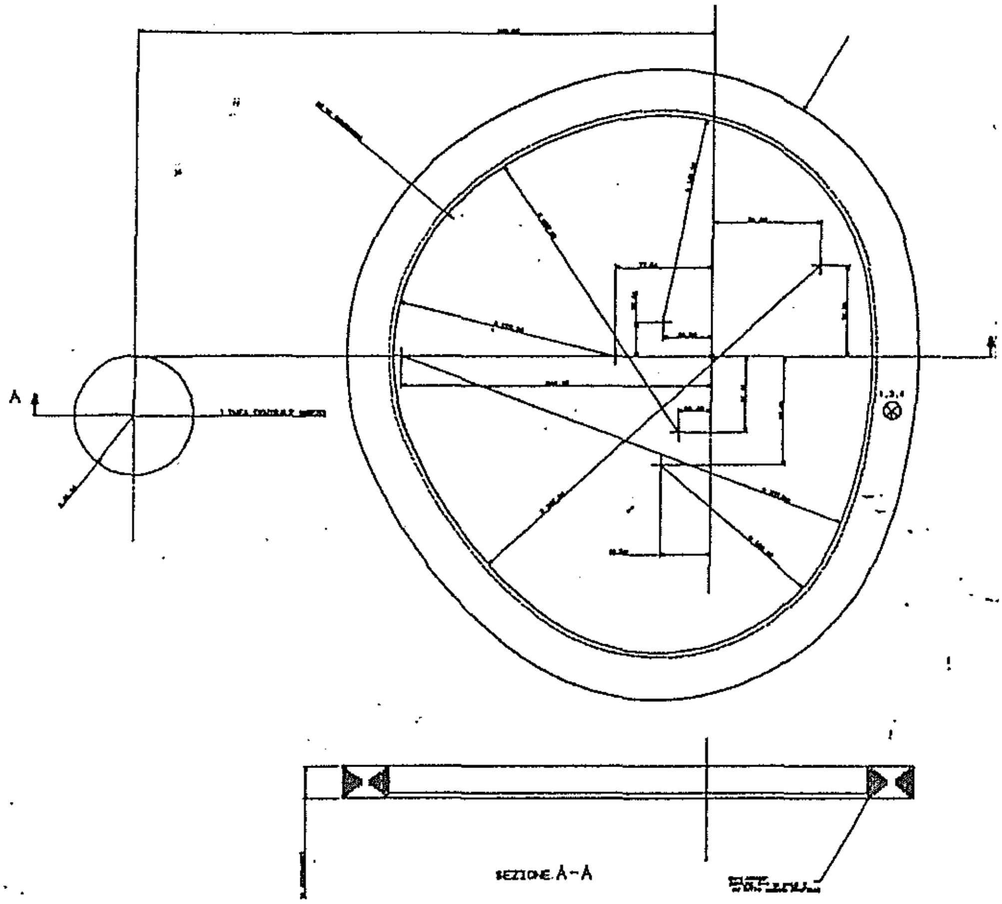

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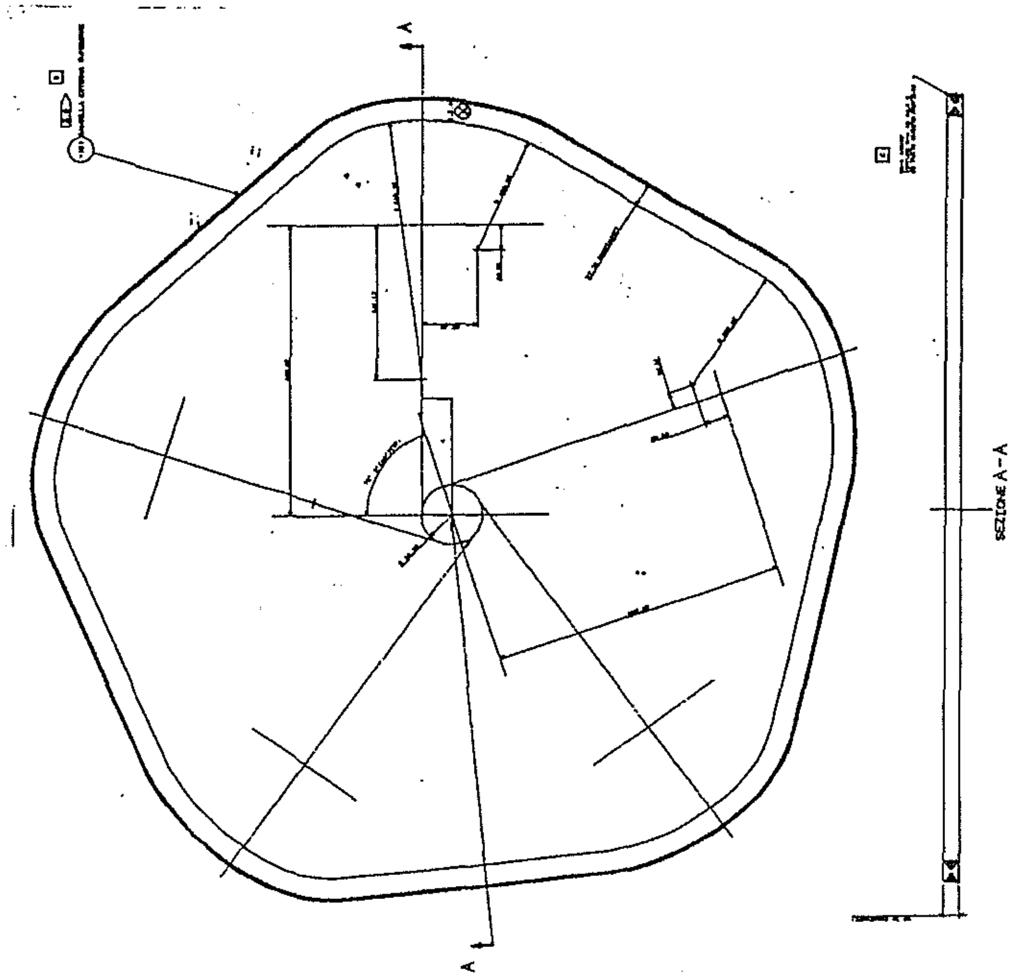

