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REPORT

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Hungarian Academy of Sciences
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ACOUSTIC EMISSION EXPERIMENTS FOR PHWR TECHNOLOGY DEVELOPMENT

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ABSTRACT

In the framework of an Indo-Hungarian common research project for applying acoustic emission techniques to solve specific problems at nuclear power plants, measurements have been performed at Bhabha Atomic Research Centre (BARC), Bombay in January, 1992. Acoustic emission measuring and analyzing hardware and software had been provided from the Hungarian side, while the measurements were carried out by BARC experts. The aim was to check the method's capability for leakage detection and shuttle movement monitoring at Pressurized Heavy Water Reactors (PHWR) as well as its applicability in monitoring manufacturing processes such as laser welding. In this paper the measurements are shortly described and results presented.

Pellionisz P, S. K. JHA, G.L. Goswami: Kísérletek akusztikus emisszióval nehézvizes atomreaktorok (PHWER) műszaki fejlesztésére KFKI-1992-19/G,I

KIVONAT

Az akusztikus emissziós technika atomerőművi alkalmazására közös indiai-magyar kutatómunka folyik. Ennek keretében közös mérések történtek 1992 januárjában, Bombay-ben, a Bhabha Atomic Research Centre-ben (BARC). Az akusztikus emissziós mérés és analízis műszereit valamint a számítógépi programokat a magyar fél bocsátotta rendelkezésre, míg a méréseket az indiai partner készítette elő. A mérések célja annak kipróbálása volt, hogyan alkalmazható a módszer szivárgások mérésére, illetve a fűtőelem-továbbító szán helyzetváltozásának jelzésére nyomott, nehézvizes (PHWR) atomreaktoroknál. Különböző megmunkálási folyamatok, például lézerhegesztés ellenőrzésére is történtek kísérletek. Jelen beszámoló röviden összegzi a méréseket és az eredményeket.

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ABSTRACT

In the framework of an Indo-Hungarian common research project for applying acoustic emission techniques to solve specific problems at nuclear power plants, measurements have been performed at Bhabha Atomic Research Centre (BARC), Bombay in January, 1992. Acoustic emission measuring and analyzing hardware and software had been provided from the Hungarian side, while the measurements were carried out by BARC experts. The aim was to check the method's capability for leakage detection and shuttle movement monitoring at Pressurized Heavy Water Reactors (PHWR) as well as its applicability in monitoring manufacturing processes such as laser welding. In this paper the measurements are shortly described and results presented.

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1. Introduction

In India, all nuclear power stations except Tarapur Atomic Power Station are designed to use heavy water as moderator in the reactors. India opted for the Pressurized Heavy Water Reactors (PHWRs) for its nuclear power programme as these rectors use natural uranium as fuel. Other advantage being that refueling is performed with reactor at full power by special fueling machine on each side of the reactor face. The major objective of the broad spectrum of activities at Bhabha Atomic Research Centre (BARC), Bombay is primarily to provide research and development support needed to sustain India's nuclear power programme in relation to concepts, designs, materials, reliability and safety. A versatile infrastructure of research facilities has been developed in this technologically self reliant nuclear research centre.

In Hungary, the KFKI Institute of Atomic Energy Research is oriented to the country's WWER-440 pressurized light-water reactors. Its activities extend from reactor physical studies to material science or surveillance systems, comprising most aspects of safe operation. In many fields, however, results of research and development can easily be applied at other types of nuclear reactors. This is the case, e.g. of acoustic emission investigations for detecting anomalies such as crack formation, leakage detection or impact noise monitoring.

This is the reason that cooperation has been started between BARC and KFKI several years ago in acoustic emission investigations. In KFKI, at the High-Reliability Systems Laboratory there is a long history of developing scientific instrumentations and software. Several special acoustic emission analyzers have been developed and successfully applied in non-destructive testing of material samples, industrial objects and manufacturing processes during the last 15 years. Acoustic emission monitoring of pressure tests of Hungarian nuclear reactor pressure vessels became regular[1]. After the proof test in 1990, a common Indo-Hungarian analysis of the experimental data was made[2]. At BARC, Bombay acoustic emission technique has been applied for on-line TIG weld monitoring, study of relaxation behaviour in multicomponent metallic glasses and on-line monitoring of high pressure steam-line and pressure vessel for possible crack propagation[3-11]. Eventhough reports are available on application of acoustic emission technique in PHWRs for monitoring leakage through seal-plugs[12], leakage through end shield[13] and detection of delayed hydride cracking[14] etc., it was decided that capabilities of the Hungarian acoustic emission technology should be tested at BARC in several experiments of PHWR technology development like monitoring the leakage through defective seal-plug, through rolled joint and shuttle movement.

PHWR nuclear reactors are comprised of several hundred horizontal fuel channels (306 in case of 235 MWe reactors). The basic component of each fuel channel are two co-axial Zr-2/Zr-4/Zr-2.5 Nb tubes. The inner tube known as pressure tube contains nuclear fuel and heavy water as coolant at pressure of 1500 psi at 250 to 300 degree C. The other tube known as calandria tube is surrounded by heavy water moderator. The pressure tube is terminated at both ends by stainless steel end-fittings and attached by a rolled joint. Each end-fitting protrudes through the biological shield and thermal insulation. Coolant enters at one end-fitting through a connection at right angles to fuel channel axis and leaves at the other end-fitting through identical configuration.

