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Revision of the Ph.D. thesis of M. Tech. Eng. Shishir Kumar Singh

The basis for reviewing the doctoral thesis is: the Act of July 20, 2018, *Law on Higher Education and Science* (Journal of Laws of 2023, item 742), as amended, and the letter of Grzegorz Żywica, Ph.D., Eng., prof. IMP PAN Deputy Director for Scientific Affairs of the Institute of Fluid Power Machinery No. RN-421-2/23 of July 17, 2023.

1. Layout of work and general remarks.

Ph.D. Thesis of M. Tech. Eng. Shishir Kumar Singh entitled "Electromechanical Impedance-based Damage Detection and Localization Employing Data Fusion Techniques" was published as a monograph in English. It contains a summary in this language, a list of publications and conference presentations with the author's participation, a table of contents, a list of figures and tables and the main substantive part. It has a total of 123 pages, including 111 pages of the main part of the work and a list of 131 publications cited in the text of the dissertation.

The problem of detecting and determining the location and size of damage of mechanical objects has been in the centre of interest of engineers and scientists for years. Various techniques are being developed, based on various physical phenomena. For some time now, attempts have been made to use electrical methods for this purpose, based on variable parameters, such as resistance to the flow of direct current or impedance measured with alternating current.

This method - measuring the change in impedance of the conductor through which electricity flows under the influence of mechanical damage - was used by the Author of the thesis. In this work, changes in the impedance of the samples were not directly measured, but using piezoelectric sensors attached to their surface. This impedance depends on the deformation of the piezoelectric element, which is a function of the change in size, shape and stiffness of the sample. The main assumption in the dissertation is that these values depend on the structure defects of the tested samples.

For this reason, in my opinion, the work is not only interesting, but also useful from a practical point of view. It contributes significantly to the development of science, providing a novel solution of a problem.

The work is basically experimental. This causes some dissatisfaction, because at the doctoral level, experimental research should be supplemented with advanced theoretical-

analytical or numerical models. Hybrid methods are also increasingly used, which naturally combine mathematical modelling and experiments.

Nevertheless, I have no doubts as to the advisability of the author taking up the topic of the work.

2. Comments on the work

The arrangement of the dissertation is typical and correct, and whole the issue is generally described correctly.

The work does not contain any significant substantive errors, although attention should be paid to some inaccuracies or doubts that arise when reading it. Some of these comments are debatable, others may result from too superficial description of some phenomena. Below I present my main comments and questions.

a. Editorial comments

- Many abbreviations are used in the work without explanation (EMI - 2^{15}; PZT - 2_{15} and others). They are known to specialists, but the doctoral thesis should be understandable to a wide range of readers. It would be extremely useful to add a list of all used abbreviations at the beginning of the work.
- Photos (Fig. 1.1) that were probably not taken by the author have no sources provided.
- Some drawings (e.g. Fig. 1.5.) are placed before their description in the text, which makes it difficult to understand the work.
- The basic unit in mechanics is the millimetre, not the centimetre, and these units should be used (22_{18} and further).
- The author explained the meaning of the H symbol in the graphs (23_4). However, there is no description of what the M symbol means.
- In charts, each group of data should be marked with a different colour (Fig. 2.7; 2.8, …).
- Some important parts of the graphs should be enlarged (e.g. Fig. 3.3 - F value graph).

b. Substantive comments

- What is "efficiency of electromechanical admittance" (10_{13})?
- The author examines structural damage to the samples. How to explain the case of adding extra mass to the specimen? (please explain this during your defence).
- All tested values are analysed as a function of frequency. It is very important to specify the resonance frequency of the tested samples. I have never found these values anywhere. Please add these values to the presented charts during your defence.
- How delamination sizes were determined (35^4, Fig. 3.1)? Is it evaluated from the image only or was the ultrasonic or other method used? Both values may sometimes differ from each other.
- Do the values S, shown e.g. in Fig. 3.4, present differences from the previous or initial (healthy) state?

- The author wrote (44_{10}) that the location of the sensors is the result of the optimization process. Please, during defence, explain in more detail what this optimization was, because it is not clearly described in the text.
- Please explain why the size of the damage (Fig. 3.14) does not have a significant impact on the obtained results.
- The maps shown in Fig. 3.24-3.29 are not sufficiently explained in the text.
- It is not explained from which sensor the values shown in Fig. 3.5 and 3.6 were obtained.
- There is no explanation of what the red and yellow lines mean in the graphs shown in Fig. 5.16 and following.
- Lack of comparison of the method used by Author with others - it is difficult to find out its advantages and disadvantages.
- The tests were carried out only on single samples. Therefore, there is no very important statistical analysis of the obtained results.

3. Conclusions

M. Tech. Eng. Shishir Kumar Singh carried out research work consisting of an experimental part and a small analytical one. The obtained results are correct, which confirms the ability to conduct scientific activities. The literature used is relevant and up-to-date. The submitted dissertation demonstrates the author's ability to conduct research.

Taking into account the general quality of the dissertation, its current topic and the Author's ability to solve an important scientific problem, I declare that the work titled: "Electromechanical Impedance-based Damage Detection and Localization Employing Data Fusion Techniques " meets the conditions set out in the Act of July 20, 2018, *Law on Higher Education and Science* (Journal of Laws of 2023, item 742), as amended, and I request that it could be admitted to public defence.