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Investigation of Vibroactivity of the Mechanical Equipment Aiming to Reduce Emitting Noise

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1. Introduction

At present, the noise problem is already widely discussed and identified as a priority to ensure human health and the prevention of occupational diseases. We understand acoustic field management as a targeted use of actions and tools to change field parameters or characteristics. In general, the most effective effects on the fields are the elimination of their generation conditions. One of the main causes of noise is human industrial activity and the mechanical equipment used for this purpose. The management of acoustic fields is ensured by the product certification system, conformity assessment, declaration of acoustic parameters [1-3] and other actions [4-8] that encourage the manufacturer to take care of the reduction of the generated acoustic noise. This affects the process of equipment design and production and for equipment in operation as well.

In the work the vibration analysis of the recuperators (AHU) was performed, the limits of the vibration parameters were determined and the correlation between the vibration activity of the device and the sound pressure level in the near environment was determined. After the design of the fan partitions and the airflow excitation of the fans with respect to vibration parameters, it was found that the abovementioned structural changes allowed to reduce the average total weighted sound pressure level in the vicinity by 8%.

2. The experimental investigation of vibroactivity of the mechanical equipment

In order to determine the nature of the acoustic field in a residential, technical environment, it is necessary to measure various acoustic parameters and their levels. These values are specified in regulatory documents [9-11]. All this allows to achieve unity of characterization and investigation of acoustic fields, to investigate the efficiency of various measures to control acoustic fields. In this work, vibration analysis of individual units of the recuperator (AHU) was performed under different work conditions. The vibration velocities of the outer (Fig. 1) housing (front, sides, back) and inner (Fig. 2) structural elements were measured to determine their vibrational activity. Measurements were made at maximum airflow, with the fans of the AHU operating at maximum and minimum operating mode. The places of internal measuring points of the recuperator were: *1* is the horizontal mounting of plate heat exchanger, *2* is the vertical mounting of plate heat exchanger, *3* is the mounting wall of exhaust air fan; *4* is the frame of exhaust air fan, *5* is the mounting wall of air intake fan, *6* is the frame of air intake fan, *7* is the inside side on right, *8* is the inside side on left.

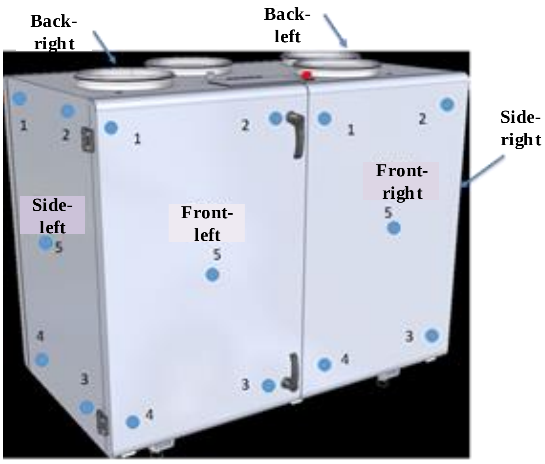


Fig. 1 The placement of external measuring points for vibration of the recuperator housing

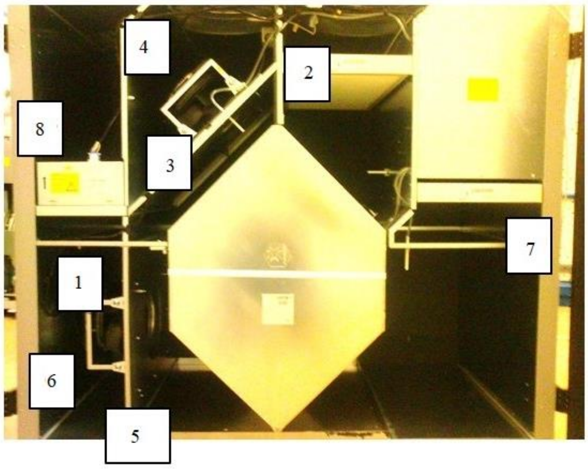


Fig. 2 The placement of measuring internal points for vibration of the recuperator housing

In order to determine the correlation between the vibration activity of the mechanical equipment (AHU) and the acoustic noise in its environment, sound pressure and acoustic intensity in one-third octave frequency bands under different fan operating modes were measured and the limits of total sound pressure variation were determined. Measurements were made on distance of 15 cm from the walls of the recuperator housing in certain segments. The sound insulation panels were used for cancelling the noise caused by the fan intake and exhaust air flow. The general view of the recuperator housing measuring segments is shown in Fig. 3.

The highest values of vibration parameters for both internal (Figs. 4, 5) and external (Fig. 6) structural elements occur when the fans are operating at highest mode.