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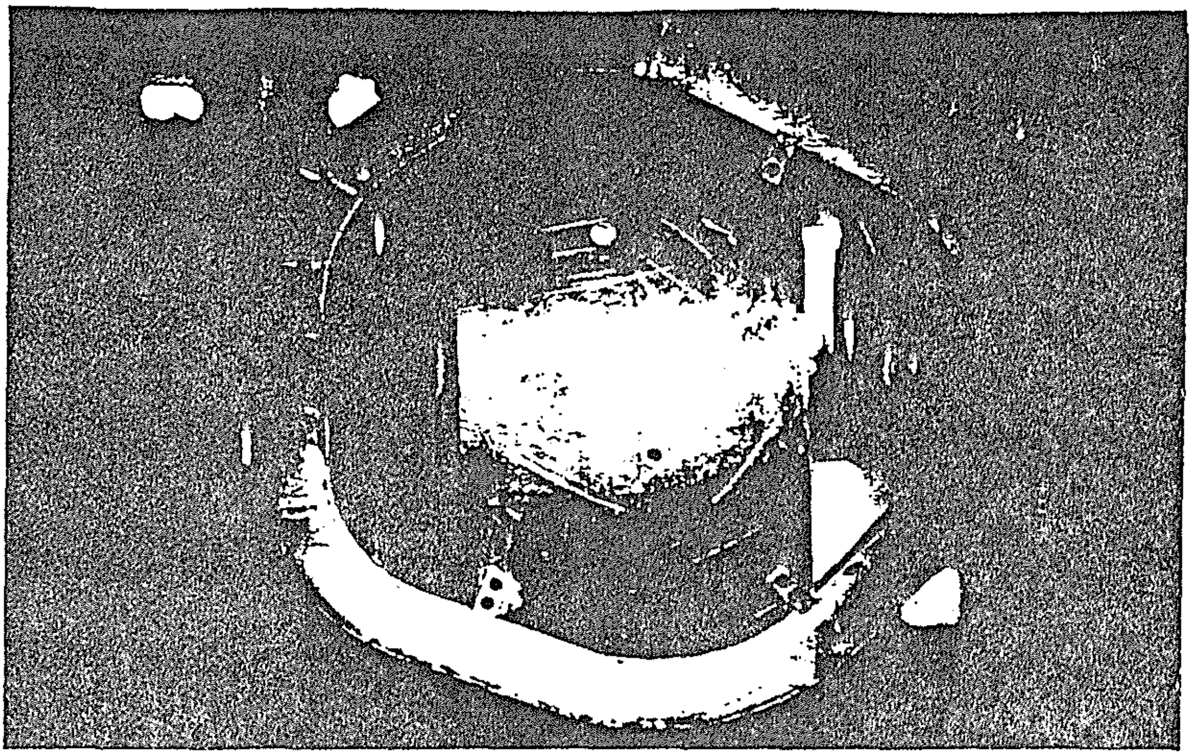

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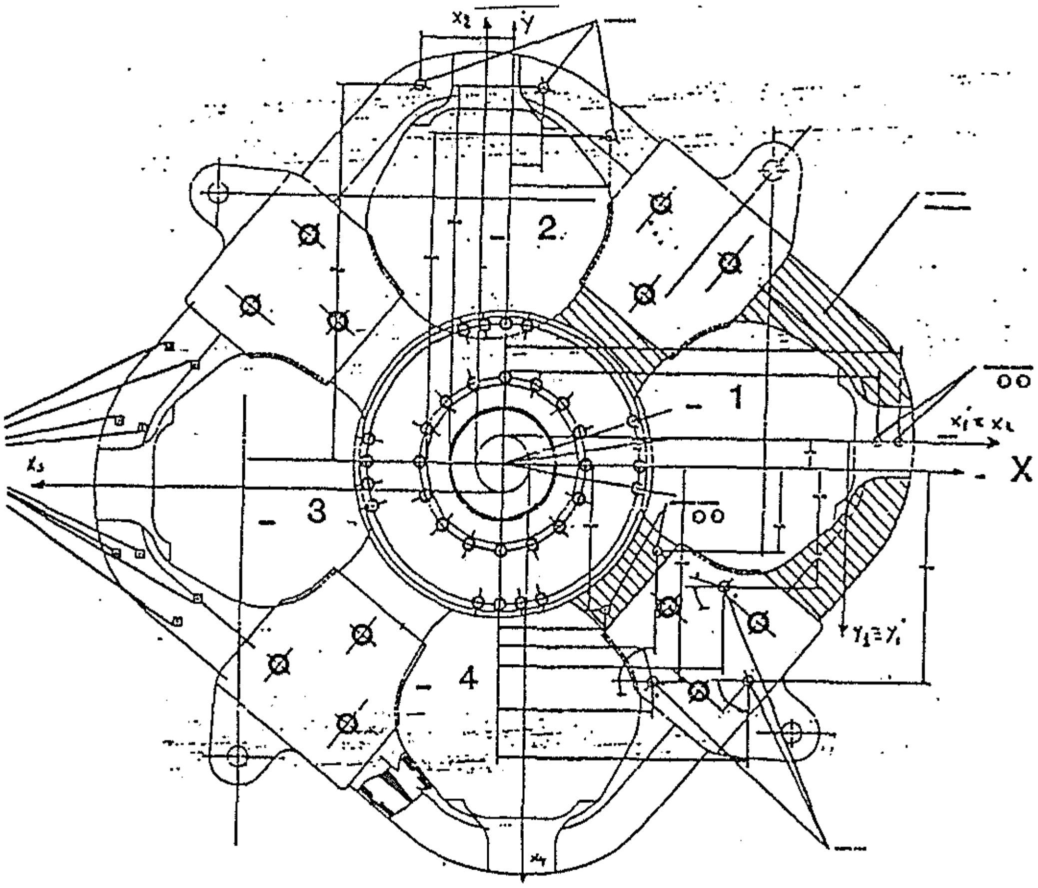

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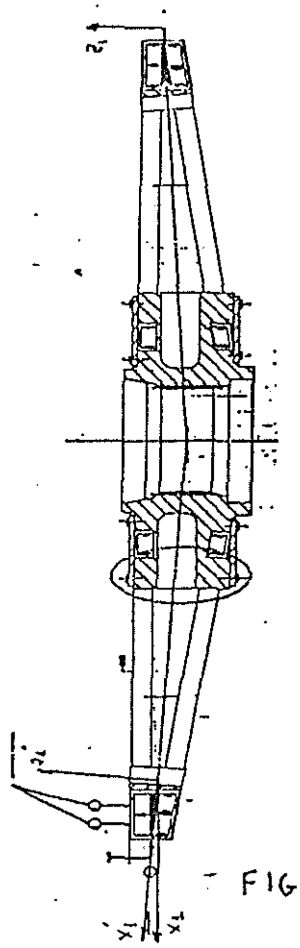

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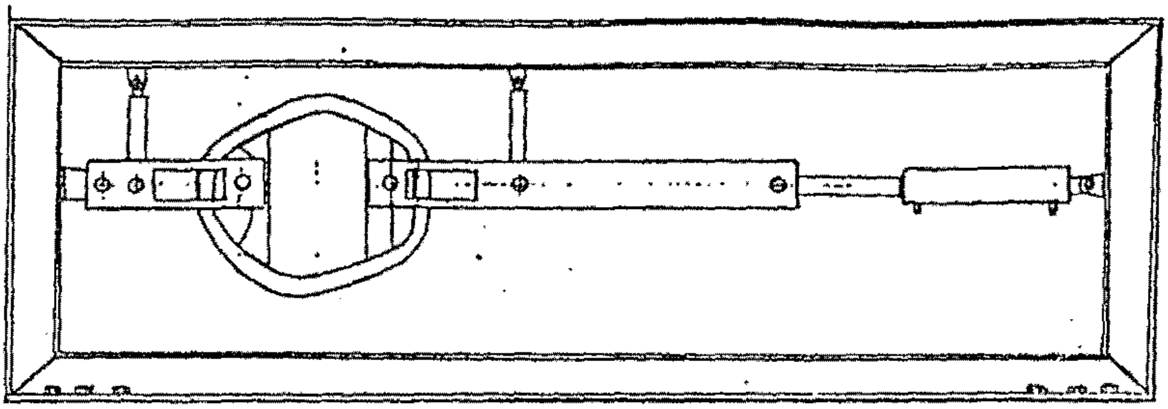

