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In situ Crack Propagation Monitoring in Aerospace Structures by Digital Sensor

M. Marchetti, G. Pisciolini

University of Rome "La Sapienza", Aerospace Department Via Eudossiana n. 16, 00184 Rome, Italy

ABSTRACT

The aim of this paper was to develop a passive system sensor in order to analyse the rise and behaviour of crack propagation coming into the surface in a plane structural elements.

The peculiarity of this system is to monitor the condition of the residual reliability of the structural element following a progressive damage, *in situ* and in the normal load condition which it has to provide.

The sensor is made by a film which support a grid, row-column, of electric conductor which will be subsequently attached on the surface of the structural object. The propagation of the defect is noticed observing the progressive interruption of the electric contact on the surface row-column of the grid.

To collect information of on-off type from the sensor it was realised a hardware interface device which collect it to a personal computer. The database is used by the managing software. The software display in a monitor the defect shape and the database values which come progressively during the process, as time, crack length, propagation speed and the propagation direction. The main goal of the sensor and of the entire system is toward of structural objects which have surface crack.

INTRODUCTION

The Fail-Safe (FS) design methodology take into account the initial defects of a structure. Their dimension must be equal to the sensitivity threshold of the Non Destructive Controls adopted in the inspection and the operative life must be equal to the range of the inspection [1]. This means that in FS methodology it is necessary to know the time-loading and the crack grow law. The materials must be choised to support long cracks without break them. Also they must

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have low crack grow speed.

For a reliable FS design it is essential to have very precise data about the crack grow speed in relation with load, and also of its variation in time and of the most significant physic and environmental parameters.

The necessity of precise data, related to structural object for which it is difficult to forecast mathematical traditional models, has been the inspiration of the present work. The in situ monitoring system, based on a digital sensor, can constitute valuable instrument for design because it provide interesting data in real time and with high accuracy. If it is employed by aeronautic and astronautic fields, it can be integrated in the on board avionic system which will on real time the post-process of the data.

SYSTEM DESCRIPTION

The system has been realised as a prototype and utilised, in this version, for the fatigue test. The general plan of the set-up of acquisition and visualisation system is shown in Fig. 1.

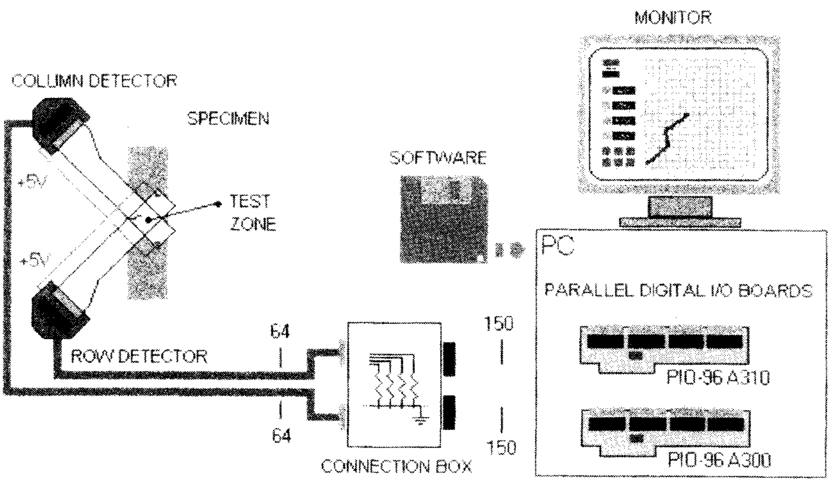

Fig. 1 General plan of the set-up

Elements of the system:

Sensor

The sensor is made by a pair of paper films. On them through a serigraph process, electric conductive tracks were developed (silver based ink DU PONT 5025). These paper films will be set orthogonally to constitute a row-column grid shape circuit. Later they will be attached on the object test either both on the same side or, if the crack surface may be treated with 2-dimentional geometry, one on one side and the other on the other side (see Fig. 2).