2. Applied Acoustic Emission Instrumentation and Software

Monitoring of acoustic emissions is based on the detection and analysis of the low-amplitude, high-frequency transient elastic waves originated in the material when microcracks are formed, cracks are growing or other degradation occurs in the object under load. From other non-destructive testing methods it distinguishes itself: with few sensors large structure can be monitored, location of sensors is not critical since sound waves spread, stable material defects keep silent etc.

Another important application field is leakage detection. Here the high-frequency part of continuous turbulence noise is measured disregarding low frequency environmental noise. By applying several sensors distributed on the object being investigated, approximate location of the acoustic source can also be identified.

In KFKI Institute of Atomic Research a multichannel acoustic emission analyzer system, named Defectophone NEZ-220 has been developed[15]. It is a complete family of acoustic emission instrumentation items, comprising amplifiers, filters, a main 4-channel analyzing device, expander unit for increasing channel number to 16, system tester for checking proper operation of the whole set-up, etc. An important part of the system is a powerful software package for IBM-PC-ATs and compatible computers enabling them to program and to control the measuring units as well as to receive and to analyze measured data arriving to the computer through RS-232-C standard asynchronous communication line.

The Defectophone device is shown in Fig.1. The device measures the most important parameters of either continuous or burst-type AE signals such as absolute average, number of bursts and their oscillations, peak-amplitude, occurrence time difference, rise time etc. The information is digitized and may be shown directly on front panel display, on a 2-pen plotter, on a computer display as may be required. Data can further be analyzed in form of plots, location maps, correlations, distributions etc. using menu-based software package (DEFPROC).

This device had been delivered to BARC for implementing the measurements described in the next chapters. It was used together with an interconnected IBM-PC/AT, where all the measurement data were stored and later analyzed.

3. Leakage Detection Experiments at Integral Thermal Facility

Defectophones are mostly used with logrithmic amplifiers in order to cover the large dynamic range of burst-type acoustic signals; sometimes as high as 80-100 dB. For measuring the continuous, high frequency noise generated by leakages where turbulences appear, linear amplifiers are to be applied, since variation of rms or average value of the noise may be small at low leakage rate vibrations.

Leakages at the seals may develop due to corrosion of the seal faces of the fuel end-fitting connections in the channels. Corrosion may take place because of poor chemistry control of the primary heat transport coolant.

Modifications were done in the existing AET linear preamplifiers to make it compatible with Defectophone with the help of engineers from Reactor Control Division (RCnD), BARC. Sensitivity of each AE sensor and AET preamplifier was compared (Tables. 1&2) and it was decided to use the most sensitive combination of sensor(X1) and preamplifier(A) for leakage detection and laser weld monitoring.

The experiments were conducted in Integral Thermal Facility (ITF) at Reactor Engineering Division (RED), BARC. Normally ITF coolant channel has simulated conditions of pressure (up to 100 bar), temperature (up to 250 degree C) and flow (about 12 kg/sec). The only difference being the use of light water as fluid instead of heavy water. AE signals were recorded using a 175kHz resonant type sensor (X1) and a linear amplifier (A) of 60dB fixed gain. Seal-plugs were intentionally provided with radial defects on sealing face to increase the leakage rate. Background noise level was recorded with and without pumps running, with and without heater on and at different levels of pressure and temperature. When the pump is not running there is no flow of fluid (water) but pressure is maintained. Because of high temperature, 20mm diameter SS waveguide was used with silicon grease as couplant (Fig.2).

AE monitoring of leakage through good seal plug (i.e. very very low rate of leakage) didn't yield much information. However, during experiments with seal plug having small defect an important observation was presence of burst AE events (200-400mV peak-to-peak) due to low rate of steam leakage at high temperature. The high peak voltage may be due to phase transformation of water at 250 degree C and 100 bar to steam at 250 degree C and 1 bar. Also, as the defect size was very small, leakage may be intermittent and therefore generation of AE was not continuous.

However, when the defect size was increased intentionally, the leakage was continuous and it caused generation of high amplitude (Table.3) overlapping AE signals (known as continuous signals). For seal plug having large defect, with the increase in temperature from 40 degree C to 250 degree C, leakage rate increased from 480 g/hour to 2800 g/hour causing an increase in noise level from 50mV (peak-to-peak) to 800mV (Table.3). Therefore there was an increase of 16 times in the amplitude of the signal. The signal pick-up can still be enhanced by optimizing the waveguide design and experimental trials will be conducted in future for determining the relationship between leak rate and AE activity.

Experiments were also carried out for detection of leakage through zircaloy-stainless steel rolled joint. It was observed that the leakage of He+Air of the order of 10^{-8} std. cc./sec through the joint does not cause any increase in the background level and therefore the analysis in amplitude domain is not suitable for such a low rate of leakage. The peak-to-peak voltage level remains 15mV after 60dB amplification. However, frequency domain analysis may yield some informations.

4. Monitoring of Shuttle Movement by AE Technique

In operating PHWRs, a shuttle is required to transport a pair of spent fuel bundles from reactor building to the storage bay. At RED, BARC, a shuttle test set-up is available for the development of 500 MWe PHWR shuttle. Shuttle test set-up consists of a pipeline of 18 meter length having six 3-meter long segments joined together by clamps. Shuttle moves to and fro in this pipe by virtue of water flow. It is desirable to monitor the position of shuttle in case it gets stuck up anywhere in the pipeline.

