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Extended Abstract

Evaluating Techniques for Joining Piezo-Electric Elements on Test Structures for Performing Vibration-Based Measurement Methods †

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Abstract: The aim of this work is to evaluate different joining technologies of piezo-electric elements on metal and polymer substrates with special respect to reversibility. Different techniques for joining piezo elements are collected considering previous work as well as newly developed approaches within the scope of the work. In the next step, frequency spectra of simple circular blanks are obtained using an Electromechanical Impedance (EMI) setup from piezo elements joined to the blanks with the appropriate joining technique. Joining by means of a two-component epoxy is considered as the reference method. All joining techniques are evaluated especially based on degree of reversibility, transmission quality, effort for implementation and durability in comparison to the reference method. Finally, recommendations regarding the proper joining technique for different experimental conditions will be given based on the results.

Keywords: piezo-electric elements, non-destructive testing, joining techniques, vibration-based measurement, reversibility, plastic and metal substrates

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1. Introduction

The early detection of damage and aging in mechanical structures is of great importance to prevent the endangerment of people and to avoid high repair costs. Vibration-based methods such as the Electromechanical Impedance (EMI) method, in which piezoelectric elements are used for the vibration excitation of the structure and as sensing elements, have great potential as non-destructive testing methods for the detection of critical changes [1-3]. Good vibration coupling between the piezo-electric element and the test structure is required for these test methods to work [4].

Previous research on vibration-based test methods using a piezo-electric element for vibration excitation or detection has focused on the simulative and experimental investigation of adhesive bonds between the piezoelectric element and the test structure. Adhesive bonds provide good and more reliable vibration coupling, but severely limit the flexibility of the test procedures [1,5]. Although first approaches for reversible connection between piezo element and test structure can be found in the literature [6-8], no comparative investigation of a large number of connection concepts has been carried out yet. That is why the EMI method and similar methods have so far only been used in structural monitoring. In order to make the EMI method usable for quality control and research tasks, alternative connection concepts with shorter preparation times and increased reversibility will be developed, investigated and evaluated in the scope of the present work.

2. Results

If particularly high demands are placed on the quality of the recorded spectra, a form-fit between the piezo-electric element and the structure is required. The comparison of the investigated form-fit joints shows that different adhesives are suitable for the vibration coupling between the piezo-electric element and the test structure. Since the same vibration modes of the structure in the investigated frequency range are excited via the bonds using cyanoacrylate and polyethylene film as for the epoxy resin adhesive (reference method), their vibrational coupling can be judged as almost ideal. In contrast to epoxy-based adhesives, the latter two can be chemically (cyanoacrylate) or thermally (polyethylene film) released in case the test structure or the piezo-electric element are appropriately resistant to the method. Additionally, the thickness of the additional joining layer plays an important role in the quality of the vibrational coupling as well as in the ease of reversibility. The thicker the layer the more the coupling is worsened due to shear-lag effect [9,10] and increased damping but at the same time, it is easier to release the piezo-electric element.

Very fast and fully reversible fastening is possible by means of force-fit connections where vibrations are transmitted by friction in the contact area between the piezo-electric element and the structure without the need of an additional joining layer. This coupling mechanism only allows exciting the same vibration modes of the test structure as the reference method up to 15 kHz while above peak density and quality are highly decreasing. Additionally, very stiff or thick test structures cannot be excited using connections by means of a spring clamp or a magnet. Only fastening by means of a screw clamp provides peaks even on a steel disk with a thickness of 3 mm, which are, however, only suitable for the detection of damage to a very limited extent due to their low amplitude. Force-fit joints via vacuum together with ring-shaped piezo-electric elements have also been studied in the scope of the work. First results seem to be promising, but improvements have to be made on the method to allow further evaluation, especially on increasing contact pressure by improving vacuum generation and stability over time.

Various adapter concepts, in which the vibrations are transmitted indirectly to the structure via the adapter element, combine the good vibration coupling of a form-fit connection between the piezo-electric element and adapter with the high flexibility of a force-fit connection between adapter and test structure. Concepts using an adapter magnet, thumbscrew or clamp are sufficient to excite and evaluate even very stiff test structures, but only in a limited though adjustable frequency range depending on the vibration modes of the adapter. The dimensions of the adapter magnet can specifically influence the measuring range improving the concept's flexibility. If, for example, influences due to damage are to be expected in a lower frequency range, the range with evaluable peaks can be shifted towards lower frequencies by using a thinner adapter magnet. A similar behavior can be observed with different tightening torques on the thumbscrew and the clamp adapter where increasing torques above the minimum needed for exciting the structure shift evaluable peaks towards higher frequencies.

Based on the experimental results, the decision diagram in Figure 1 is derived that gives recommendations to support the selection of an application-specific piezo-electric element connection.