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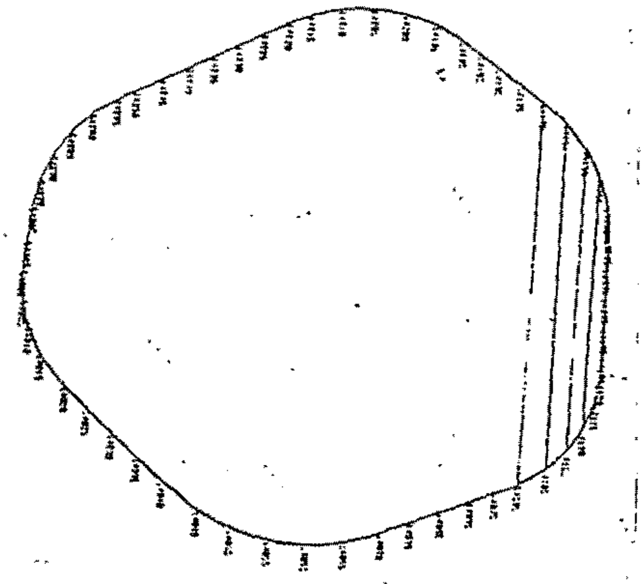

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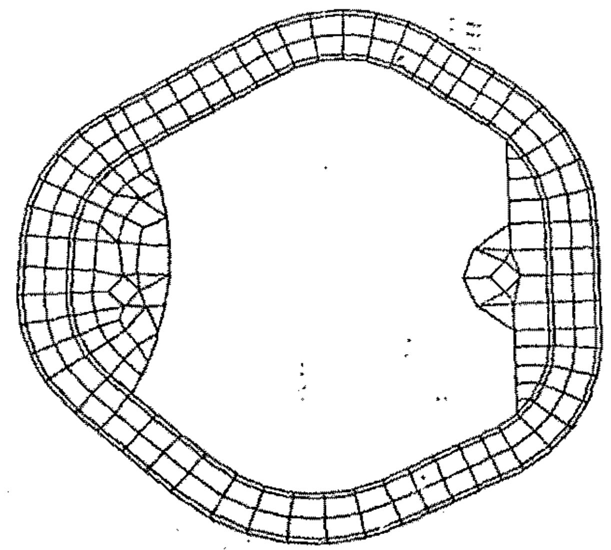

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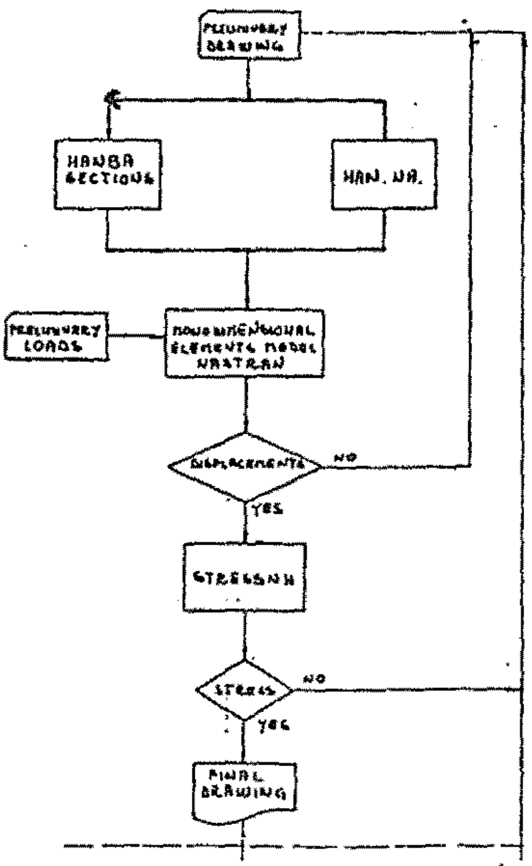

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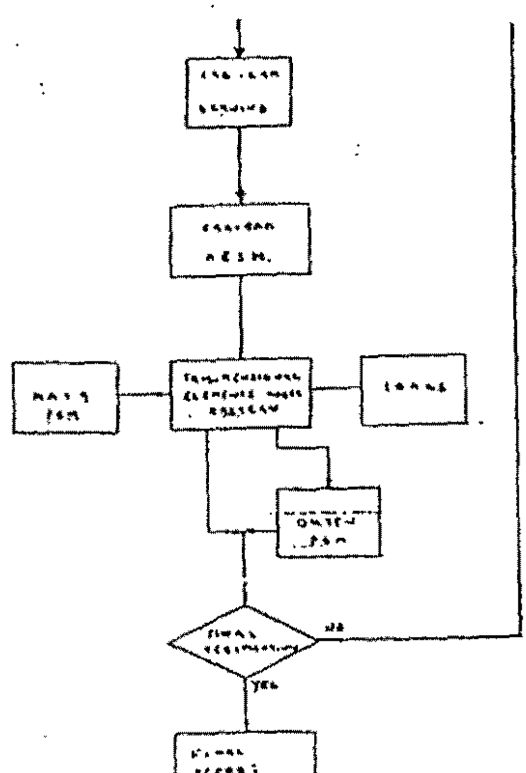

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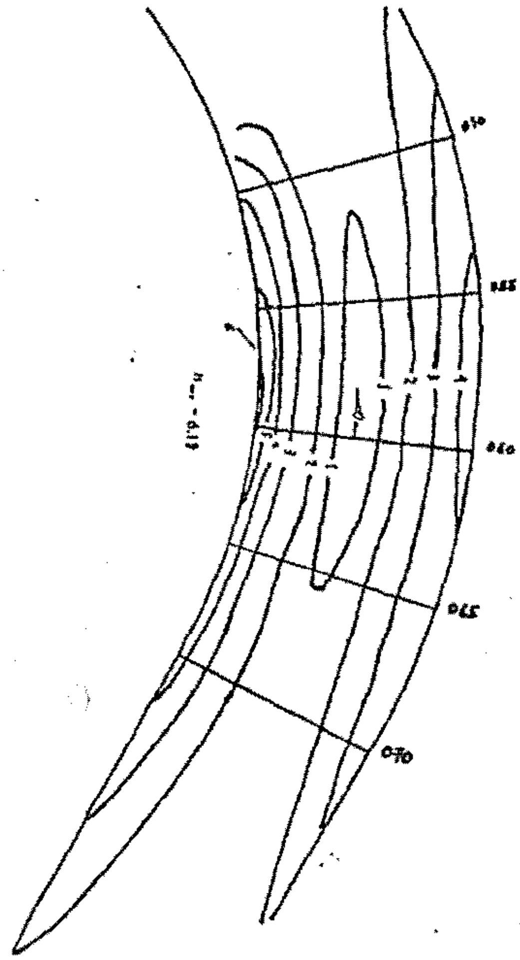

