ACOUSTIC EMISSION

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Acoustic Emission

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To my teachers

Preface

The loss of an accommodation platform in the North Sea early in 1980 highlighted the need for improved safety checks on the integrity of modern highly stressed structures. Engineers have always attempted to design equipment to take full advantage of the materials available to them, and developments in the aircraft, nuclear and offshore industries have in recent years pushed steels and aluminium alloys to the limits of resistance to stress and fatigue. As a consequence, even when full advantage can be taken of large-scale testing, the number of structures placed at risk due to material failure is greater than in the earlier days of cautious over-design. Fracture mechanics and advances in the metallurgist's understanding of material failure mechanisms have enabled designers to devise structures inconceivable even ten years ago. Economic and technical factors dictate that modern materials are used under conditions where failure can occur unless construction methods are nearly perfect. At the same time the economic and social effects of failure in, for example, a nuclear power station or an oil rig are very great. There is a clear need for non-destructive testing of such structures during construction and service, and acoustic emission techniques can now provide safety checks for most modern highly stressed equipment. Moreover, such checks can be carried out in service, twenty four hours a day under the severest conditions. This recent development has not hitherto been reviewed at length and so I have set out a dispassionate account of the capabilities of this technique in a way which will appeal to those seeking guidance on possible new applications, as well as to the specialist. Acoustic emission is not in itself the complete answer to integrity monitoring under critical stress conditions — conventional methods can also play their part — but it is the most powerful of the modern methods available to those concerned with the safety of structures.

I am fortunate in having been involved throughout the development work, carried out over the past five years, leading to the successful application of acoustic emission to the integrity and safety inspection of offshore, as well as many land-based, structures. I have tried to give details of both the acoustic emission equipment and its practical applications. Due reference is made to the now mature science of fracture mechanics: somewhat less detailed attention is given to purely metallurgical factors, but reference is made to papers — some highly theoretical — discussing microstructural phenomena and their relation to acoustic emission.

The acoustic emission community achieves rapid and full exchange of information between its members. This book is a distillation of the information available from many sources: various publications, conference notes and, in some cases, as yet unpublished papers. I have found the acoustic emission community particularly generous in its help and guidance. The over-enthusiastic claims of the early days of the technique have been replaced by a healthy, sceptical approach to new applications, backed by testing methods leading to real success in application in the field. All this I have tried to set down in this monograph. Needless to say any errors of fact or judgement are my own.

Dr R V Williams
21 April 1980

Acknowledgments

I would like to thank the many members of the acoustic emission fraternity who have helped me to understand the art and science of acoustic emission. I am particularly grateful to my colleagues in the Unit Inspection Company, who have generously given of their time and results while this book was in preparation. Viv Peters and Len Rogers were more than helpful; the chapter on offshore applications is taken almost entirely from their work. Dr Eric Duckworth of the Fulmer Research Institute generously provided material for the section on the testing of concrete, and Don Birchon, the father of acoustic emission in the United Kingdom, was most helpful to me when I was new to the field.

Acoustic emission is a particularly fortunate discipline in that it possesses a vigorous fraternity of practitioners in EWGAE — the European Working Group on Acoustic Emission. Members of this club have been generous in their help and advice, particularly Peter Bartle of the Welding Institute, Manlio Mirabile of Centro Sperimentale Metallurgico, Rome, and Aved Nielsen of the Risø National Laboratory, Roskilde, Denmark. All three contributed to my knowledge of this interesting but sometimes difficult subject, and have patiently explained its finer points. Their understanding of acoustic emission is immense, and the science of non-destructive testing owes much to them. It goes without saying that any errors in this book are entirely due to the author.

Two talented young ladies, Mrs Freye Kennedy and Miss Jenny Wood, have successfully interpreted my indecipherable handwriting with patience and tact to produce an excellent text which has been turned into a fine book by the efforts of Paul Nagle and the other staff of Adam Hilger Ltd. Lastly, a word of thanks to my family who have lived with the writing of this book for some time with their usual good-natured tolerance.