The experiment involved calibration studies to find out the sound velocity, background noise with (18dB) and without (4dB) water flow, signal attenuation as a function of distance and also across joint and effect of shoe on signal attenuation using a pulsar attachment and logrithmic amplifier. During the trial experiments only the events having peak amplitude more than 40dB were recorded. And, it was observed that whenever shuttle passes through any of the pipe joints, where invariably some mismatch exists, there is generation of stress wave and the same have been recorded (Fig.3). There exists a good correlation between detection time and shuttle movement. In the beginning the shuttle travels at a slower speed and therefore takes more time to travel from first joint to second joint and that is why the time gap between first and second events is larger. Second and third events are from the same joint as they occur within a time difference of few milliseconds. Third event is generated when the rear portion of shuttle strikes the joint. Therefore the time gap between second & fourth events and fourth & fifth events are almost same as the speed of shuttle is uniform.

The low amplitude from the first joint, even after considering the attenuation loss, may be due to lower speed in the beginning or lesser degree of mismatch at the first joint. Had speed and mismatch been uniform, it is expected that events of same strength should be generated. The second and third events have higher amplitudes because the sensor was kept near the second joint. Therefore, it may be possible to use this technique for monitoring shuttle movement in a long pipeline by employing more number of channels and sensors, which will also enhance the accuracy of results.

5. AE Monitoring during Laser Welding of SS and Aluminium

AE signals were recorded during bead-on-plate welding of stainless steel and aluminium plates of thickness 3.6mm and 7.0mm respectively. The welding trials were done using a pulsed Nd:YAG laser with different set of parameters (like pulse energy, pulse width, repetition rate etc.). Dead time for recording AE events was also reduced to detect inter-pulse phase transformations in the material. It resulted in increase in number of events from 170 to 425 in case of stainless steel. In the first case the amplitude remains almost uniform throughout the welding trial (Fig.4), but there is a large variation in second case (Fig.5). The low amplitude signal may be attributed to phase transformation(s). However, when the dead-time is large, there seems to be an AE event corresponding to each pulse. Laser welding of aluminium (Fig.6) resulted low amplitude AE signals; 40 dB compared to 65 dB for SS for same set of parameters. The results are yet to be analyzed in detail to determine the effect of each parameter on the characteristics of AE.

6. AE Monitoring during Mechanical Testing

AE monitoring was done during tensile testing of zircaloy-2 (Figs. 7&8) and mild steel (Fig.9) specimens and also, during tensile loading of precracked compact tensile specimens (Figs. 10&11) at Metallurgy Division (Met. Div.), BARC. These experiments provided informations regarding AE behaviour of different material with and without a pre-existing crack. Fig.7 shows cumulative events recorded upto yielding and Fig.8 shows the cumulative events and also the amplitude of AE signals after yielding for zircaloy-2 tensile specimens. Fig.9 shows the variation in cumulative events and amplitude against time for mild steel specimen after yielding. It is clear from the Figs. 8&9 that mild steel is much more noisy compared to zircaloy-2 as total events recorded for mild steel is 3000 against 55 for zircaloy-2.

Fig.10 shows the AE events and load against time for tensile loading of precracked SS specimen. As seen in the figure, there is generation of AE events even when the load is constant and later even with the increasing load, there is not many AE events. Further, there are few events generated within a short time indicating a fast crack growth and few events just before the fracture. Fig.11 shows the amplitude distribution for the same experiment. However, a number of experimental trials are required to be conducted at laboratory scale for predicting crack propagation velocity or study of material properties.

7. ACKNOWLEDGEMENTS

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TABLE-1

CALIBRATION OF AET SENSORS AND PREAMPLIFIERS (PENCIL-BREAK TEST)

SL. NO.	SENSOR			AMPLIFIER			BACKGROUND NOISE (mV$_{pp}$)	EFFECT OF STIMULATION (V$_{pp}$)
	FREQUENCY (kHz)	CODE	ID NO	MODEL	FILTER (kHz)	CODE		
1	175	X1	-	AET 160B	125-250	A	15	4.4
2	175	X1	-	AET 160B	125-250	B	17	3.0
3	175	X2	5010	AET 160B	125-250	A	15	2.6
4	375	Y1	3062	AET 160B	250-500	C	19	1.3
5	375	Y2	3568	AET 160B	250-500	C	18	0.7

TABLE-2

CALIBRATION OF RUSSIAN SENSORS (WITH PULSER)

SL. NO.	SENSOR IDENTIFICATION NO.	BACKGROUND NOISE (dB)	EFFECT OF STIMULATION (dB)
1	059-0	4	64
2	066-0	3	61
3	061-0	22	35
4	006-0	0	26

TABLE - 3

AE MONITORING OF LEAKAGE THROUGH SEAL-PLUGS HAVING LARGE DEFECTS

SL. NO.	TEMPERATURE (DEGREE C)	PRESSURE ([illegible])	STATUS OF		SIGNAL VOLTAGE (mV$_{pp}$)	LEAKAGE RATE (G/HOUR)
			PUMP	HEATER		
1	40	90	OFF	ON	50	480
2	40	90	OFF	OFF	30	480
[illegible]	40	90	OFF	ON	50	480
4	155	85	ON	ON	250	-
5	174	88	ON	ON	440	700
6	250	90	ON	ON	800	2800
7	250	90	OFF	OFF	800	2800