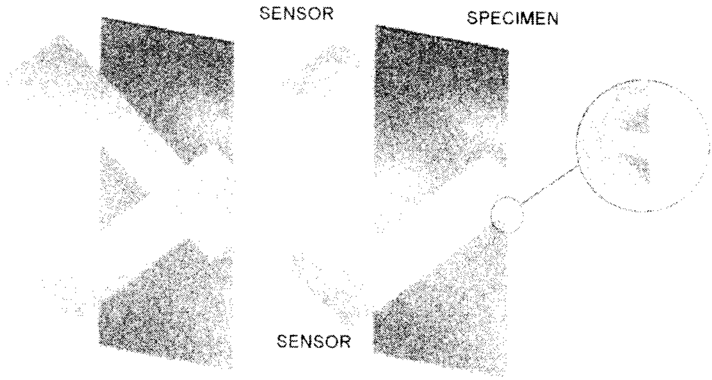

Fig. 2 An example to correct positioning

It is important to remark that the application of the sensor does not modify consistently the structural characteristics of the object test. The conductive tracks join a common supplying area at +5 Volt voltage. At the other side of the sensor, where contacts are collected, the voltage is +5 Volt if the track is undamaged and 0 volt if it is damage. The crack during its growing face damages these above tracks.

From a digital point of view, the undamaged track corresponds to '1' logic and the damaged track corresponds to '0' logic. The following acquisition system will be able to read two binary word (for instance: 000111111...), one for the row and one for the column of the grid. For technological reasons the number of rows and columns is fixed at 64, which means the binary strings, both for rows and columns, are constituted by 64 bit. To have a better idea it is useful to see the Fig. 3.

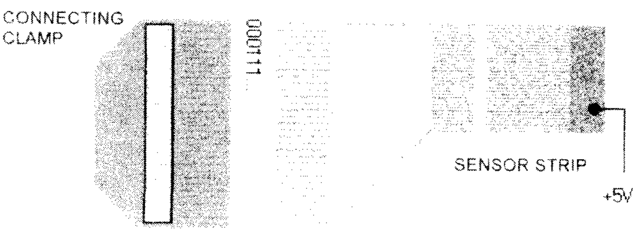

Fig. 3 Clamp and sensor

Parallel Digital I/O Board (PIO-96) and Software

PIO 96 is a interface board with 96 input-output parallel lines for the personal computer PC-XT-AT-PS2 and it has been designed on the chip Intel 8255-24 bit. The inputs and outputs of this board can be addressed starting from a base-address to set by the switch [2].

The values of the base-address of both boards, one for the rows and one for the columns, are respectively H310 and H300. In the Tab. 1 is shown the addresses map of the port PA, PB, PC for each of the four connectors J1- J4. The pair of boards join the electric part with the software part. In the following Fig. 4 is shown an example of only J1 connection.

In Fig. 5 is shown also the Connection Box and the sensor.

LOCATION	FUNCTION	TYPE
Bits 0-23: Base Address	+0 8255 PA Port +1 8255 PB Port +2 8255 PC Port +3 8255 Control	Read/Write Read/Write Read/Write Write Only
Bits 24-47: Base Address	+4 8255 PA Port +5 8255 PB Port +6 8255 PC Port +7 8255 Control	Read/Write Read/Write Read/Write Write Only
Bits 48-71: Base Address	+8 8255 PA Port +9 8255 PB Port +10 8255 PC Port +11 8255 Control	Read/Write Read/Write Read/Write Write Only
Bits 72-95: Base Address	+12 8255 PA Port +13 8255 PB Port +14 8255 PC Port +15 8255 Control	Read/Write Read/Write Read/Write Write Only

Tab. 1 J1-J4 addresses

The acquisition and computing programme written for the Windows operative systems, does a sweep of rows and columns every 1/10 seconds. This corresponds to a frequency which is enough for observing slow phenomena such as the crack grow.

The sweep which starts from the row and column farther from the tip of the cracks stops, recording the position, at the first '0' of row and column. The sweep proceeds the established frequency. The purpose is to verify the changing position of this '0' logic.