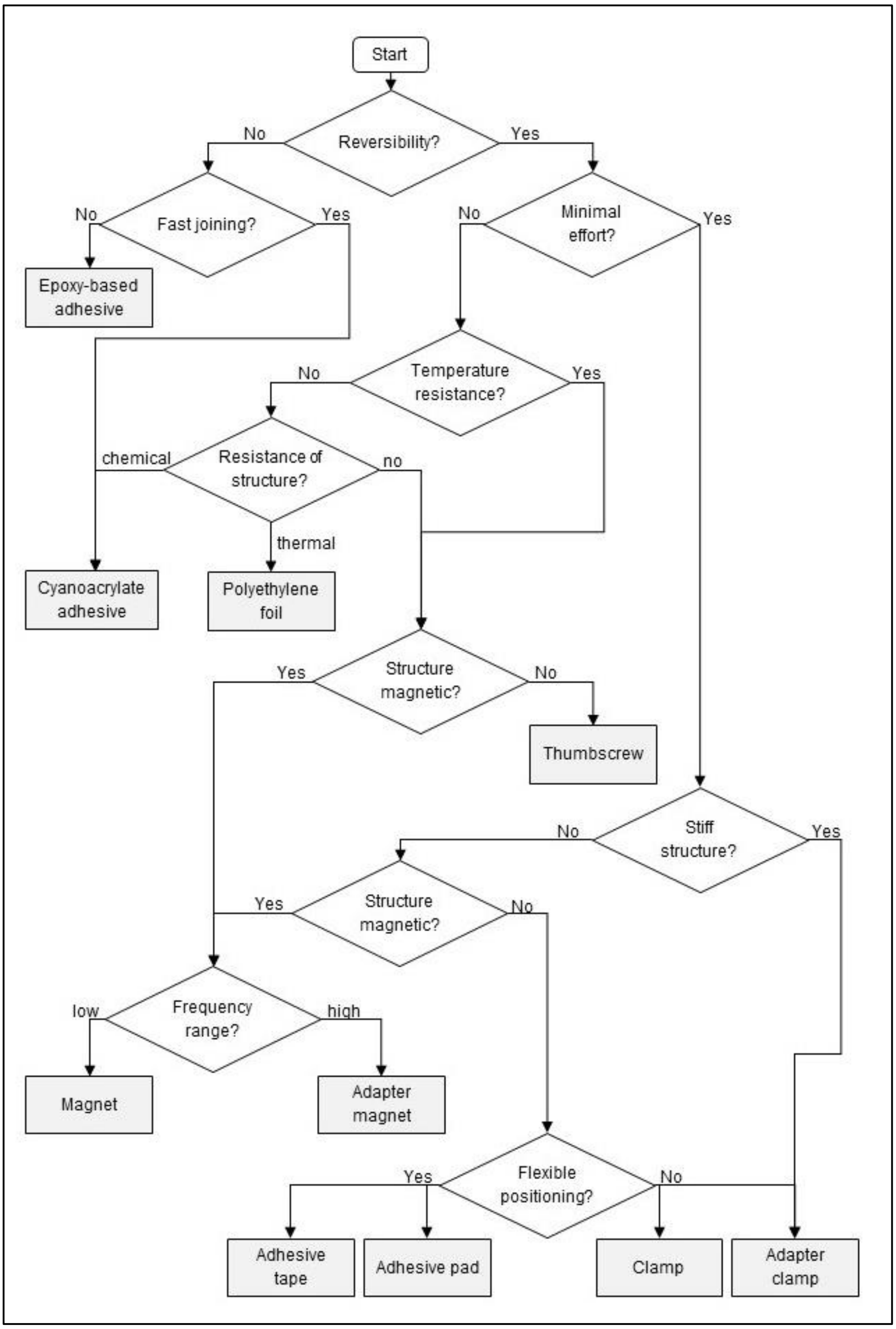

Figure 1. Decision diagram for the selection of a piezo element connection.

3. Conclusion

In the present work, a range of new and improved concepts for vibration coupling between the piezo-electric element and the test structure are experimentally investigated and evaluated. It can be concluded that in addition to the conventional epoxy resin adhesive bond, other joining techniques are suitable for vibration coupling between the piezoelectric element and the test structure. The experimental investigations are carried out for the EMI method, but are similarly transferable to other vibration-based test methods in which piezo elements are used as sensors or actuators. On the basis of the recommendations in this work, it is possible to transfer the joining techniques to real applications.

The flexibility of all investigated connection concepts is limited by a missing or strongly restricted repeatability. In order to extend the field of application of the EMI method and similar test methods to areas of quality assurance or discontinuous condition monitoring, the causes for the scattering of the connections will be identified in the following investigations.

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