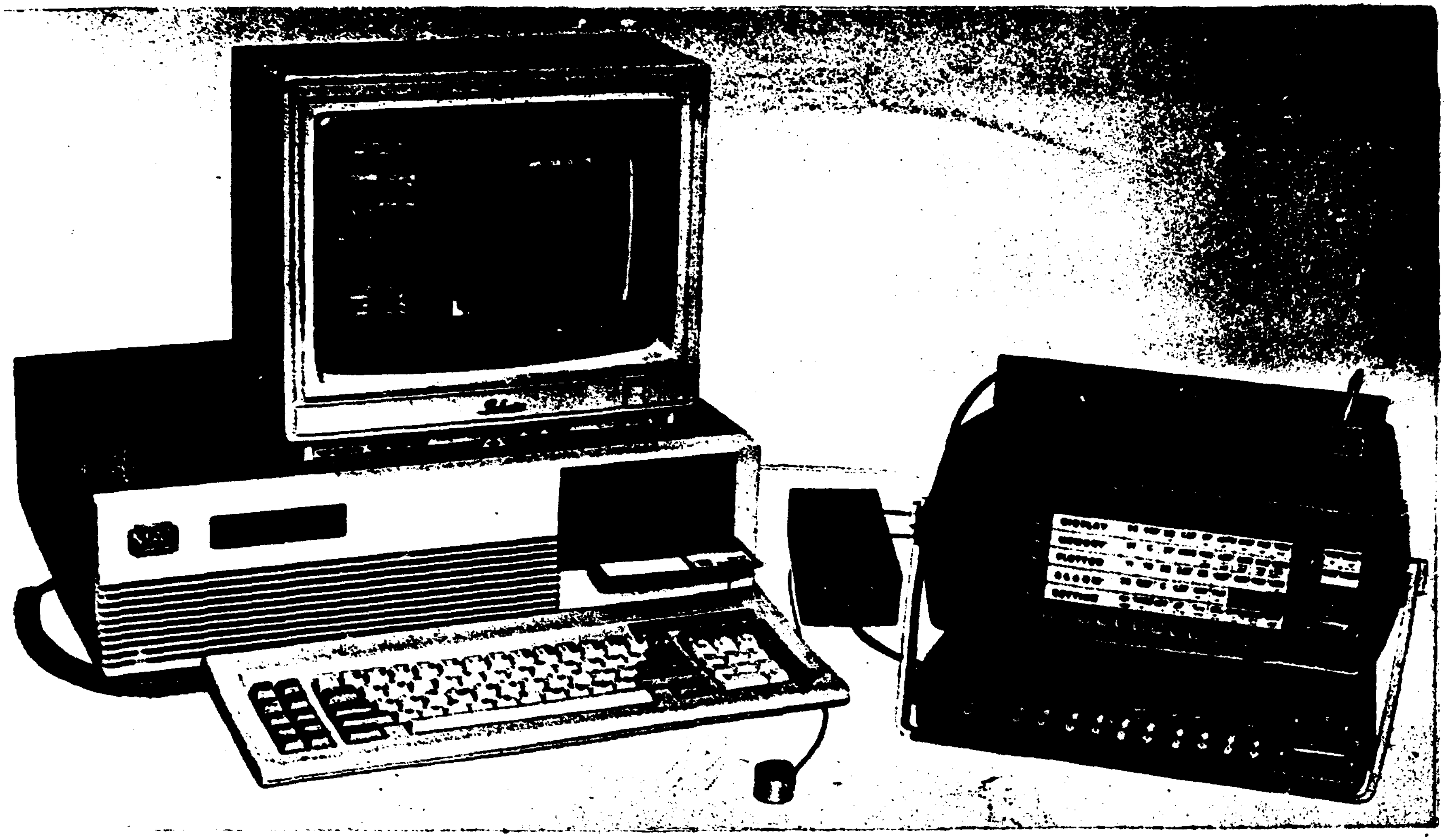


Fig. 1 : Defectophone : a portable, stand-alone measuring device or a remote front-end processor coupled to IBM-PC-ATs.

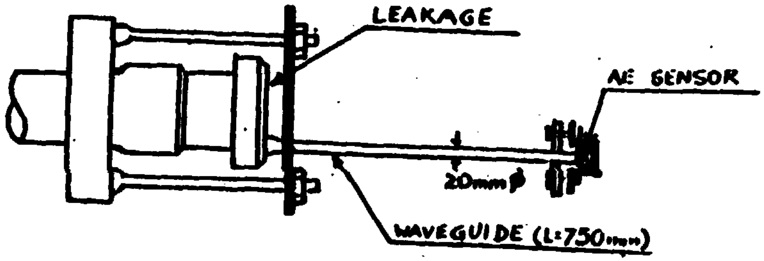
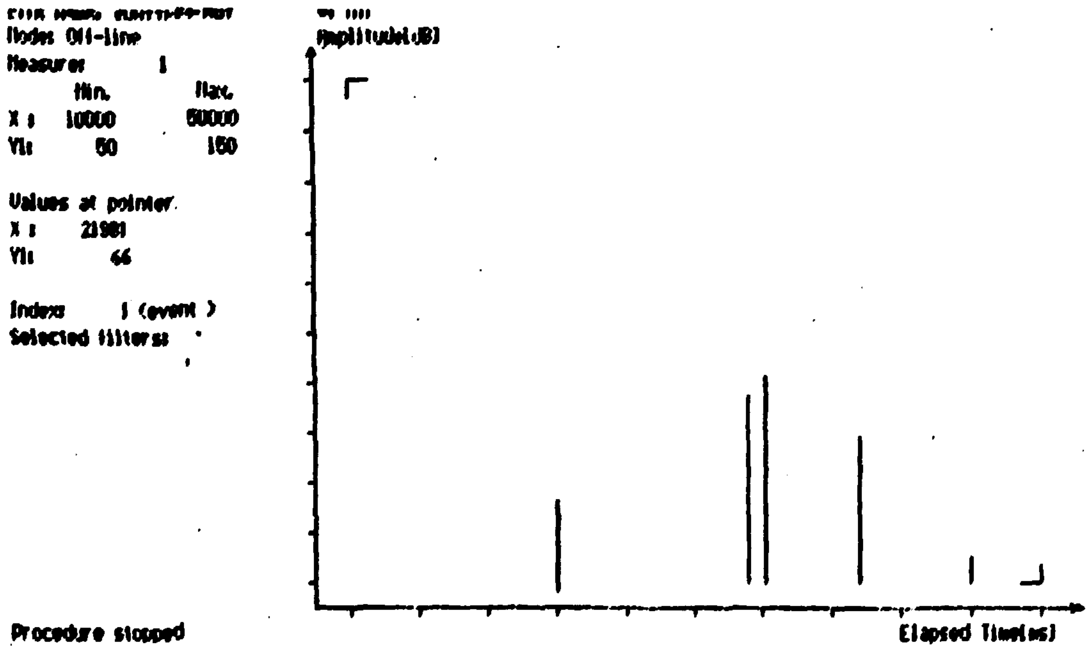