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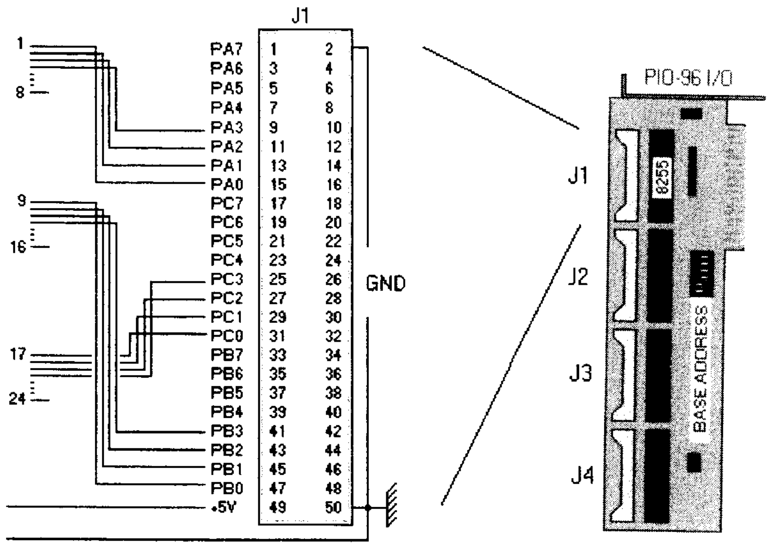

Fig. 4 J1 ports (PA,PB,PC) layout.

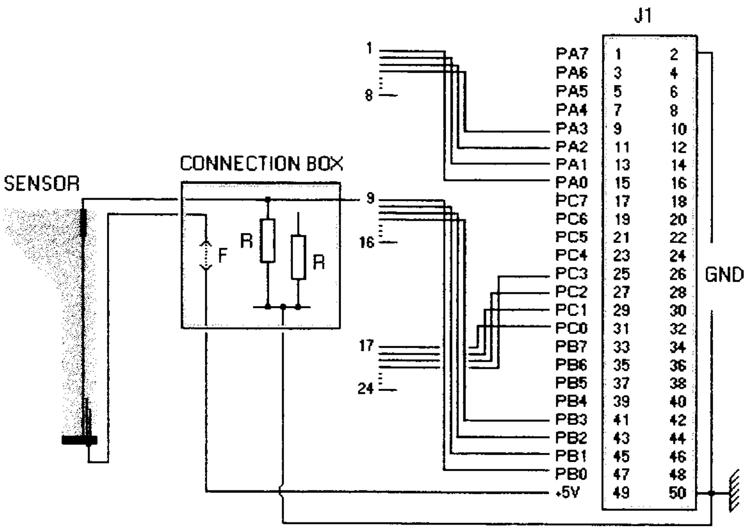

Fig. 5 Hardware layout

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The recorded data enable us to compute the length of crack in the advancing direction, the time of the test and the speed and direction of grow. To control the effective capacity of the system to follow the crack along its evolution a taste has been made cutting only the sensors in a geometrically recognisable way. The test result is shown in Fig. 6.

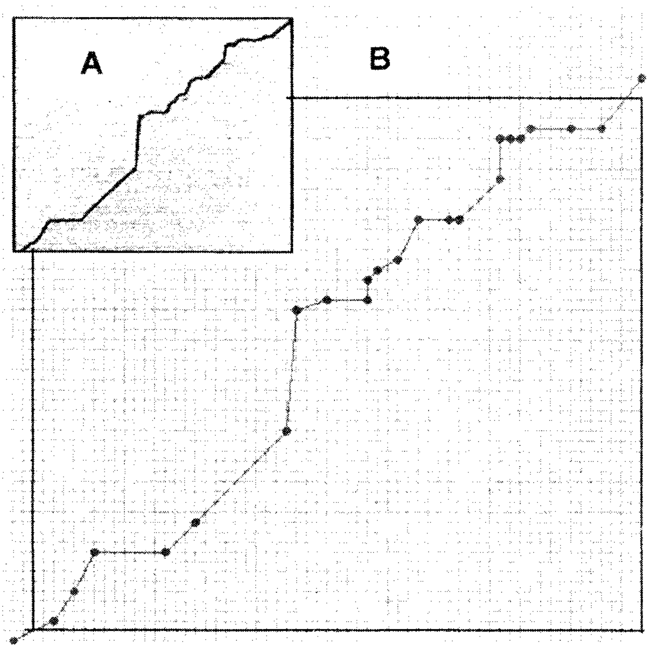

Fig. 6 Fracture shape; A: true, B: monitored (grid resolution ≅ 0.63mm)

