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AN OVERVIEW OF DIFFERENT POSSIBILITIES TO MASTER THE CHALLENGE OF COUPLING AN AE-SENSOR TO AN OBJECT OF INTEREST PARTLY USING EXAMPLES OF PREVIOUS INVESTIGATIONS

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Abstract

Acoustic emission analysis is defined as a passive, non-destructive investigation method, which only listens for AE-waves (AEW), generated actively by an object of interest. Therefore, the AEW must have the possibility to propagate from their source to an acoustic emission sensor (AES). By virtue of the piezoelectric effect, the AEW transmitted into electrical signals inside of the AES. During the analysation of these electrical signals we earn –online– information about the object of interest, e.g. the operating characteristic of a machine or the strength of the friction of a tribolocical system. To enable the AEW to propagate into the AES, the sensor has to be fixed suitable onto the object of interest. Hereby has to be strictly respected, that the sensor is fixed in a reproducible mechanical way as well as to ensure that the through-transmission has a weak attenuation (couplant). Standard AES have the shape of a circular cylinder (diameter and height depend on the operation purpose), the AEW pass through one of the frontends into the sensor. The objects of interest can have different geometry of the surface (e.g. plane, cylindrical, unspecific) or temperatures which usually conflicting the operating range of the sensor. Depending on the operational purpose, there are many different couplants to use. This article offers help to master the different connecting challenges within the range of acoustic emission analysis.

Keywords: *Acoustic emission sensor, application, mounting, couplant, wave-guide*

1. Introduction

For the detecting of Acoustic emission waves (further short: AEW) usually acoustic emission sensors (further short: AES) are used. A great number of sources may generate AEW (e.g. solid friction, boundary friction, fluid friction, corrosion processes, cracks and crack growth, cutting processes, etc.). Due to that, there are many challenges for a successful through-transmission of the AEW from the surface of their sources (within an object to inspect, further short: OTI) to the AES. The topic of the presented article concerns the possibilities for a successfully propagation of the AEW from the OTI into the AES, regarding material and shape properties and environment conditions.

Acoustic emission sensors are characterised by their dimension, frequency response function and their operating range regarding e.g. temperature and pressure. Typical temperature ranges of commercial AES are from -5 to 85°C, specialised one endure temperatures from -200 to 540°C.

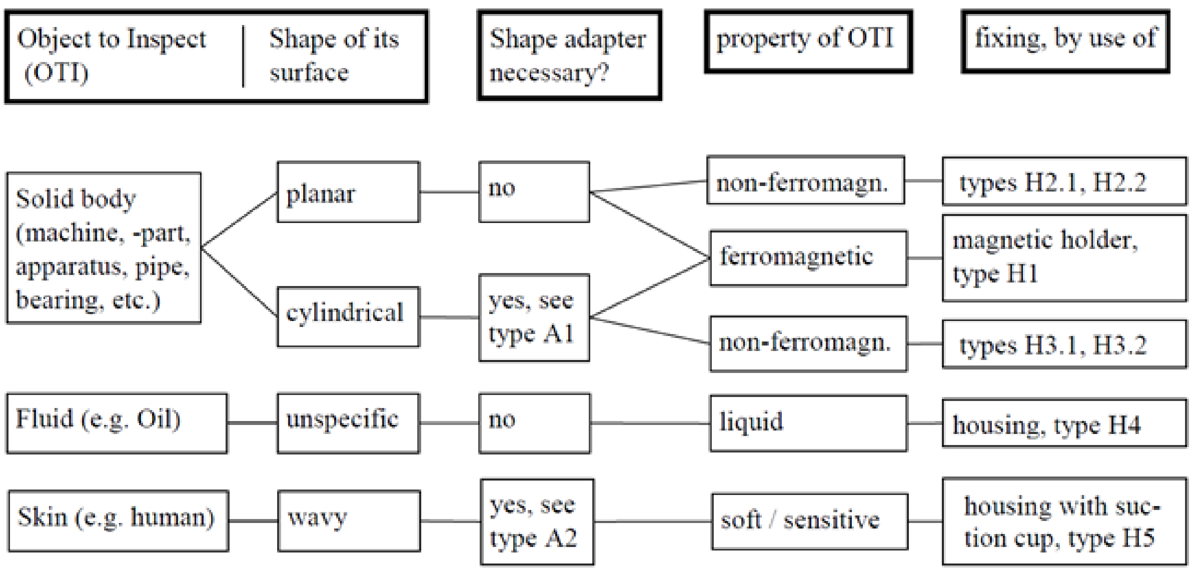
They can be watertight up to 10 bar some of them up to 68 bar. There are also commercial radiation resistant (gamma ray E9 rads, neutron flux 2,23 E17 n/cm²) sensors, for nuclear power industry [1].