Fig. 2 : Schematic of Coolant Channel, Waveguide and Sensor Location.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Y1:       50          150

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Y1:        66

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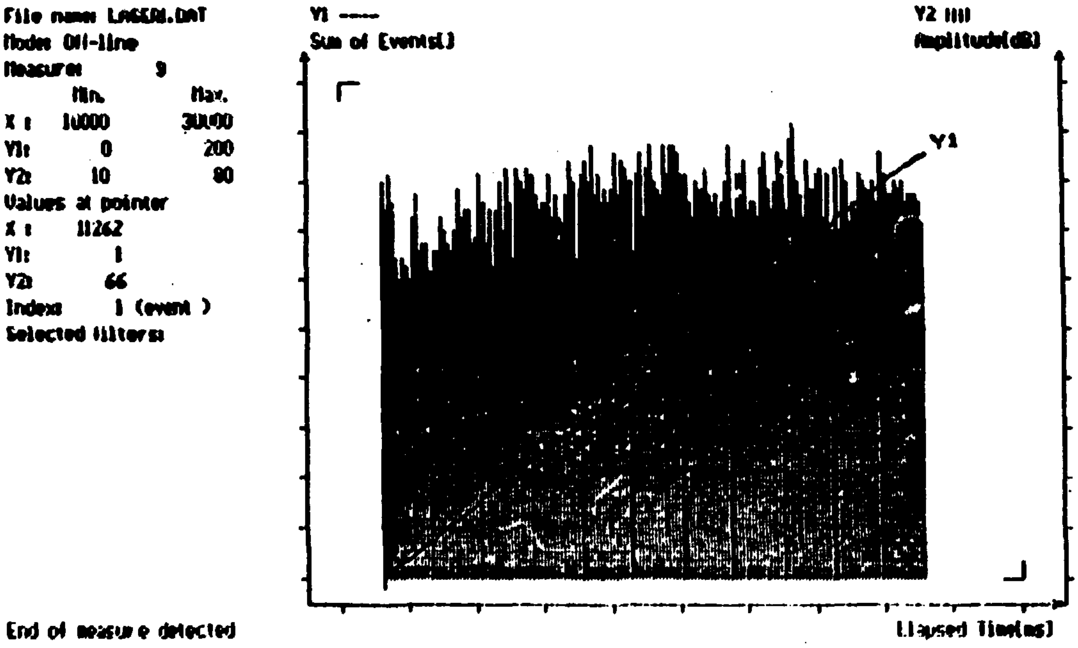
Fig. 3 : Amplitude Vs. time for AE signals recorded during shuttle movement



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Y2:      10          80
Values at pointer
X :    11262
Y1:        1
Y2:       66
Index:      1 (event )
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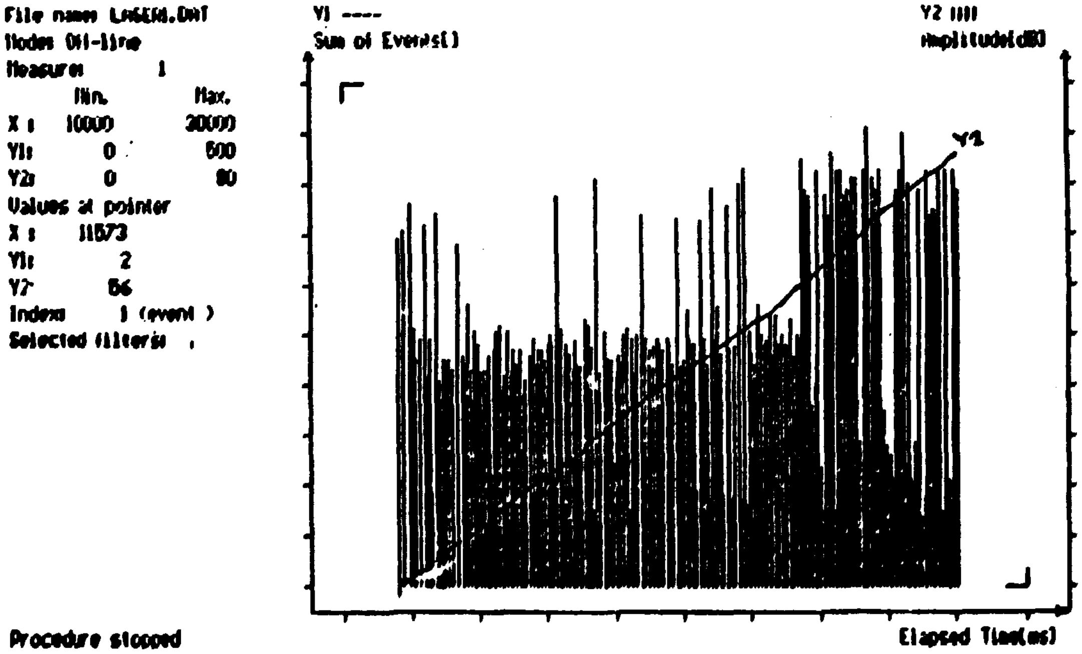
Fig. 4 : Cumulative events and Amplitude against Elapsed Time during laser welding of stainless steel (T_{Dead} = 40 m sec)