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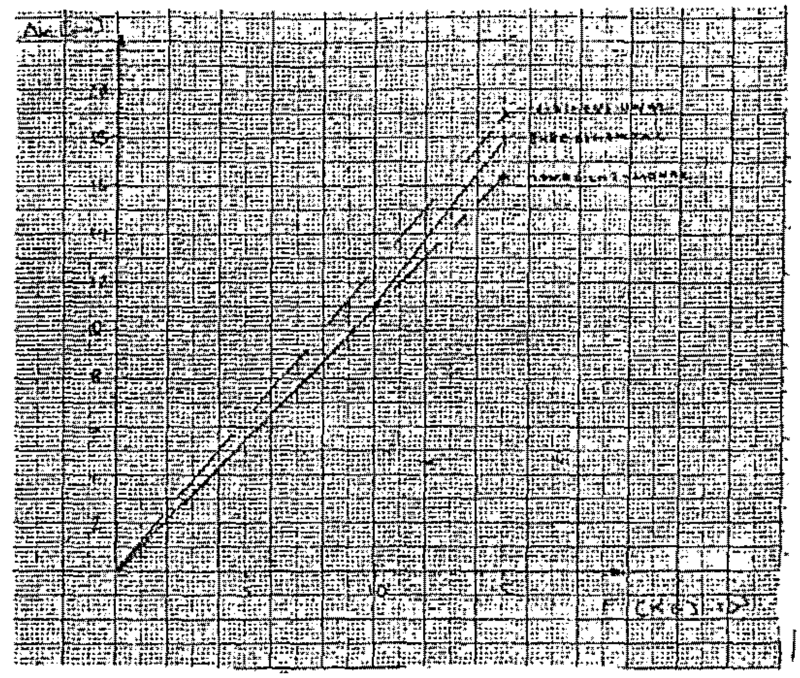

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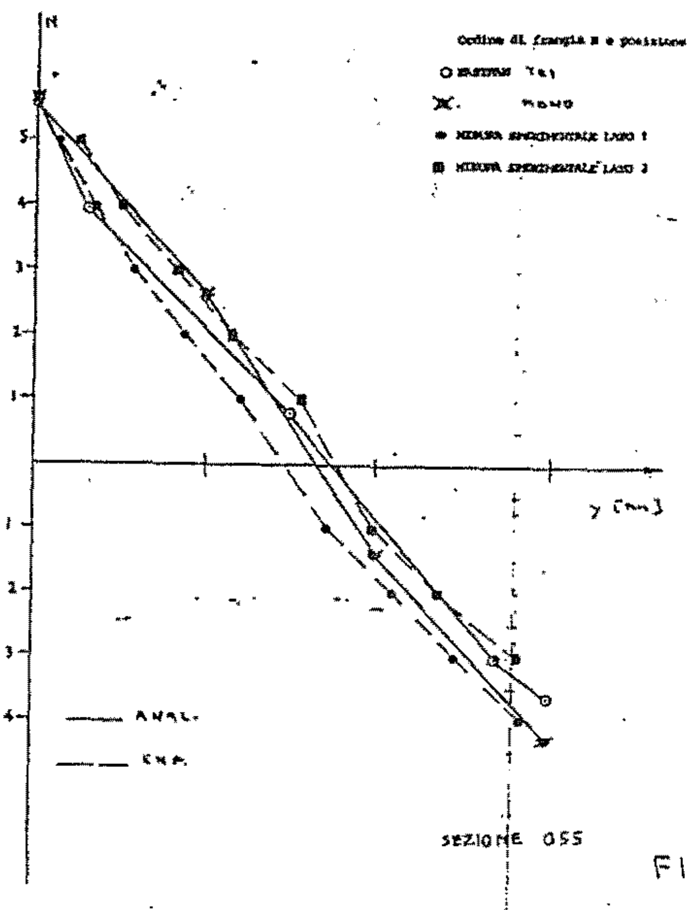

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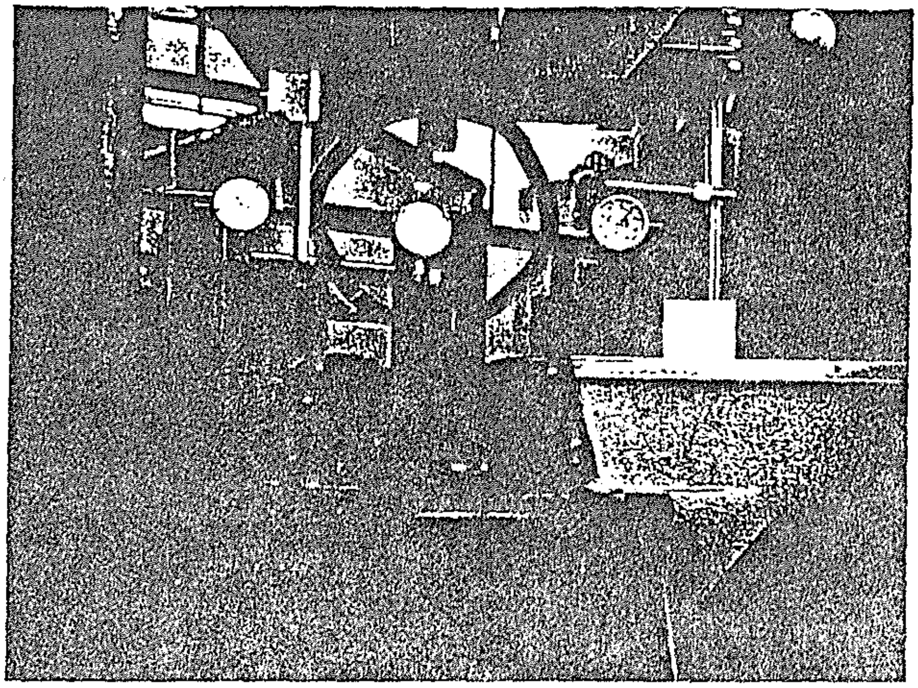

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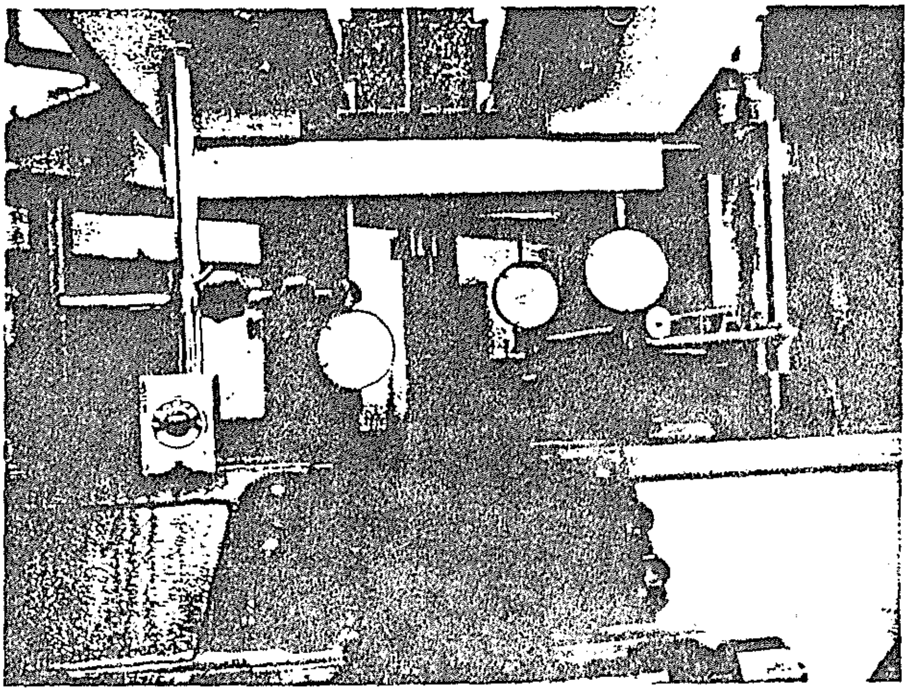