The nature and method of mounting an AES can have a great influence on the performance of those sensors and therefore on the results of an investigation. In common, there are two main methods for mounting. Bonding, that means a direct attachment of the AES to the OTI with a suitable adhesive. The disadvantage of this method is that the bonded sensor can only be used once. Compression mounts, herby the AES, will be pressed through the OTI by a force (usually 10 N up to 100 N), which leads to an intimate contact and a sufficient transmission of acoustic energy. A couplant between the AES/OTI Interface is absolutely necessary if using this mounting method. This article predominantly examines the possibilities for compression mounting including couplant and waveguides.

2. Connecting dependencies acc. the shape and the material of the object to inspect

In this chapter we investigate the influence of the surface shape of the OTI relatively to a standard AES with a cylindrical shape and therefore with a circular, planar sensitive area. The temperature of the OTI should be within the operating ranges of the involved AES and materials. Tab. 1 presents us an overview of the resulting connecting dependences and the possibilities to solve the cases.

Tab. 1. Scheme of some connecting dependences of AES with a planar sensitive area



If the object to inspect has ferromagnetic properties, one can use a magnetic holder (type H1) to fix an AES on the surface of the OTI. Not only at planar surfaces but also on cylindrical ones are. Fig. 1 – at the following page- shows us a typical commercial magnetic holder for constant hold down force [2]. Nearly every company in the range of acoustic emission sells magnetic holders in a great variation range relating to size, material, holding force of the magnets, etc.

In the case of a non-ferromagnetic, planar surface, a holder for AES with simple suction cups (type H2.1) can be a good choice. Fig. 2 presents us this fixing method using the example of a steam sterilizer under over pressure test by cold water (Δp_{max} = 5 bar) [3]. The all in all 16 AES and the lead-in of the cables are therefore watertight. If the material of the sterilizer is damaged through the daily use, it will emit typically AEW during the increasing of the pressure.

Especially, for short time coupling of AES, e.g. in laboratory investigations, clamps are established (type H2.2). The clamping force is easy adjustable by the moving and fixing the slider of the clamp. Fig. 3 shows us a so called F-Clamp with electric-isolated tensioning arms fixing two

AES "face-to-face" for calibration (One AES works as sender the other is the one that is testing) [4]. It is also possible to use a clamp for fixing an AES onto the surface of a machine or apparatus, which generates AEW.

Fig. 1. Typical magnetic holder for AES constant hold force, type H [2]

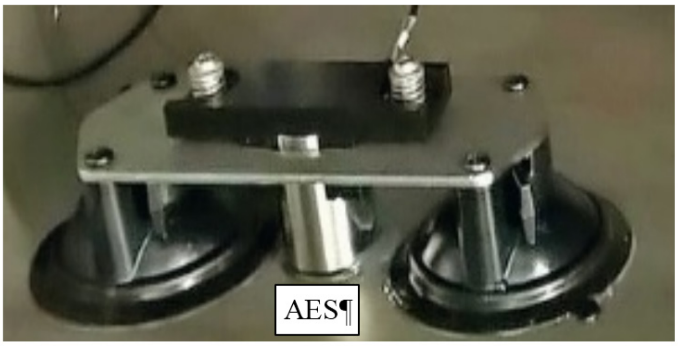


Fig. 2. Holder for AES using suction cups for non-magnetic surface, type H.2.1 [3]

For mounting AES on cylindrical surfaces e.g. pipes made of austenitic steel one can use only a textile tension belt or a textile tension belt with a special seat for the AES (type H3.1), see Fig. 4. The advantages of this construction are the nearly constant clamping force by virtue of the spring and the easier installing on the surface of a pipe especially by only one person and regarding the couplant. In common and esp., in this case it is very important that no extra AEW (interfering) be generated due to friction between the metallic pieces of the holder and pipe surface [5]. Especially Hook-and-loop-fastener strips may generate interfering (burst-signals) by virtue of its construction; they are not advisable to substitute the textile tension belts.