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Y2:       0          80
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Y1:        2
Y2:       66
Index:      1 (event )
Selected filters:   ,

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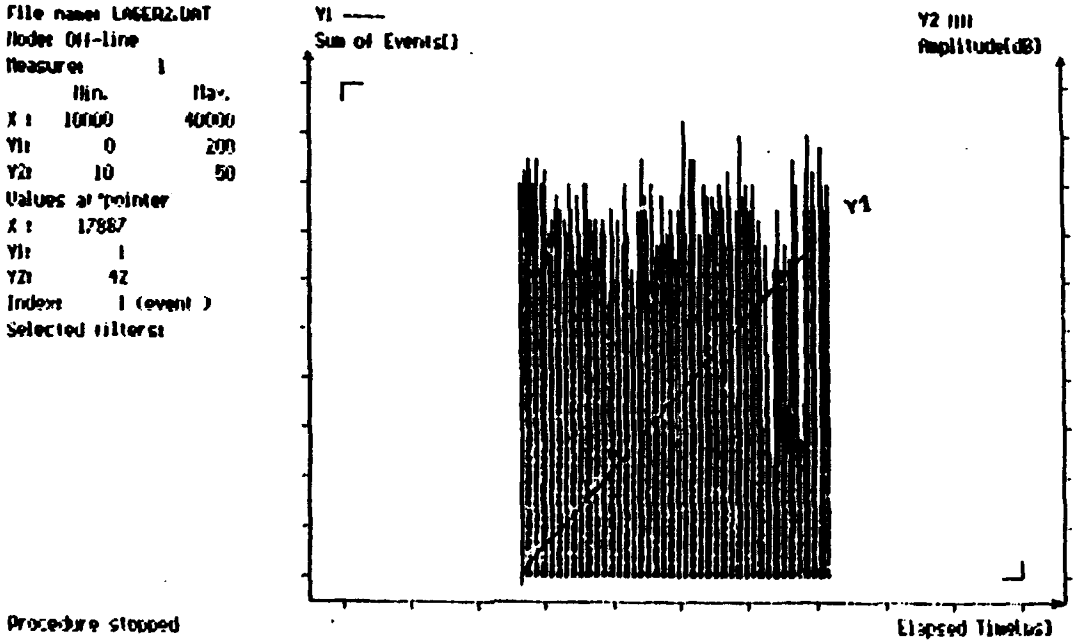
Fig. 5 : Cumulative events and Amplitude against Elapsed Time during laser welding of stainless steel (T_{Dead} = 0.1 m sec.)



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Y2:      10            50
Values at pointer
X :    17887
Y1:        1
Y2:       42
Index:      1 (event )
Selected filters:

Procedure stopped
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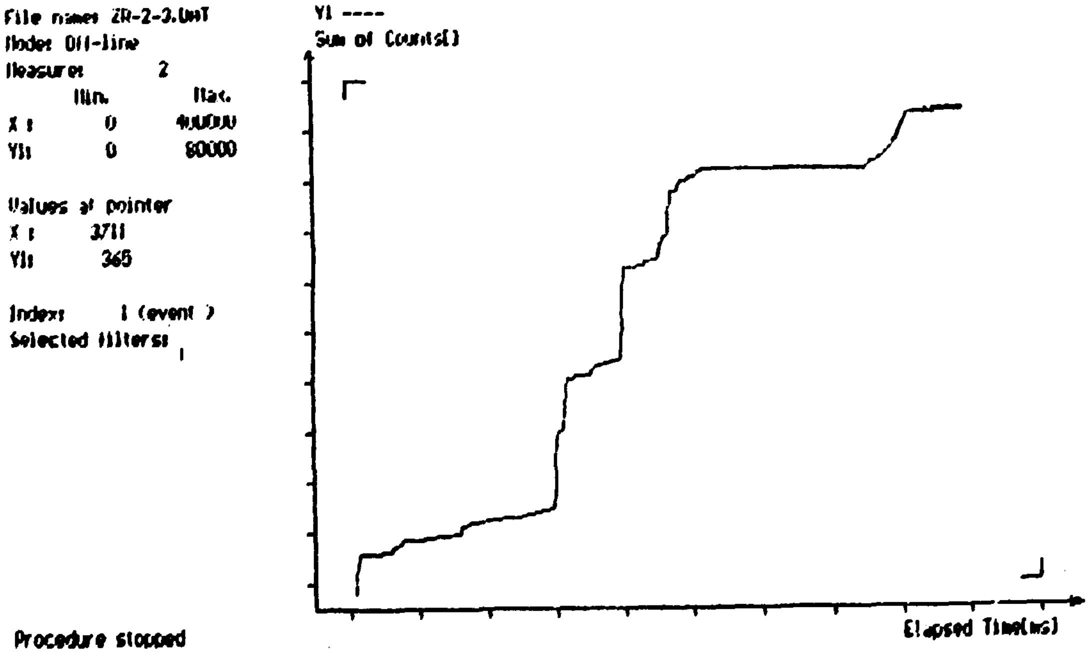
Fig. 6 : Cumulative events and Amplitude against Elapsed Time for Laser Welding of Aluminium.