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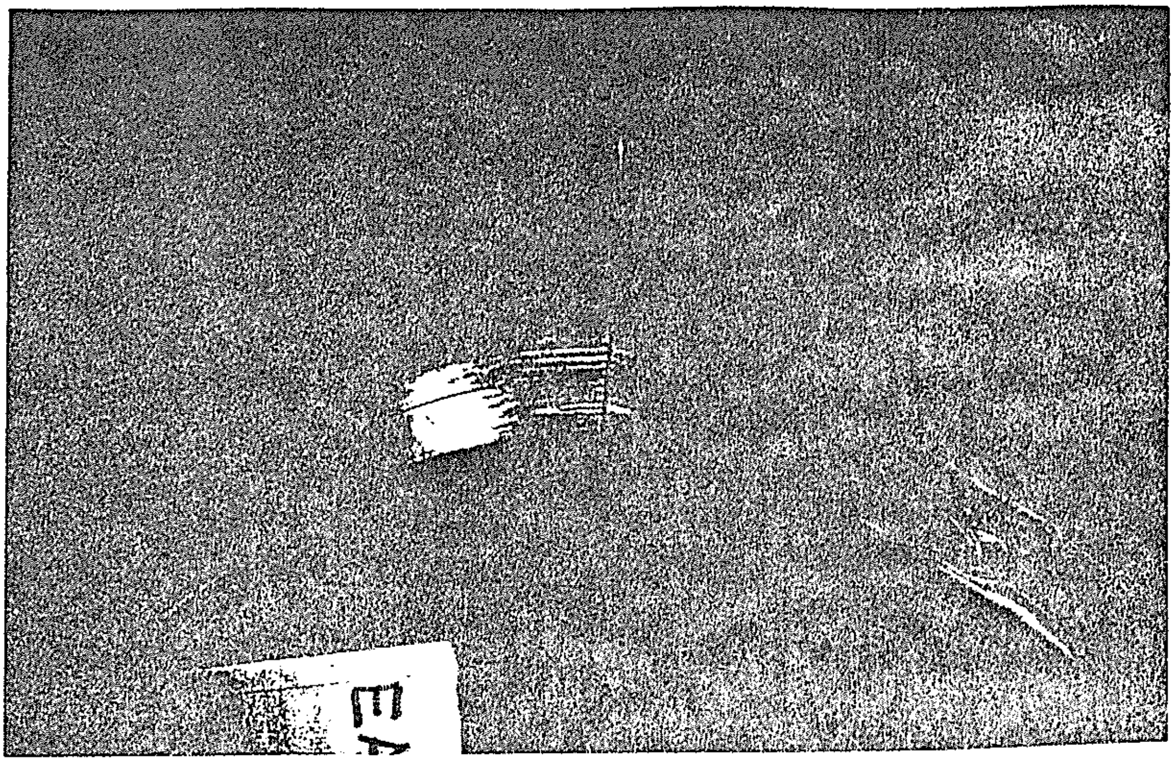

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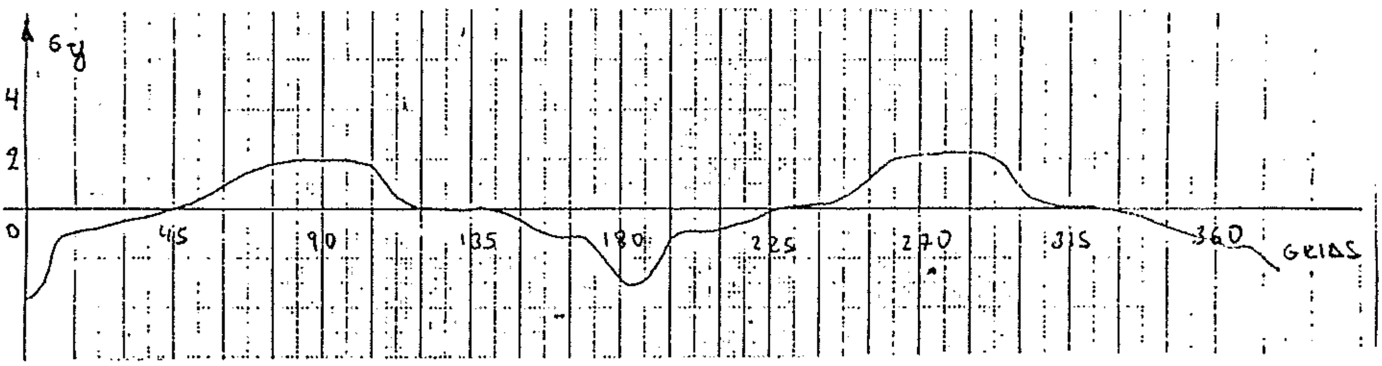

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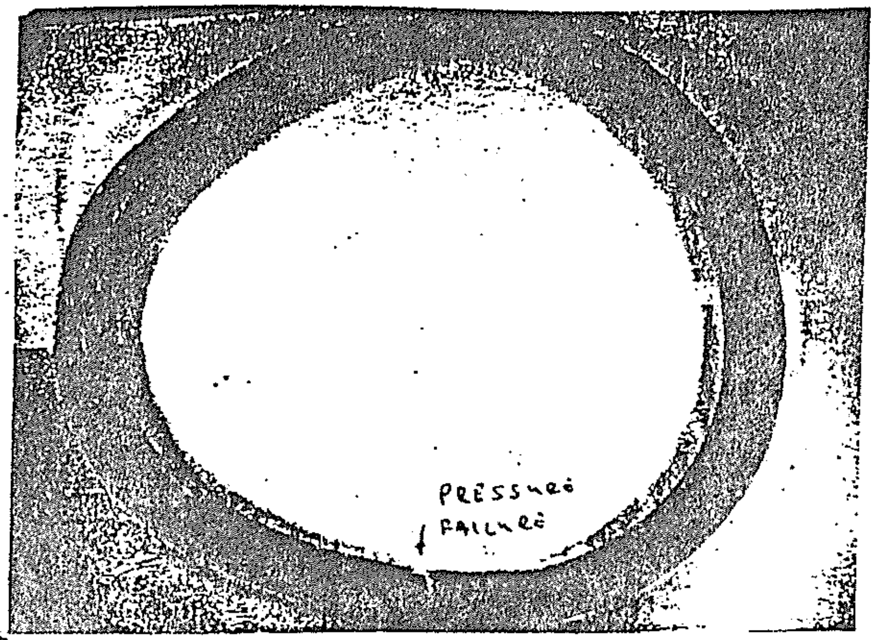