EXPERIMENTAL TESTS and DATA ANALYSIS

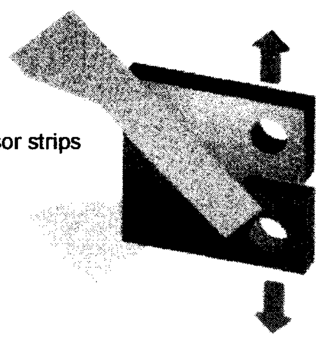

Fig. 7 CT specimen

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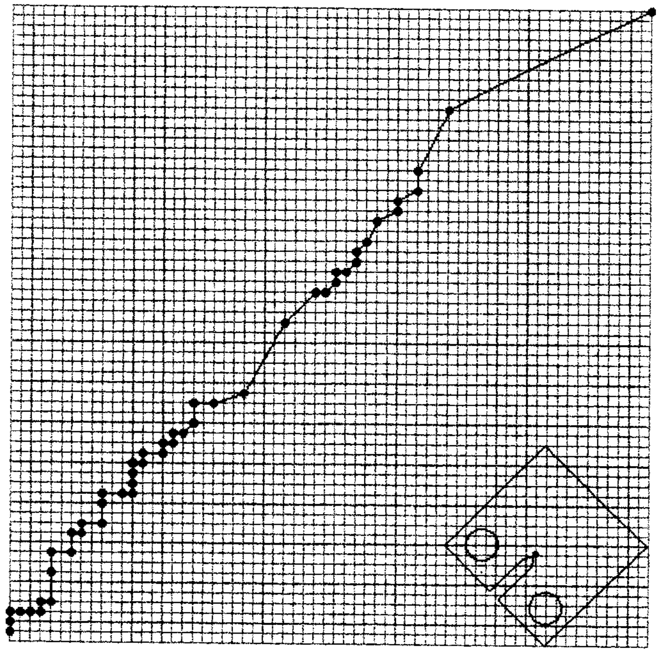
As we stated in the introduction, we made fatigue tests on specimens CT alloys such as AL 7075-T6 e AL 2024-T351 (Fig. 7) following the indication ASTM E647-88a. The reason of this selection is in the high data quantity in our possession which will enable us to compare with our data [3].

Before showing the results, it's suitable to point out that the system has not been thought for fatigue tests. These tests have been made in order to have a first approximate evaluation of the sensor defect tracking capability.

Here we present two tests result.



specimen type	$P_{MAX}(kN)$	$P_{min}(kN)$	R	$f(Hz)$
Al 7075-T6 CT #1	**3.5**	**$\approx$ 1.0**	**0.3**	**10**