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Y1:       0        80000

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Y1:      365

Index:      1 (event )
Selected filters:

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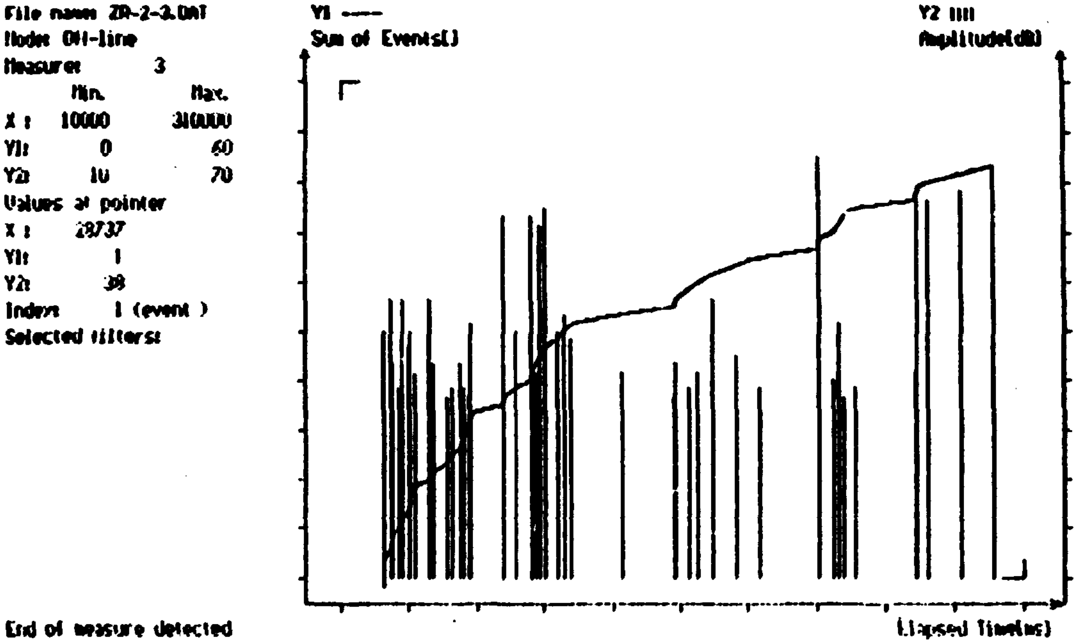
Fig. 7 : Cumulative Ringdown Counts (RDC) Vs. Elapsed Time for Tensile testing of Zircaloy-2 (upto yielding).



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       Min.        Max.
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Y1:       0          60
Y2:      10          70
Values at pointer
X :    29737
Y1:        1
Y2:       38
Index:     1 (event )
Selected filters:

End of measure detected
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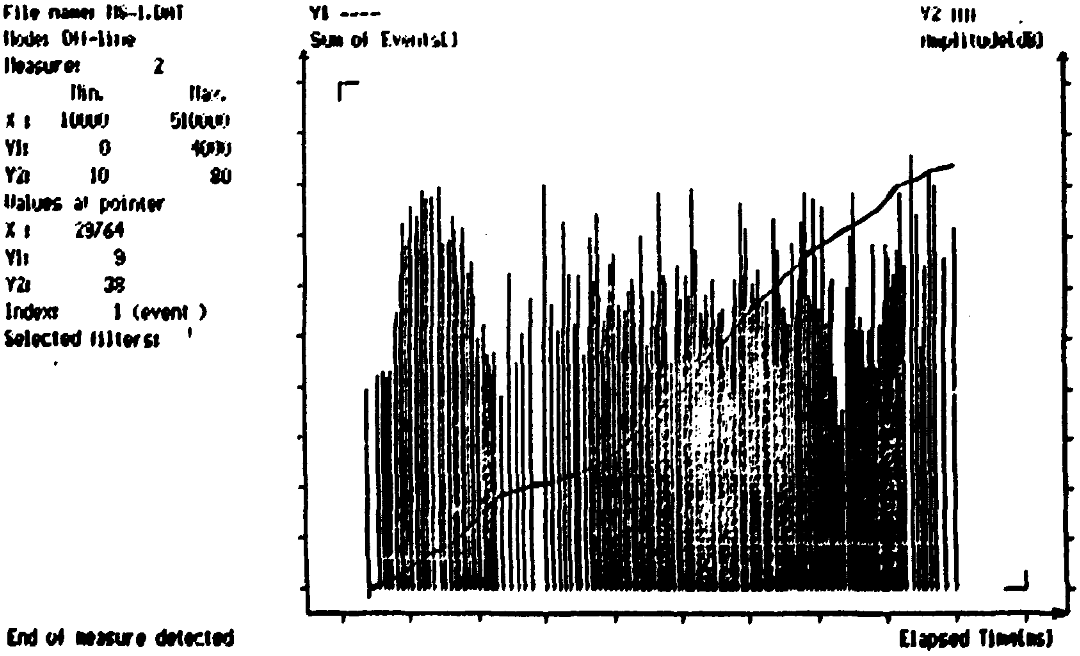
Fig. 8 : Cumulative Events and Amplitude Vs. Elapsed Time for Tensile testing of Zircaloy-2 (from yield point to fracture).