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1 Introduction

It has been known for many years that when a solid is subjected to stress at certain levels, discrete acoustic wave packets are generated which can be detected by transducers placed on, or in acoustic contact with, the solid. The phenomenon of sound generation in materials under stress is termed acoustic emission (AE), or, alternatively, stress wave emission. The purpose of the present monograph is to discuss this phenomenon with particular reference to its application as a non-destructive testing (NDT) technique. The monograph also includes a considerable section devoted to the design and use of systems able to detect the very low levels of acoustic energy generated by acoustic emission processes. Acoustic emission can be explained in terms of dislocation and other deformation processes in materials but these are not discussed in depth; rather the applications of the technique in construction and engineering are more extensively discussed.

Most materials which are designed to withstand high stress levels emit acoustic energy when stressed, including the well known metallic alloys such as steels, cast irons and alloys of aluminium. Glasses and fibres (as the high yield stress component of composite structures) as well as concrete and ceramic materials also emit acoustic energy when stressed. In view of the importance of concrete structures some attention is paid to the use of acoustic emission for the testing of concrete beams.

The subject is now of some reasonable antiquity. The noise due to the twinning experienced by fine tin when deformed is described in elementary chemistry textbooks and is known as the 'cry of tin'. As early as 1938, Frenkel and Kontorova proposed that the process of plastic deformation or twinning consists of a caterpillar-like motion of one atomic chain over another. These authors predicted acoustic emissions as did Frank (1949) in another early publication. Modern equipment can detect emissions produced by very small strain levels, as low as 0·05% or less in certain materials, and, approaching fracture, emissions can be very easily detected from most engineering materials.

This monograph was written because there appears to be no coherent account of the state of acoustic emission technology in the late 1970s. Excellent earlier publications do exist, notably the two sets of conference proceedings, published by the American Society for Testing and Materials, *Special Technical Publications 505* (1972) and *571* (1975) (these will be frequently referred to in the text as STP 505 and STP 571). Also, Dr R W Nichols (1976) has edited a series of papers, presented at a conference in Israel, in a book entitled *Acoustic Emission*. The third major publication in this field is a review article written by Ying (1973) in the *CRC Critical Reviews in Solid State Sciences*. This concentrates on the solid state physics aspects of the subject with rather less emphasis on applications; it is commended to the reader's attention. Also well worth noting is a bibliography compiled by Drolliard (1979).

Mention must be made immediately of the phenomenon observed in acoustic emission known as the Kaiser effect. This was discovered during PhD studies by Kaiser in Germany and published in his thesis from the Technische Hochschule Munich in 1950; an account is also given in Nichols (1976). Kaiser observed acoustic emission from polycrystallised specimens of zinc, steel, aluminium, copper and lead. While suggesting that grain boundary sliding was a source of the emission, he also noted that if crystals are stressed while emissions are being monitored and the stress is then relaxed, no new emissions will occur until the previous maximum stress has been exceeded. This phenomenon is not universal; it is associated with the incidence of the Bauschinger effect in the material under observation (the Bauschinger effect refers to the decrease in compression yield strength and increase in tensile yield when a metal is plastically strained beyond yield). Reference to the Kaiser effect is made in several later chapters of the present monograph.

It is appropriate at this stage, before going on to study applications and systems in more detail, to quickly review the advantages and disadvantages and state of application of the technique at the time of writing. Acoustic emission is essentially a method of non-destructively testing engineering structures which have to be examined for quality assurance or safety reasons. It responds, because of the Kaiser effect, only to stress levels which are greater than those which have been previously, and in many cases safely, maintained.

Arguably the most important reason why the method is now being actively used for testing structures is that it is essentially non-localised; it is not necessary for the receiving transducer to be particularly near the source of the emissions or the area which is under test. For example, a critical node in an offshore structure could be tested in service by only one dozen transducers while ultrasonic methods would need about a thousand sensors. Welds can be also checked during welding by just one transducer on the welding head. It is very easy to scan a large structure using acoustic emission probes placed at 1–10 m intervals on the surface of a structure. This ability to examine a large volume of material is in direct contrast to alternative methods of non-destructive examination such as ultrasonics or radiography. Ultrasonics in particular requires that a probe must scan over practically every part of the structure to be examined. A third reason why acoustic emission is a particularly attractive NDT tool stems from its value for the continuous in-service monitoring of structures. This is particularly important in offshore applications where other methods of inspection, which usually require divers, cannot be used in adverse weather conditions, while acoustic emission monitors will operate 24 hours each day, even in the worst storms when safety monitoring is particularly important. Strain gauges also have a '24 hour a day' capability but require to be placed very close to a suspected defect. The use of vibration monitoring of structures has also been developed in recent years. In this technique a frequency analysis of the natural vibration of a structure is recorded periodically. Any major change in the structure will be reflected in the vibration signature. Unfortunately, this method only indicates a really large fault — even to the extent that, in some cases, a whole member of a structure has to be removed before the fault is detected by this method.