Fig. 8 Crack path, CT#1

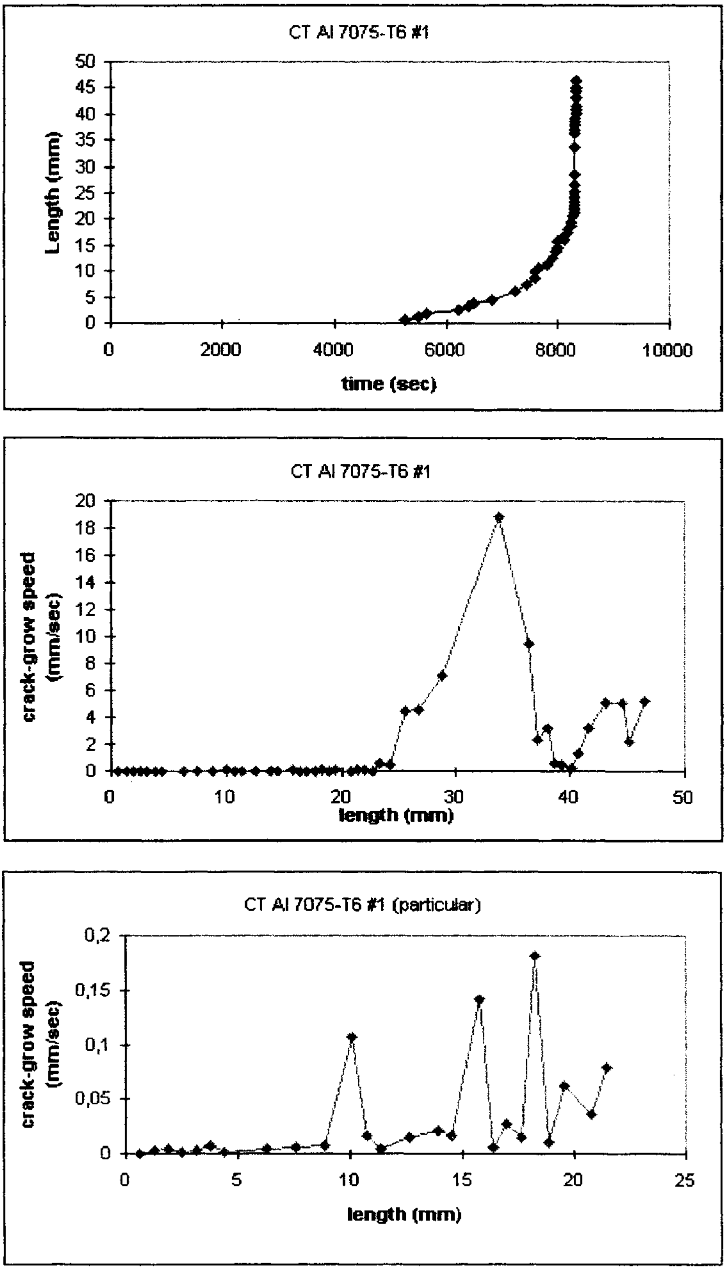


Fig. 9 Crack length and crack-grow speed

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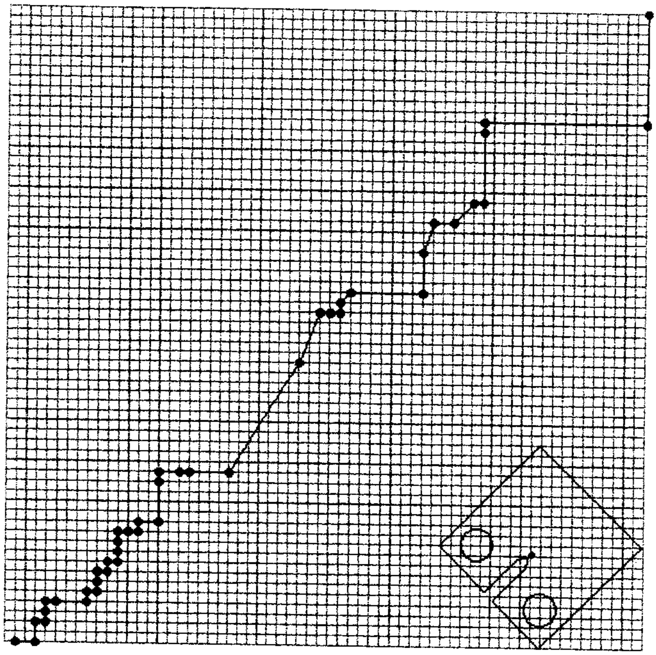

specimen type	$P_{MAX}(kN)$	$P_{\min}(kN)$	R	$f(Hz)$
Al 7075-T351 CT #2	**4.5**	**2.25**	**0.5**	**10**