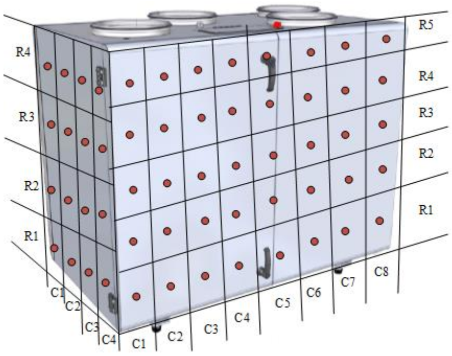


Fig. 3 A general layout of numbering of measuring segments of the AHU body

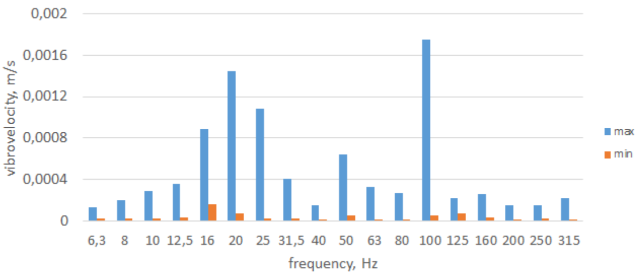


Fig. 4 Vibration velocity of the inner 3-th point at different fan operating modes in octave frequency band

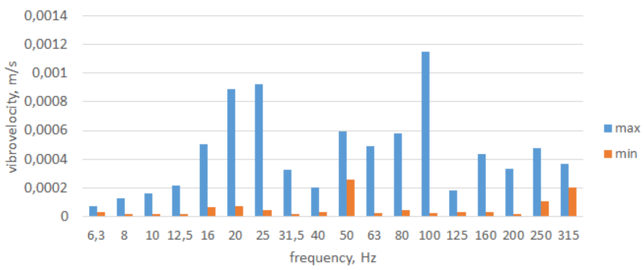


Fig. 5 Vibration velocity of the outer 5-th point at different fan operating modes in octave frequency band

The highest value of vibration velocity was defined at the inner 3-th point of the AHU (exhaust air fan wall) - 0.0017 m / s. Comparing the vibration activity of the individual components of the mechanical equipment, it was found that the walls of the exhaust and supply air fans gain the highest values. When comparing the vibrational activity of the outer structural elements of the housing, its maximum values are in the surface areas of the unit close to the fans.

By means of a vibroacoustic experiment, a correlation was found between the interior elements of the AHU body, the surface vibration activity and the sound pressure level in the surrounding environment.

3. Optimization of the AHU design to reduce the vibration activity of the unit

During the experimental investigation of vibration activity of individual components of the AHU, it was observed that highest values of vibrations gain the partitions to which the fans are attached. After determining the main excitation frequencies of the AHU operating at maximum mode: fan speeds ~ 56 Hz and fan impellers ~ 400 Hz, their influence on the weighted sound pressure level in the vicinity of the device housing is observed.

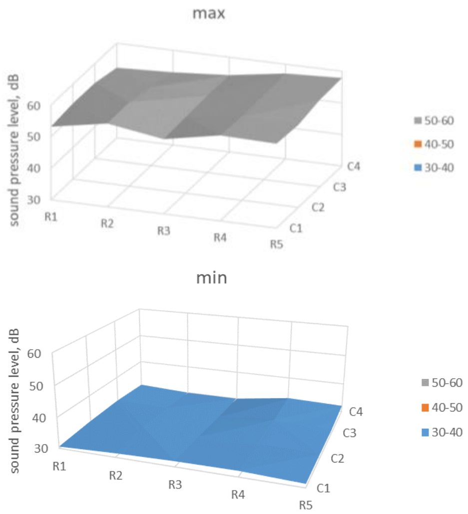


Fig. 6 The total weighted sound pressure nearby the side-left surface of the AHU at different fan operating modes

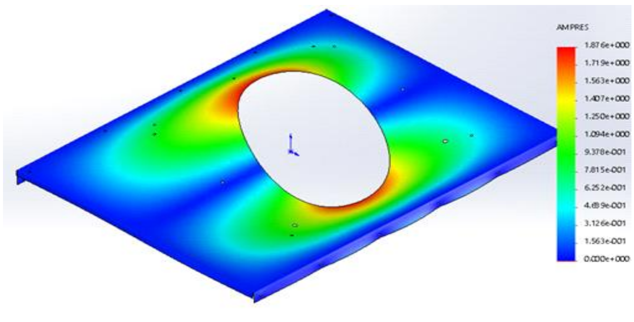
We can conclude that the main parameters which control the acoustic radiation from a vibrating structure are its speed of vibration (or frequency) and its size. It is common in acoustics to non-dimensionalize the problem in terms of the quantity *ka*, where *k* is the acoustic wavenumber and *a* is the characteristic dimension of the vibrating structure. In fact, acoustical power can be calculated knowing a structure's radiation resistance R_0 and spatially- and time-averaged normal velocity *v* [12]:

$$P_{rad} = R_0 \left\langle |v|^2 \right\rangle. \tag{1}$$

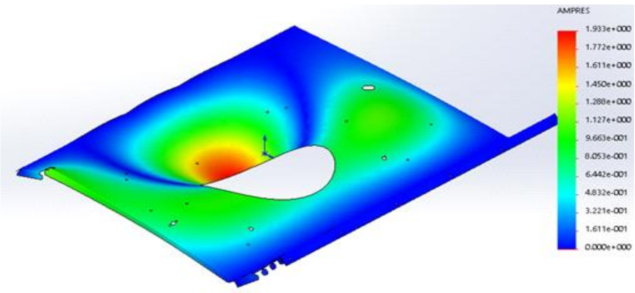
The vibration velocity of the vibrating structure, in turn, depends on its dynamic properties. One of that is the resonant frequency. The resonant frequency of structural elements of elementary geometric form may be calculated using the formula [13]:

$$f = \left(\frac{\pi}{4\sqrt{3}}\right) c_L h \left[(1/a)^2 + (1/b)^2 \right]. \tag{2}$$

Here: c_L is the velocity of the longitudinal sound wave in the material, m/s; *h* is the thickness of the element, m; *a* and *b* are the dimensions of the element, m. The finite element method (FEM) can be applied to determine the resonant frequency of elements of more complex spatial geometric form and construction. In our case, the structural elements of the highest vibrational activity during AHU operation are partitions. Because of their complex geometry, the theoretical modal analysis was performed to determine the forms and eigenfrequencies also the maximum deformation zones using the "SIMULATION FEM" subroutine of the "SOLIDWORKS 2015" software package. The results of the modal analysis are presented in Fig. 7.



a



b

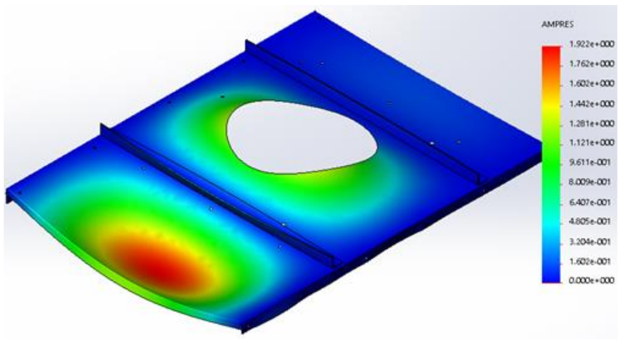
Fig. 7 The first mode of oscillation of fan partitions: a – lower f_1 = 26.67 Hz; b – upper f_1 = 23.08 Hz

The results of the modal analysis showed that the multiple first and second frequencies of the partitions and the third and fourth eigenfrequencies of the partitions are close to the maximum rotation speed of the fans. The optimization of partitions in the sense of vibrational activity is the elimination of conditions for resonance to occur. For this purpose, the structural elements were modified by attaching mechanically two metal 20x20x2 vertical angles. The angle attachment sites were selected based on modal analysis results - in places where maximum deformation occurs. After this structural modification, the modal analysis of the partitions was repeatedly performed using the FEM model and the influence of the partition modification on the vibrational activity was determined experimentally.

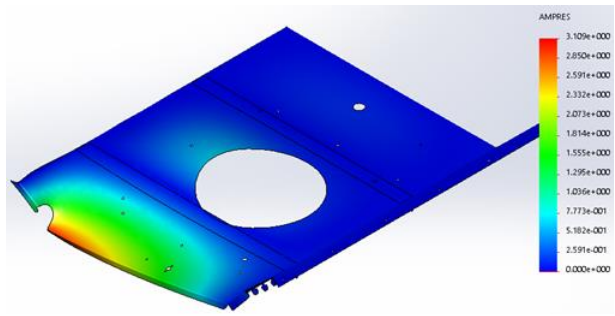
After modifying the partitions of the AHU fans, modal analysis revealed that the eigenfrequencies of partitions increased (Fig. 8). The deformation zones and deformation values of these structural elements have also changed. The results of the theoretical experiment allow thinking that the vibrational activity of the unit should decrease during operation, when eigenfrequencies of partitions differ from excitation frequencies of the fans. For this purpose, an experiment with modified partitions was repeated, during which the vibrational displacements of partitions were measured to determine their vibrational activity.

Measurements were made at maximum airflow when the fans of the AHU were in maximum operating mode. Along with vibration measurement, sound pressure and acoustic intensity were measured in one-third octave frequency bands with different fan operating modes and the limits of the total sound pressure level were determined. Below are the results of the experiment.