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Y2:      10          80
Values at pointer
X :    29764
Y1:        9
Y2:       38
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Selected filters:

End of measure detected
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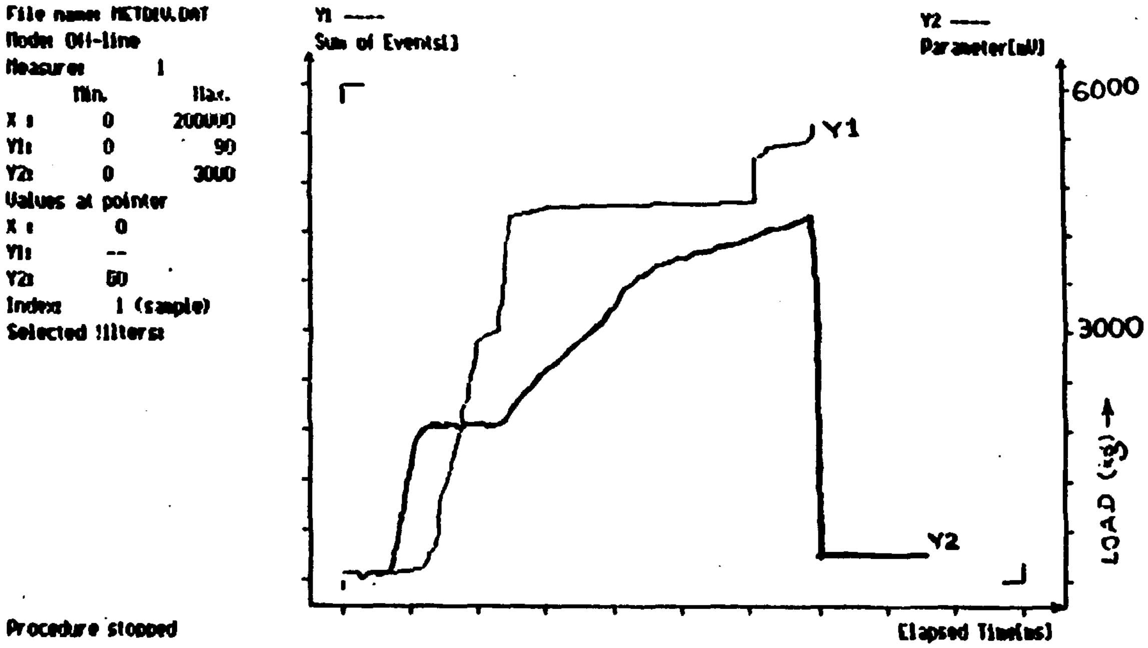
Fig. 9 : Cumulative Events and Amplitude Vs. Elapsed Time for Tensile testing of mild steel.



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Y2:       0          3000
Values at pointer
X :       0
Y1:       --
Y2:       60
Index:     1 (sample)
Selected filters:

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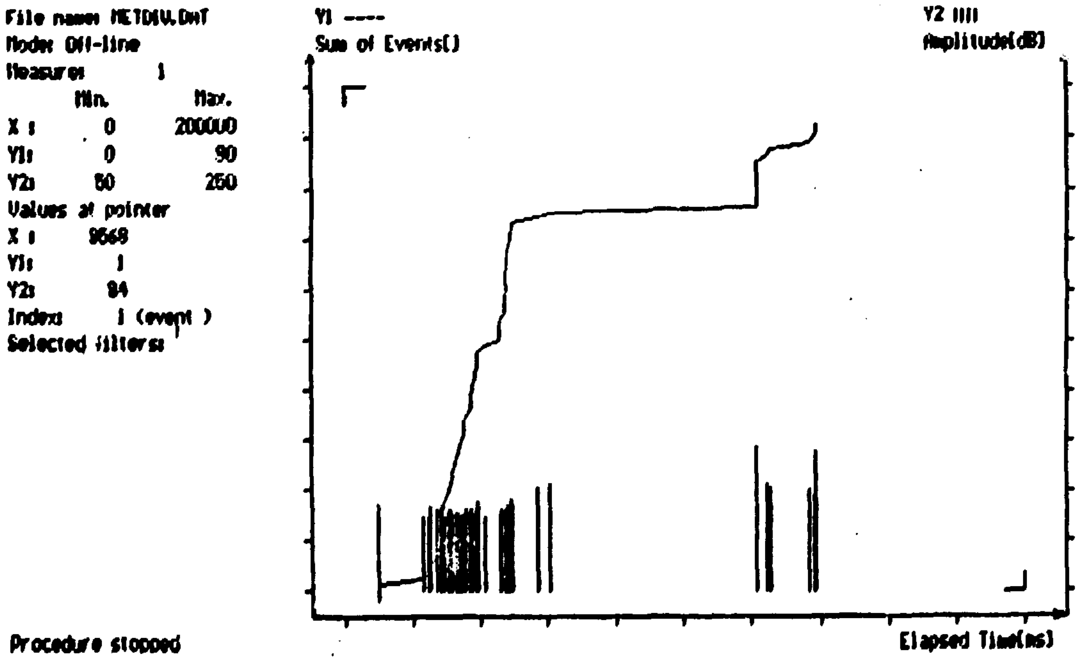
Fig. 10 : Cumulative Events and Load Vs. Elapsed Time for Tensile loading of pre-cracked stainless steel specimen.



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Y1:       0            90
Y2:      60           250
Values at pointer
X :    9668
Y1:       1
Y2:      84
Index:     1 (event )
Selected filters:

Procedure stopped
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Fig. 11 : Cumulative Events and Amplitude Vs. Elapsed Time for Tensile loading of pre-cracked stainless steel specimen.

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