Fig. 10 Crack path, CT#2

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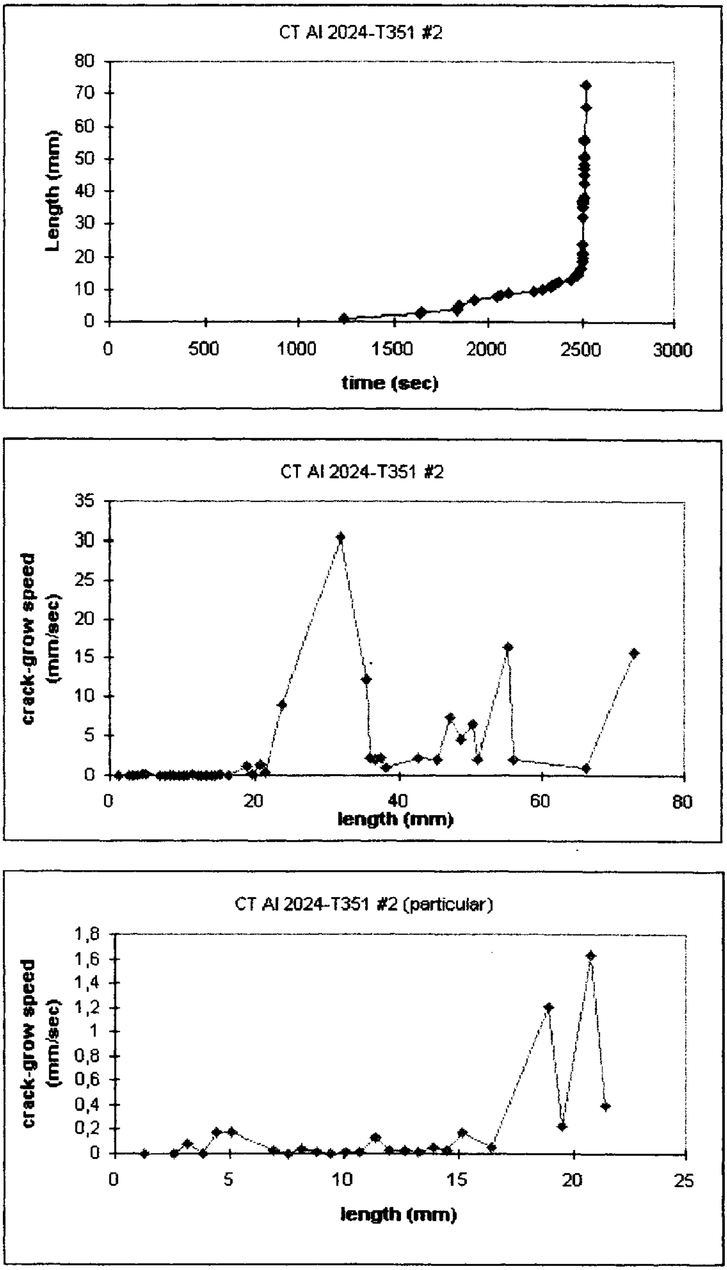

Fig. 11 Crack length and crack-grow speed

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Examining the Figg. 8,10 where the fracture trace appears, we immediately notice a common characteristic, in the first part, where the crack propagation speed is lower, the monitored crack proceeds to zig-zag.

Surely the real fracture proceeds more regular than what is showed [4]. Otherwise even the analysis of specimen proved this. Following, with the aid of the Fig. 12 we examine the reasons about this discordance.