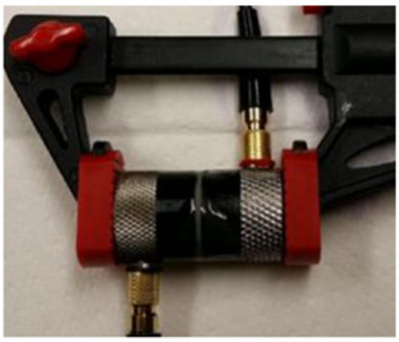


Fig. 3. Fixing two AES "face-to-face" (F2F) with a clamp, type H2.2 [4]

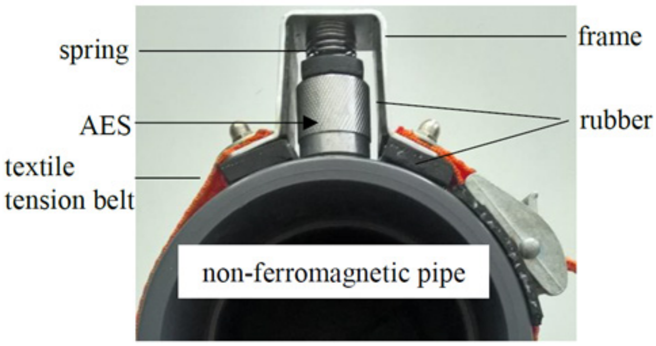


Fig. 4. AES fixing with a textile tension belt, type H3.1 [5]

If the OTI offer higher temperatures, e.g. 530°C, a stainless steel tension belt in combination with special high temperature AES is necessary. On still higher temperatures (e.g. 625°C) a wave-guide made of austenite steel is needed [6], see also Cap. 3.

In case of mounting an AES, with a -in common- flat sensitive frontend, directly on an OTI with a cylindrically surface only line contact and therefore a bad through-transmission of the AEW appear. The higher the outer radius of the pipe, relative to the diameter of the AEW, the bigger gaps are between the contact partners. Filling the gaps with a high viscosity couplant leads to a lower damping of the AEW but also a strongly change of their frequency content. Besides that, this solution is unsteady and not reproducible. The application of an adapter, who enables a cylinder-cylinder contact on its one frontend and a plane-plane contact on its other leads to a successful through-transmission of the AEW. With the implicit understanding that a couplant is used in both contact areas. Depending on the physical sizes of pipe and AES different designs of the adapters are possible, see Fig. 5. The material of the adapter (e.g. aluminium or wood) depends on the material of the pipe / rod and the machining possibilities. On the basic of the authors' experience, for small dimensions specific 3D printing techniques (selective laser melting) has advantages over machining.

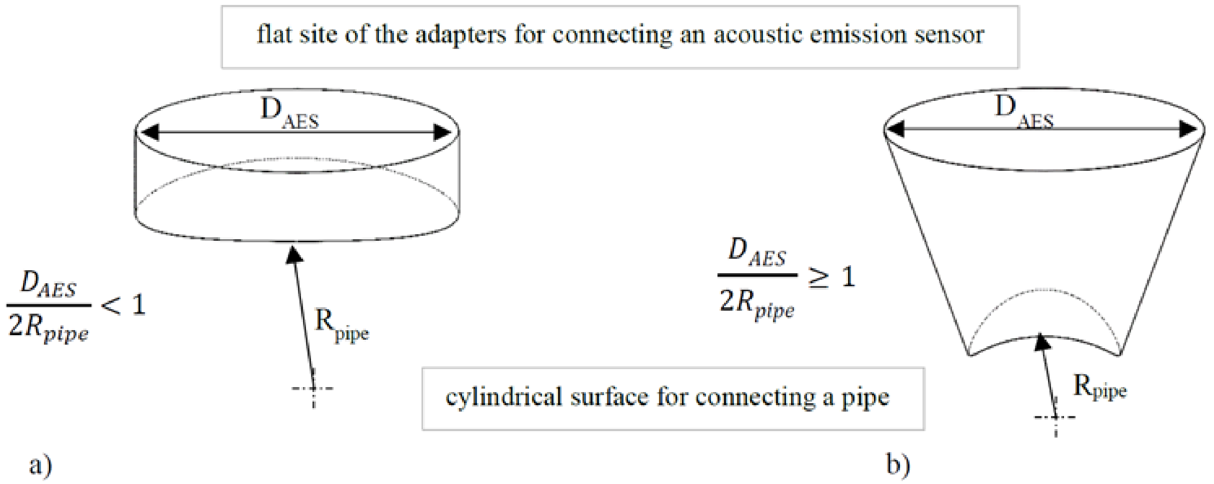


Fig. 5. Different designs of adapters (type A1) depending on the ratio of the diameter of the acoustic emission sensor (AES) to the double of the outer radius of a pipe / rod

In case of a small dimension of the pipe we usually use the following assembly of frame (type H3.2), AES, adapter (type A1) and pipe, see Fig. 6.