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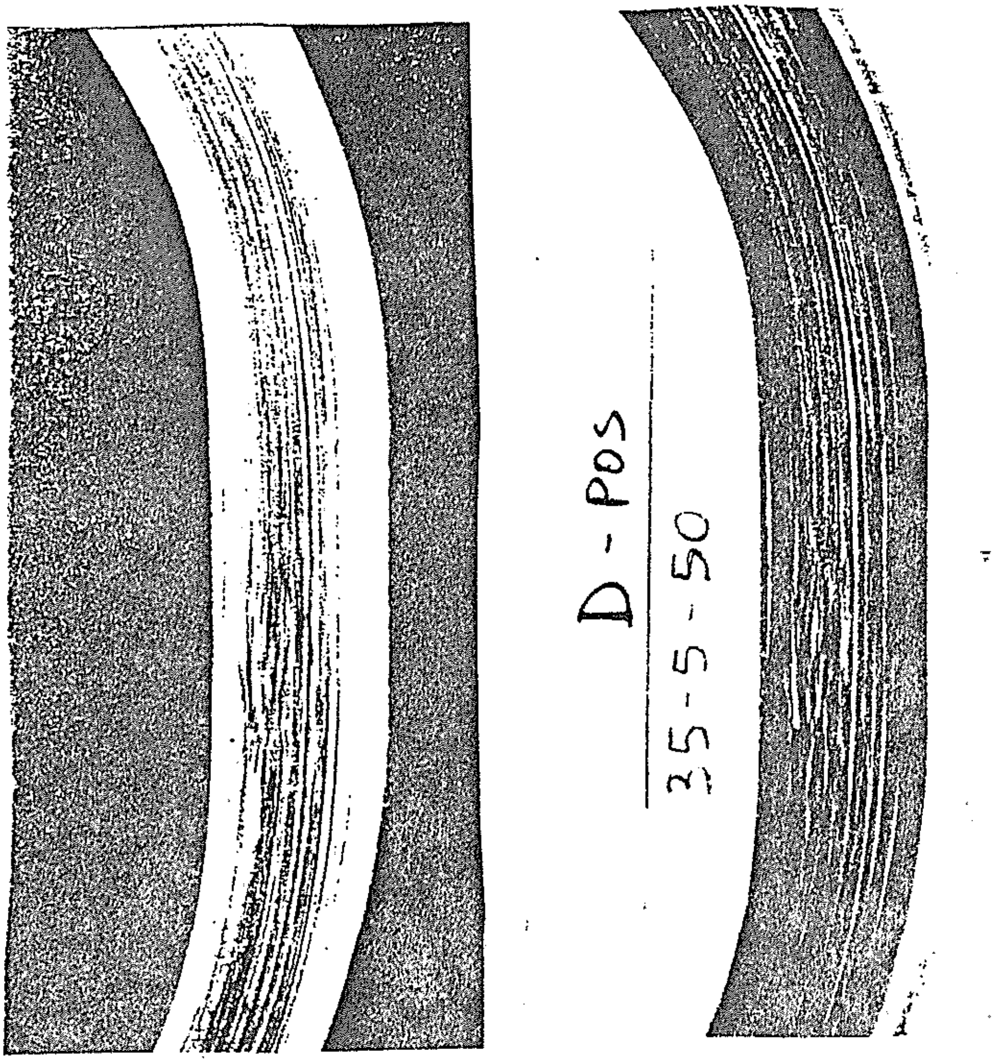

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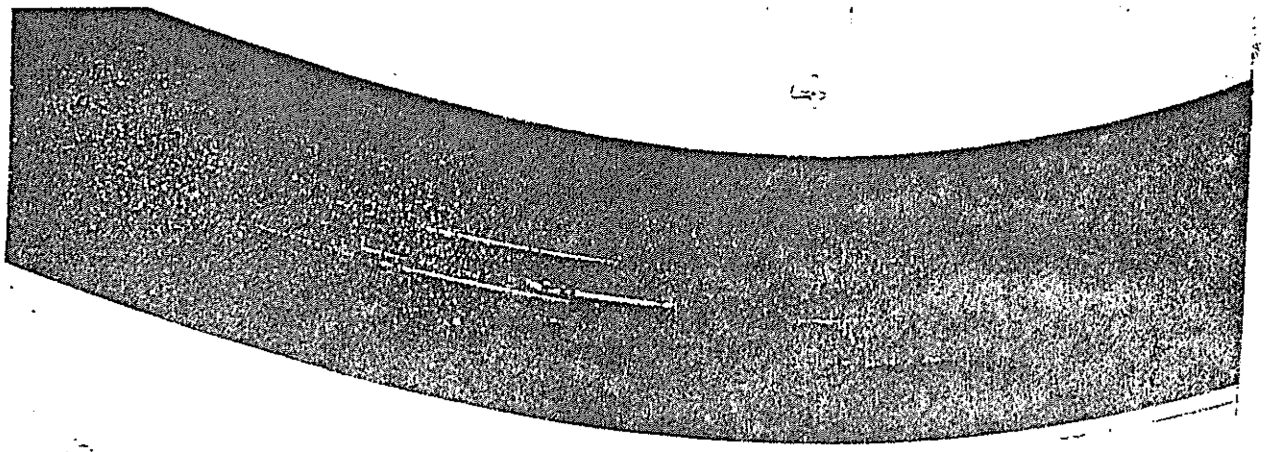

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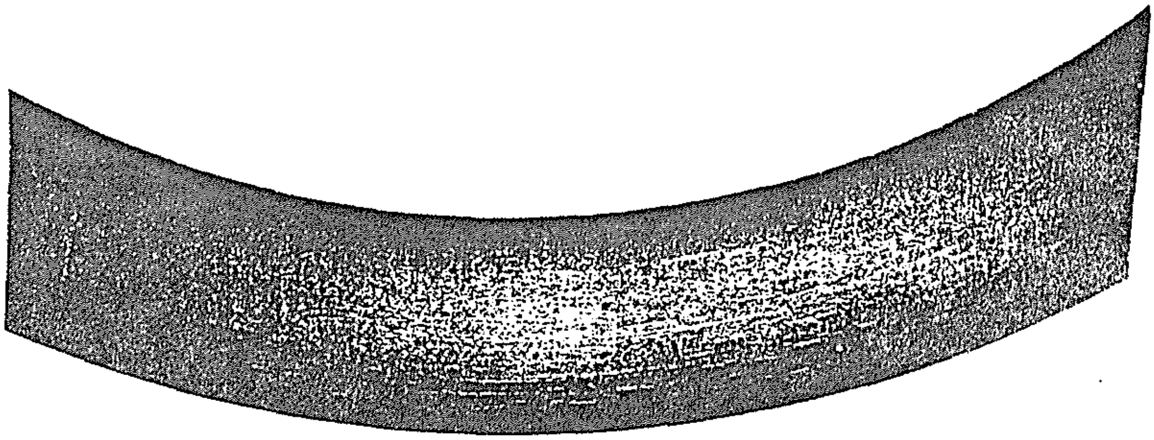