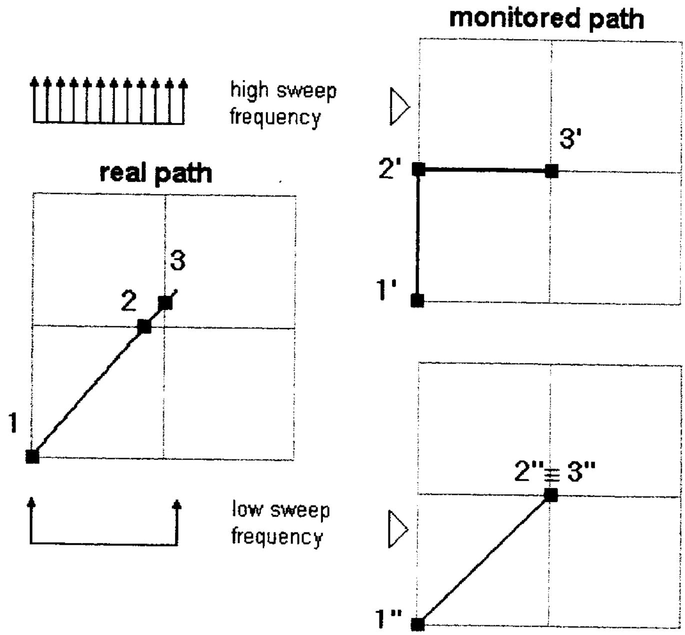

Fig. 12 Sweep frequency effect

On consider, for example, a fracture that it is propagating with a constant speed in the tract 1÷3. If the sweep frequency is high, the system registers the crossing to the 2 point but it assigns to the point 2' of the grid. The displayed path is very different from the real one. Studying an opportune sweep frequency we can get a path more realistic.

The high frequency sweep effect is particularly significant especially in the evaluation of the crack-grow speed. In fact if we suppose that the crack-grow speed is constant in the path 1÷3, the 2÷3 path is crossing by a lower time than the 1÷2 path. If we assign these times to the respective paths 1'÷2', 2'÷3'(same length path) the calculate speed in the 2'÷3' path, it would result much higher than the one of 1'÷2' path.

This situation is showed in Figg. 9,11 where we can notice clearly some disproportional speed peaks.

Following these considerations it was effected a new processing on the experimental data choosing only the most significant referred to the ASTM rules mentioned above.

The results (Figg. 13,14) we are substantially equal to those in literature.