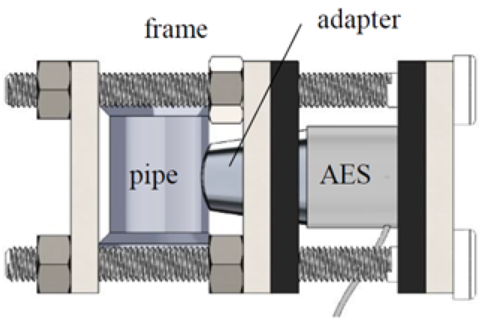


Fig. 6. Holder type H3.2 with adapter type A1 [7]

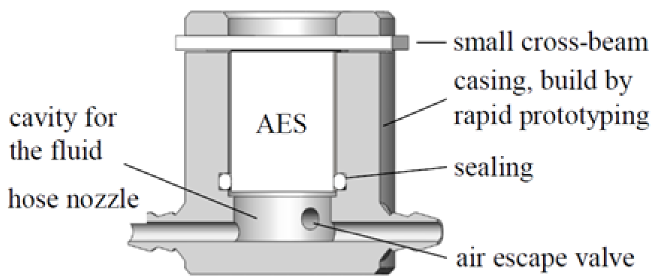
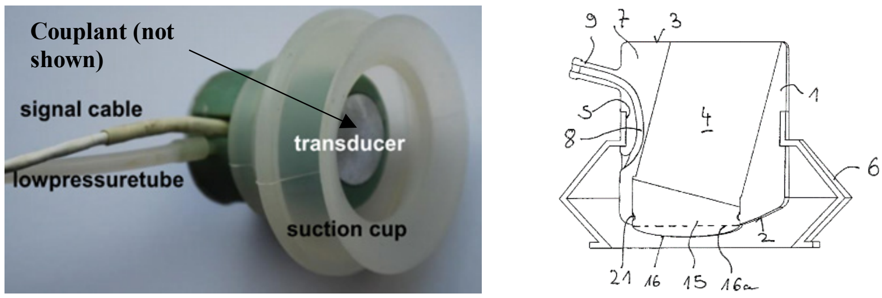


Fig. 7. Special housing for fluids, type H4 [8]

The through-transmission of AEW, propagating within a fluid, to an AES needs a special housing. Fig. 7 shows us one executed possibility (type H4) [8]. A special casing (material: VeroWhite by strat.o.sys GmbH), built by rapid prototyping, contains a commercial AES. An O-ring seals the free space between the sensor and the casing. Two hose nozzles enable the contact with the fluid, e.g. oil. It is very important, that no air bubbles be within the hose or within the cavitation for the fluid. An air escape valve in the housing makes this possible. A small crossbeam avoids the pop out of the AES because of an overpressure of the fluid, e.g. 150hPa.

To fix an AES in the field of orthopedically diagnostic, to example on the surface (skin) of a human knee joint, a special holder has been developed (type H5) [9-11]. The wavy resp. soft skin makes it necessary to use low pressure to reach a good contact between the surface of the skin and the AES resp. transmission wedge, see No. 15 in Fig. 8 at the following page. Besides that, the properties of the human skin are very variable from person to person and its shape is changing due to the movement of the knee joint. Because of the danger to generate hematoma, in case of too strong under pressure, the whole construction has been optimized regarding its weight, holding force and through-transmission of the body-borne AEW generated in the knee-joint.



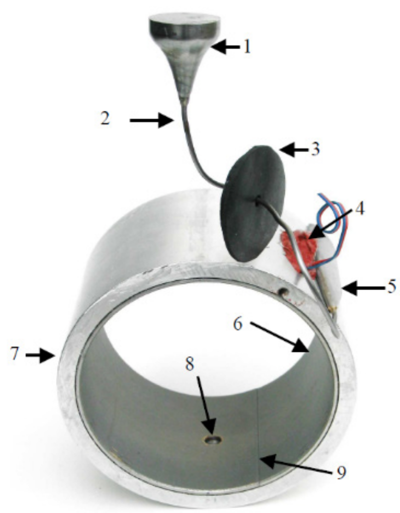
1 casing (Rapid Prototyping)
4 free space for AE-Sensor
6 suction cup
8 low-pressure channel
9 low-pressure connection
15 transmission wedge
16 spherical surface for optimal contact with human skin

Fig. 8. Medical diagnostic system BoneDiaS® based on a AES, type A2 and type H5 [9, 10].