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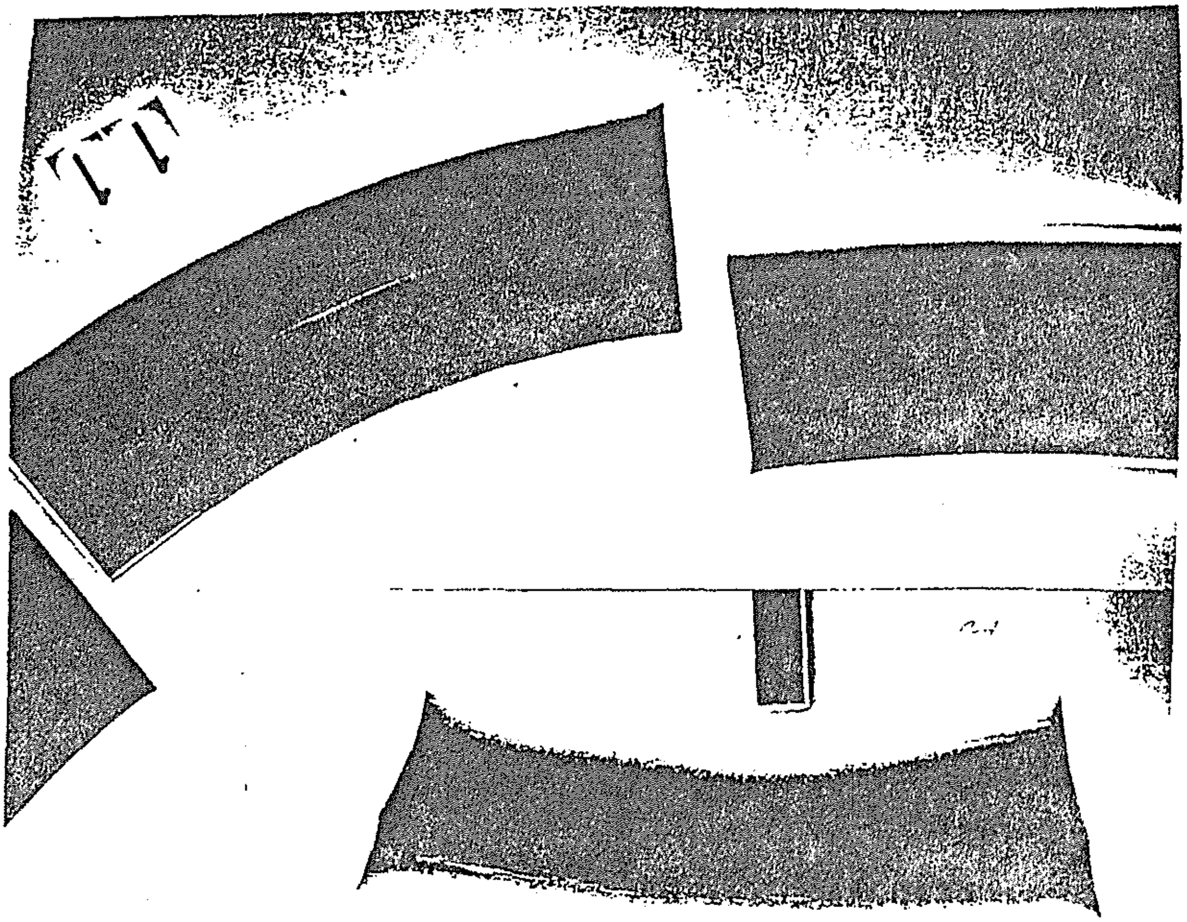