The results of the experiment show that the modification of the partition construction significantly reduced the vibrations of these elements during recuperator operation (Figs. 9, 10). Some components of the vibration spectrum have decreased several times after modification. The



a



b

Fig. 8 The first mode of oscillation of fan partitions: a – lower f_1 = 71.01 Hz; b – upper f_1 = 63.62 Hz

reason is the change of eigenfrequencies of these structural elements. Changed dynamic behavior of the internal structural elements of the recuperator influenced the vibrations of the housing elements and the parameters of the acoustic field close to the AHU. The Fig. 11 shows that the sound pressure in the close environment in all areas of the recuperator has decreased. Meanwhile, Fig. 12 shows how the sound pressure level of the device in the different spectral components and the weighted total sound pressure level in the immediate environment have changed after the optimization

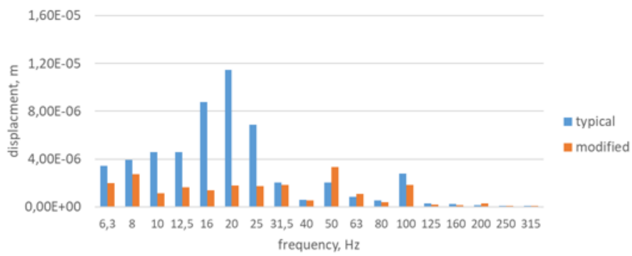


Fig. 9 The vibrational displacement of the upper partition 3-th point in the one-third octave band depending on the design

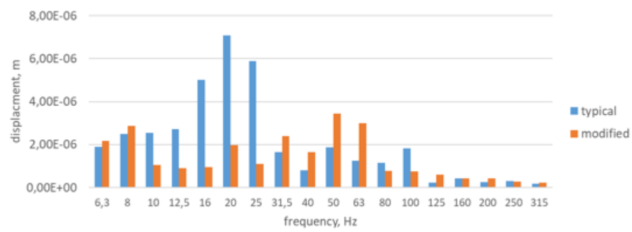


Fig. 10 The vibrational displacement of the lower partition 5-th in the one-third octave band depending on the design

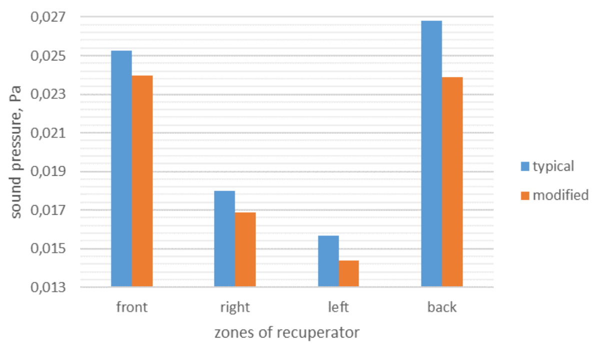


Fig. 11 The total sound pressure nearby of a typical and modified construction of the AHU in different zones

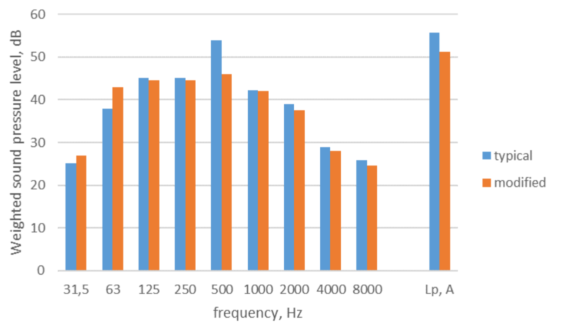


Fig. 12 The weighted sound pressure level of a typical and modified construction of the AHU nearby frontal surface

4. Conclusions

- Vibration analysis of the recuperator was performed, the limits of vibration parameters and correlation between the vibration activity of the unit and the sound pressure level in the near environment were determined.
- The fan partitions has been optimized with regard to vibrational parameters. The optimization of complex geometric partitions was performed using FEM. It has been experimentally determined that the aforementioned structural changes, after the optimization of the elements, allowed to reduce the average total weighted sound pressure level by 8%.
- In future, based on the research, it is planned to develop the structure and algorithm of the structural element selection system, to develop a special computational program, which allows to optimize the design of a specific device with respect to emitting acoustic noise.

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INVESTIGATION OF VIBROACTIVITY OF THE MECHANICAL EQUIPMENT AIMING TO REDUCE EMITTING NOISE

S u m m a r y

At present, the noise problem is already widely discussed and identified as a priority to ensure human health and the prevention of occupational diseases. One of the main causes of noise is human industrial activity and the mechanical equipment used for this purpose. In the work the vibration analysis of the recuperators (AHU) was performed. In future, it is planned to develop the structural element selection system, to develop a special computational program, which allows to optimize the design of a specific device with respect to emitting acoustic noise.

Keywords: noise control, AHU, vibration, structure.

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