3. Waveguides

According Nondestructive Testing Encyclopedia [12] a "waveguide is a device that couple's elastic energy from a structure or other test object to a remotely mounted sensor during AE monitoring. An example of an acoustic emission waveguide would be a solid wire or rod that is coupled at one end to a monitored structure, and to a sensor at the other end." In other words, if a direct coupling of an AES on the OTI is not possible, due to its operating range (see chap.1) or dimension a wire or rod enables the guiding of the AEW to the sensor. Herby the sensor is fixed at a "sensor-friendly" position. Disadvantages of this solution are the insert of another interface on the way of propagation of the AEW which leads to a damping of the signal strength and the converting of the frequency content of the signal due to the diameter of the waveguide. By virtue of the length of the guide there is a little time delay which must be taken into account in the field of source location.

Figure 9 presents us a non-commercial wave-guide for leading AEW from the outside of a bearing bush inside a bearing housing to the AES [13]. The temperature of the bush has an amount of roughly 80°C and there is a lot of oil vapour inside the hydrodynamic journal slide bearing test stand.



1) coupling cone of the Wave guide
2) rod of the wave guide
3) sealing (oil vapour)
4) temperature sensor
5) housing of wave guide adapter
6) bearing bush
7) bearing housing
8) lubricant supply orifice
9) butt joint of the bearing bush

Fig. 9. Special wave guide for the through-transmission of AEW generated within a hydrodynamic bearing [13]

The waveguide itself contents 3 parts (No. 1, 2 and 5 in Fig. 9) connected to each other by brazing. The housing to waveguide adapter is bonded by a temperature-resisted glue to the bearing housing. The coupling cone guiding the AEW from the small diameter of the rod (2 mm) to the full diameter (25 mm) of the sensitive plan area of the used AES with low-losses. The coupling cone and the AES are connected with a similar holder type H.3.2, see also Fig. 6. A sealing reject the oil vapour from the environment and from the AES. The diameter of the orifice centrically in the sealing is optimised for a good seal effect and that there is no contact (friction) to the rod of the waveguide possible.

Typical commercial waveguides are of stainless steel rod. Their diameter has an amount from 6 to 13 mm, their max. length is about 300 mm, with or without a sensor mounting conical end piece, see Fig. 10. They may be welded to an OTI or with a point end for pressed contact. They are also valuable in laboratory for conducting high or low temperature AE testing, e.g. platinum wire wave-guide was used to detect oxide cracking and spallation at 1000°C [14].

It is also possible to use a fluid jet, e.g. a jet of coolant lubrication, as a wave-guide, see Fig. 11. The generated AEW that occur during the lathing process are propagating upstream within the fluid through an AES, which is integrated inside the nozzle casing. An uninterruptible, air bubble free jet presents optimum conditions for conducting the signals. The flow speed of the jet has only a small influence on the through-transmission of the signals because of the relatively high speed of sound within the jet (about 1437 m/s). The advantage of this method is that one can measure close to a tool /workpiece, also on rotating spindles or tools. The frequency ranges from 100 kHz up to 1MHz [15].

Fig. 10. Standard waveguides with different length of the austenitic rod with casing to fix an AE-Sensor on to the plane surface of the coupling cone [2]

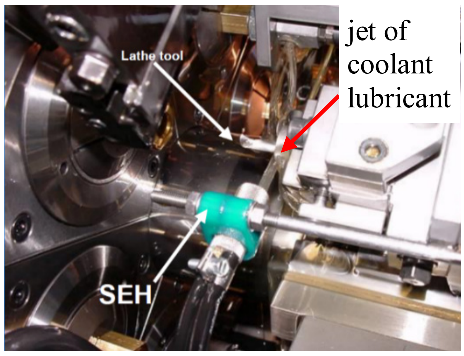
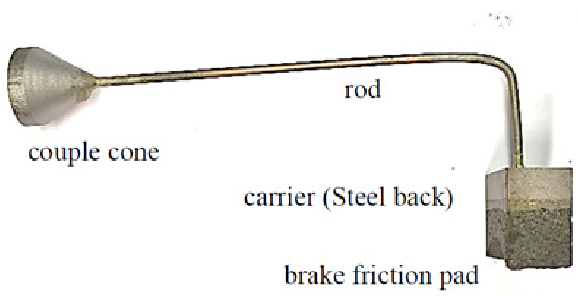


Fig. 11. Wave conducting via a jet of coolant lubricant [15]

An example for using a wave-guide to protect the AES against temperatures above 600°C is presented in Fig. 12. The waveguide is conducting the AEW generated during a brake friction test to an AES mounted onto a position with acceptable temperatures regarding its operation conditions.