FIG 29

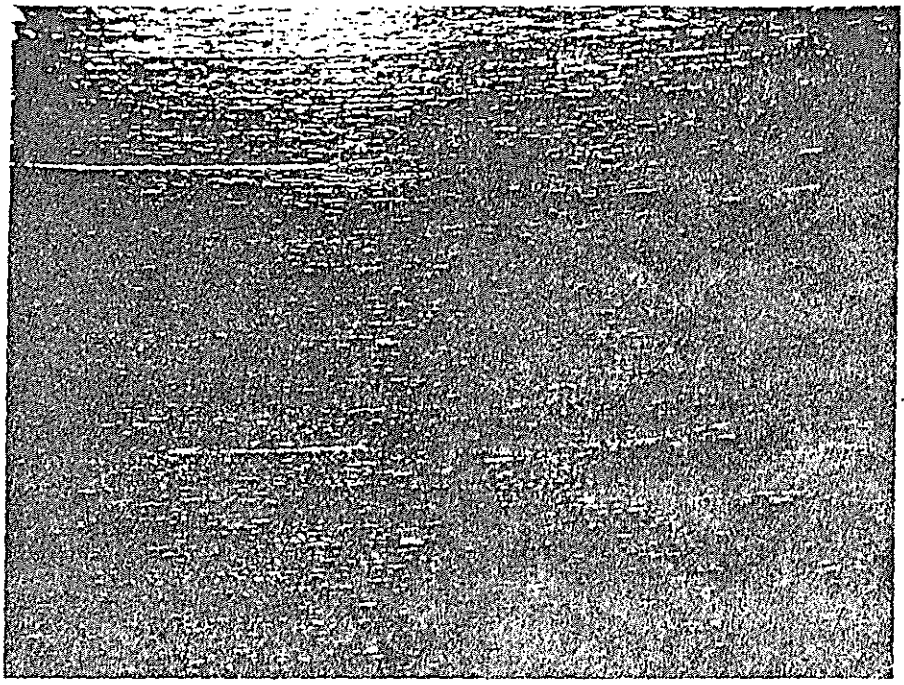

FIG 30

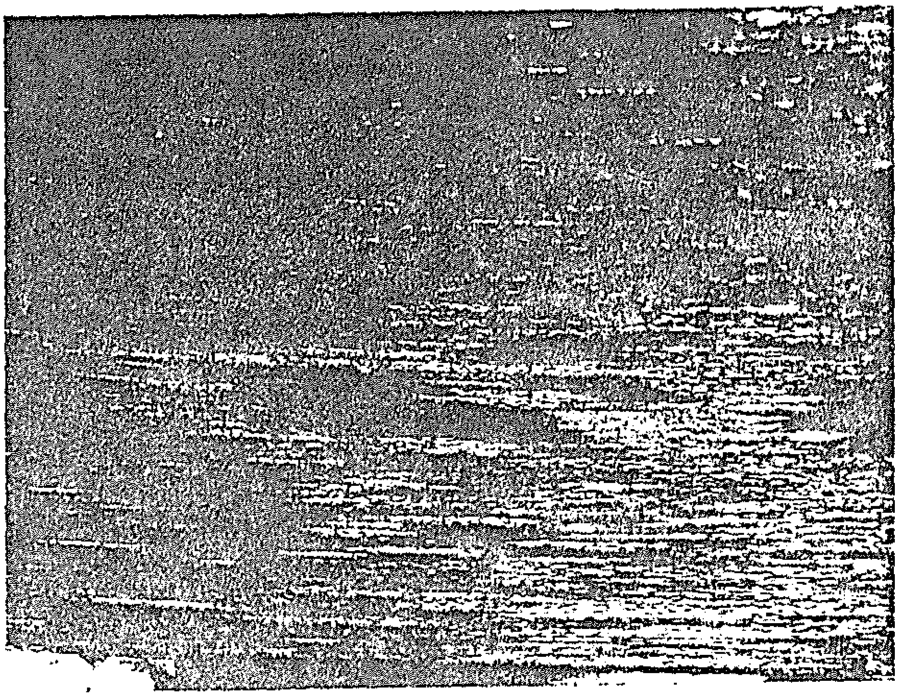

FIG 31

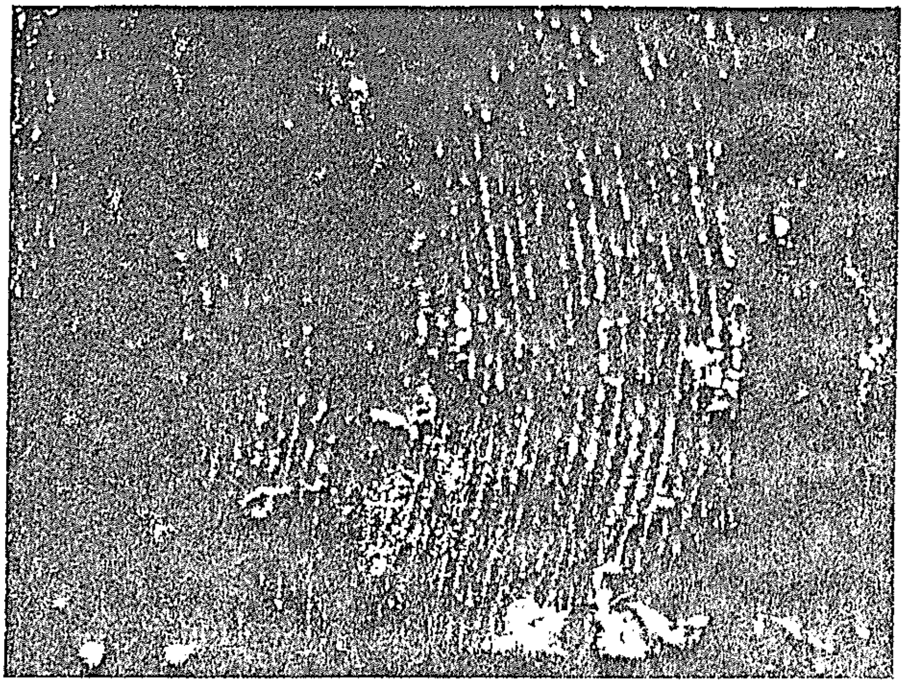

FIG 32

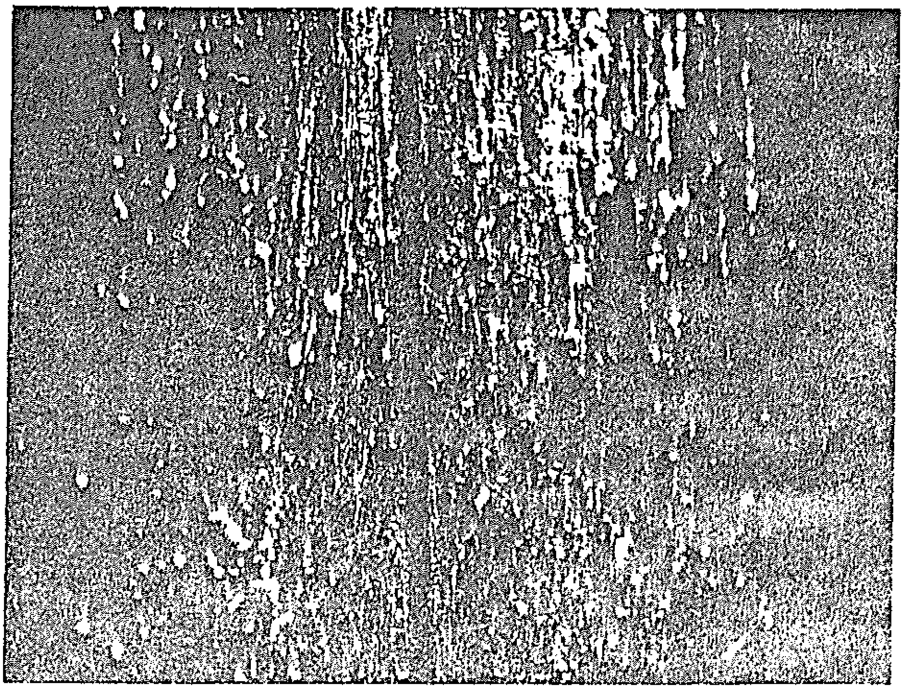

FIG 33

		DISTRIBUTED LOAD APPLICATED	CONCENTRATED LOAD APPLICATED
		ΔX (mm /1000 Nt)	ΔX (mm /1000 Nt)
	1	.2024	.227
HIGH MODULUS	2		.2
HIGH STRAIN TAPE	3	.2024	
	4	.1948	
	5		.22
	6	.2	
VF = 50% (1)	7	.1968	
MODERATE	8	.2472	
MODULUS TAPE	9	.2472	
VF = 50% (2)	10	.2424	
INTERMED.	12		.253
MODULUS TAPE	15	.2168	.226
VF = 50% (3)	17	.2154	.2354
INTERMED.	11		.33 (DAMAGES)
MODULUS ROVING	C2	.208	.2142
VF = 46% (4)	C5	.2016	.2092

TABLE 1

$\Delta X1/\Delta X2$ $Et1/Et2$ $Ef1/Ef2$	1	2	3	4
		1.232	1.084	1.027
1	1	1.47	1.24	1.13
		1.415	1.28	1.25
			0.878	0.835
2		1	0.85	0.766
			0.905	0.855
				0.948
3			1	0.915
				0.975
4				1

TABLE 2

PRELIMINARY PRODUCTION	TOTAL PRODUCED	TESTS OTHER MATERIALS	PRODUCED	O.K.	PERCENTAGE
LOWER INTERNAL	18	4	14	10	71.5%
LOWER EXTERNAL	7	3	4	2	50%
UPPER INTERNAL	30	13	17	16	94%
UPPER EXTERNAL	4	1	3	2	66.6%
TOT. PROD.	59	21	38	30	79%

TABLE 3

PROTOTYPE PRODUCTION					
LOWER INTERNAL	26		26	20	77%
LOWER EXTERNAL	4		4	2	50%
UPPER INTERNAL	25	7	18	16	88%
UPPER EXTERNAL	4		4	4	100%
TOT. PROD.	59	7	52	42	80.8%

TABLE 4

PRELIMINARY & PROTOTYPE PROD.					
LOWER INTERNAL	44	4	40	30	75%
LOWER EXTERNAL	11	3	8	4	50%
UPPER INTERNAL	55	20	35	32	91.4%
UPPER EXTERNAL	8	1	7	6	85.7%
TOT. PROD.	118	28	90	72	80%

TABLE 5