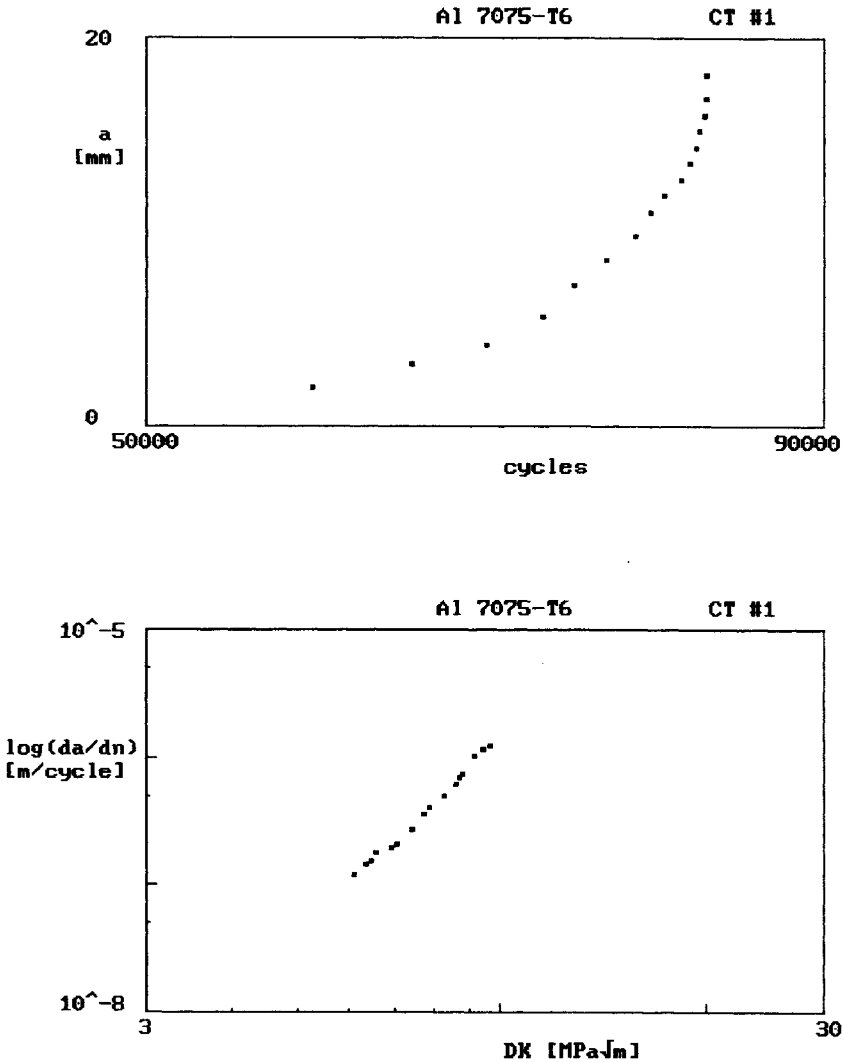

Fig. 13 a-N , da/dN-ΔK plots for specimen CT #1

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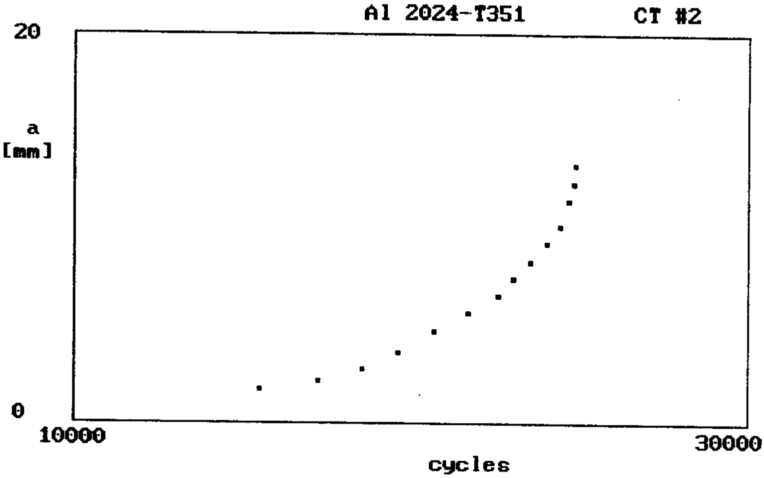

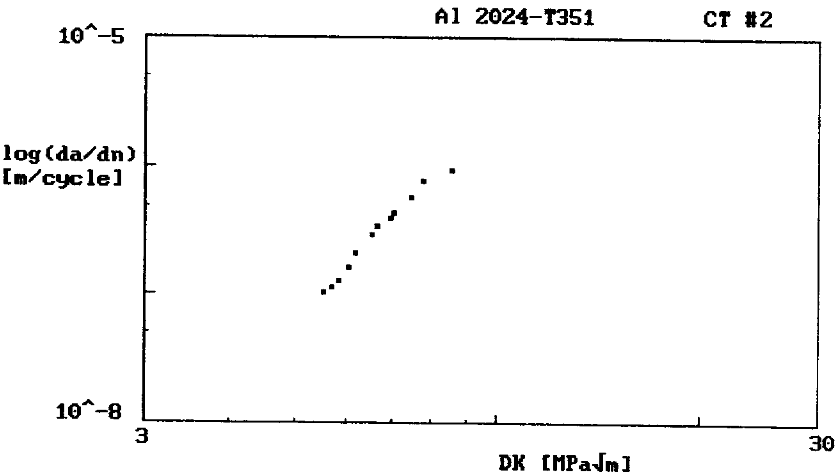

Fig. 14 a-N , da/dN-ΔK plots for specimen CT #2

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CONCLUSIONS

The system proposed is only its initial phase of development, but it seems to us there are some reasons to continue the researches in the direction of digital type sensors. In its prototype version it won't be used by industrial applications if we don't execute a technological sharpening. In particular it's necessary to thicken the grid, so we can increase the resolution at least of a factor 5 by the actual 0.63mm and to endow the sensor by a local microchip for reducing the number of the connectors toward the processing unit in a drastic way.

We conclude this work pointing out some particular characteristic.

Localisation Capability:
it is useful to highlight only the emergent defects on surface, revealed if in the covered sensor area.

Reliability:
it is high if we chiefly study very well the interface between the sensor and the object to monitor.

Post-process request:
it is very low, and at reduced costs.

Informative contribution:
It furnishes information only if the defect emerges in surface, even if it's temporarily silent.

Precision:
It depends on the resolution of the grid and it has not biased from other factors. A value easily attainable is 0.1mm.

Temperature exercise:
employment in own sites of the electronic devices.

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