Acoustic emission, of course, has disadvantages. The acoustic pulses have energies, in some cases, near to the lower level of detection of piezoelectric (PZ) transducers, which means that sophisticated and expensive electronic apparatus must then be used to detect faults. The main difficulty, however, is associated with the background noise which is frequently present during in-service tests of structures. Care has to be taken to reduce interference from noise generated in pumps, waves or moving machinery, and ways of overcoming this problem will be discussed later.

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2 Acoustic Emission Techniques and Systems

2.1 Techniques

2.1.1 Introduction

The techniques of linear elastic fracture mechanics provide the design engineer with the information necessary to minimise the risk of unstable and dangerous fracture in structures, in terms of a maximum service stress coupled with a maximum allowable defect size. Even when the applied stresses are below those required to cause rapid crack growth and fracture, it is still possible for cracks to extend by a stable crack growth mechanism such as fatigue if the structure is subjected to fluctuating loads, or stress–corrosion if a corrosive environment is combined with stress. The practical conditions governing the initiation and growth of cracks are not always well understood, and thus it is advisable to inspect the structure periodically in order to detect any crack growth which may have occurred. For inspection purposes, conventional non-destructive techniques are available which can locate and size certain types of defects. However, these techniques are limited in applicability since large areas of a structure must be inspected. In addition they cannot identify the mechanism of cracking and are dependent upon the experience and judgement of the operator. Finally, some parts of structures are physically inaccessible for inspection purposes; clearly a remote method of locating, sizing and identifying the mode of propagation of defects in structures is desirable.

The atomic rearrangements which occur within a material during deformation and cracking produce elastic waves which travel through the material and can be detected at a surface by piezoelectric transducers. The transducer signals can thus be used to detect deformations or cracks in materials; this has practical application in the non-destructive testing of structures and components. It is possible, in principle, to obtain information about the nature and the severity of changes occurring at defects in structures under load; additionally, three or more transducers can be used to locate the position of the deformation within the structure or component. It must be stated, however, that the need for a skilled operator has not yet disappeared.

This is the basis upon which acoustic emission is used as a non-destructive testing technique. Figure 2.1 is a schematic illustration of this method. The equipment, which will be described in detail below, comprises the transducer, firmly bonded to the surface of the material under test, signal leads, whose design is important, connected to electronic signal conditioners, counters and recorders.

All the common materials used in structures (metallic alloys, glasses, polymers, ceramics and cements) exhibit acoustic emission. The transducer usually picks up a series of pulses of elastic energy rather than a

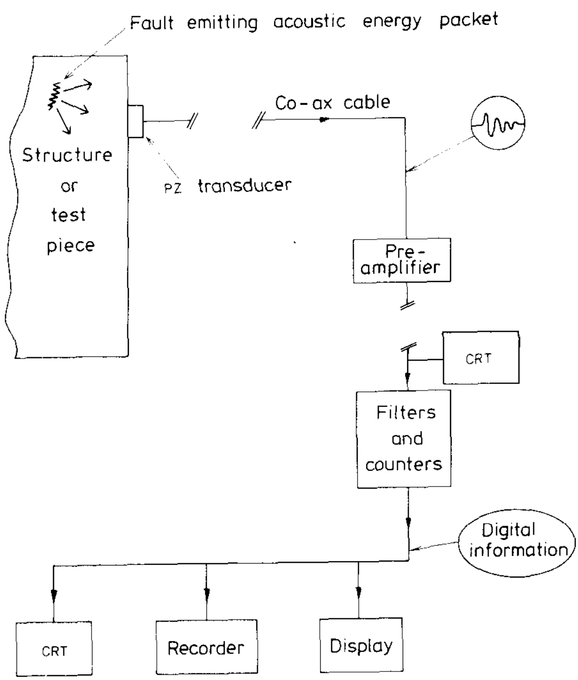

Figure 2.1 Diagram of a simple acoustic emission system.