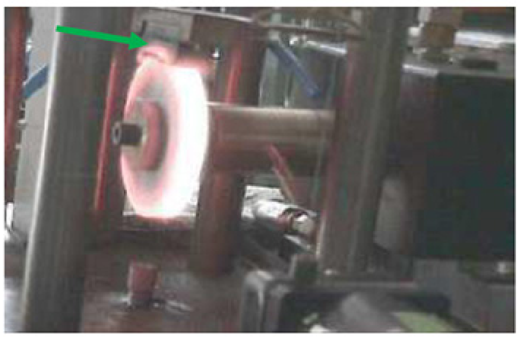


Fig. 12. Picture to the left: Wave guide coupled on the steel back of a brake friction pad; picture to the right: Steel brake disc (red-hot glowing) under test; the friction pad is marked with a green arrow [16]

4. Couplants

The NDT Encyclopaedia [12] defines a couplant as follows: “A material used at the structure-to-sensor interface to improve the transmission of acoustic energy across the interface during AE monitoring”. The reasons are the following:

Because of the surface`s roughness of OTI, (adapter or wave guide) and the sensitive area of a AES, each interface included air which weakens strongly the SE-Waves during through-transmission. The acoustic impedance of air is around 5 orders of magnitude lower than that of the two contacting surfaces, allowing for very little transmission of acoustic energy at the frequency range typical for AE. The removal of air from the interface between a measurement surface and an AES is essential for the transmission of ultrasonic energy [17]. The higher frequencies of the signal the more important the properties of the couplant are. "Ideally, the acoustic impedance of the couplant should match to the acoustic impedance of both surfaces that are being coupled" [18]. A forgotten couplant is mostly the reason for week AE-Signals of Acoustic emission and a typical beginners` fault. Couplants are also important to reject out-of-plane motion of the coupled participants (e.g. sensor on the surface of a test block). In the investigation “Through-Transmission Characteristics of AE Sensor Couplants” one can get detailed information about the coupling properties of the following fluids: Water, motor oil (SAE 5-30 grade), honey, Vaseline, high vacuum silicone grease, stopcock silicone grease, couplant resin (SC-6, AET), ultrasonic shear gel and a plastic film as dry couplant (Saran wrap) [17]. One of the results is that the thickness of the usually used sanitary silicon grease has a great influence on to the frequency changing during transmission. Please use the silicon grease layer as thin as possible.

Good experiences were made with common low viscosity fluids like “bicycle-oil” and hand-milk (for skin care) as couplant for the face-to-face (F2F) calibration of AES, see Fig. 3 [4]. By using a very thin layer of these fluids a low damping and a minimum of frequency changing occurs.

Different commercial couplants and adhesive content, e.g. micro-sized particles are to adapt their acoustic impedance on to the requirements. Beside that, the data sheets inform about the allowed temperature range and the optimal application procedure.

The thinnest practical layer of a continuous couplant (without voids or air bubbles) is usually the best. To reach the aforementioned requirements on the couplant layer one must place a small amount of material in the centre of the AES sensitive area. After that the acoustic emission sensor shall pressed carefully against the surface of the OTI or adapter resp. wave-guide until a bit of couplant leaves uniformly the gap [19]. To avoid air bubbles within the couplant, please turn the AES during application in a shear movement (± 90°) [20].

For healthy and environmentally reasons the used coolants may not be toxic. Besides that, they may not have an undesirable influence (e.g. dissolution, corrosion) on to the engaged materials.

5. Summary

The through-transmission of an acoustic emission wave from its source within an object of inspect (OTI) in to an acoustic emission sensor (AES) cannot be enforced. The only way to get strong signals with a nearly original frequency content is to make the propagation path as comfortable as possible for the acoustic emission waves.

The challenge starts on the surface of the object to inspect, in dependence of its shape and temperature, one must use an adapter to equalise the surface shapes of OTI and AES, or a wave guide to protect the AES against temperatures (lower and higher) outside its working range. In addition, the nature and method of mounting an AES can have a great influence on the performance of those sensors and therefore on the results of an investigation.

This article tries to give an overview of the different mounting possibilities of AES, including adapters and waveguides, to reach successfully acoustic emission measurements.

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