Development of Predictive Model for Vibro-Acoustic Protections in Industrial Hall

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Abstract

The paper presents stages of developing a prognostic model for implementing noise protection in an industrial hall. The main source of vibroacoustic problems is the glass hardening furnace, which was installed in a new production hall. It generates vibroacoustic problems at the furnace operators' work stations and at work stations at other devices placed in this hall and in the adjacent hall. These problems are mainly result from mistakes made during the preparation of the furnace placement, as well as the assembly of the machine and accessories. The conducted vibroacoustic tests were aimed at diagnosing problems and developing appropriate ways to minimize the risk of noise and vibration hazards. The basic research tool was to create the correct hall acoustic model, determine the sound power of partial sources and calibrate the model. Modelling the sound protection efficiency of each noise reducing element has allowed the selection of appropriate solutions in terms of acoustic efficiency and approximate application costs. Measurements were carried out according to standard procedures. The article presents only some of the results of vibroacoustic tests directly related to the developed acoustic model. Analysis of vibration paths and noise propagation, indication of assembly defects is a recommendation to formulate vibroacoustic requirements for newly installed devices.

Keywords: noise, workstation, predicting software, work environment

1. Introduction

The principles of combustion noise in industrial and power systems using gas and liquid fuels apply generally to all types of combustion systems [1]. The new glass hardening lines are distinguished by their efficiency, energy efficiency, high performance and the quality of tempered glass. Most functions are automated, fully controlled and managed by the PLC system from the computer. The glass panes, after being loaded into the furnace, are tempered. The glass formats are heated to the required temperature with the assumed speed of movement and the temperature curve, then the glass is tempered and cooled.

The authors present a case study of many vibroacoustic problems, which appeared after installing a glass hardening furnace in the industrial hall. Problems occur not only at workplaces, both in cases of excessive vibration and noise.

To analyze the possibilities of efficiency different types of noise protection solutions, Odeon, specialized software of room acoustics, was used. The purpose of computer simulations was to achieve the required noise levels by using effective noise abatement with the lowest possible investment cost.

For the design of low-noise indoor environments it is crucial that both the noise sources and the surrounding room surfaces are taken into account [2, 3]. Using a room acoustic computer model the first step is to model the room surfaces in terms of absorption and scattering properties. Next the real sources are modelled, and while some sources may be sufficiently modelled by a simple point source, this is not sufficient for large noise sources [5, 7].

In the design process the computer model offers a handful of tools like grid maps of noise distribution, reverberation time, spatial decay rate, identification of the most important sources, and possible effects of various noise control measures [4, 5, 8]. The distribution of early reflected sound over the particularly areas in halls could be investigated, especially with respect to the shape of halls [6, 9].

The usage of predictive acoustic software in industrial hall environment is frequent. In this paper, an acoustic noise analysis of an operating industrial plant is presented.

2. Problem statement

The plant has two big halls separated by a shared wall. In one of these halls, a furnace for glass hardening was placed. This furnace has been subjected to vibroacoustic tests as a source of excessive noise and vibration in the hall environment, causing noise pollution at the furnace work stations and neighboring machines. Overall dimensions of furnace are 22 m x 3.8 m x 3.8 m, and its weight is 32 tons. The heating power of the furnace is 624 kW, and its cooling capacity is 1130 kW. During operation, in the furnace are tempered glass plates with a thickness of 3.2 mm to 19 mm. The furnace is operated by two two-person teams of operators whose workplaces are located at the beginning and the end of the glass hardening processing line.

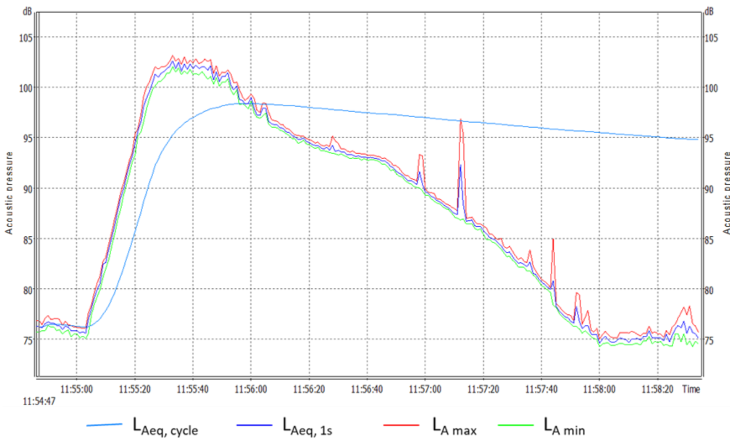

Figure 1. One cycle of hardening glass process

The technical process involves loading two panes of glass on feed rollers, that guide the glass panes through the furnace chambers, where the process of hardening occurs, and then operators pick up the glass pane from conveyors and placement them in special racks.

The cycle of two glass panes passing through the furnace is on average about 4 minutes (Fig. 1). The glass hardening process is accompanied by high level noise related to the blowing air into the furnace. The furnace is supported by four blowers equipped with 220 kW electric motors operating at a speed of 1450 rpm.

3. Noise measurements and hall modelling

3.1. *Measurements*

To assess the impact of noise from furnace devices for glass hardening, sound measurements were made at operator work stations and at selected points (Fig. 2) in both halls, using the measurement methods described in the standards [11 - 13]:

- noise measurements around 3 fan motors that blow air into the furnace at a distance of 1 m from the machine contour [11];
- measurements of noise levels around the furnace at a distance of 1 m from the furnace contour [12];
- measurements at operators' work stations [13];
- measurements at neighboring work places for the glass hardening furnace [13],
- measurements in selected locations in the neighboring hall.

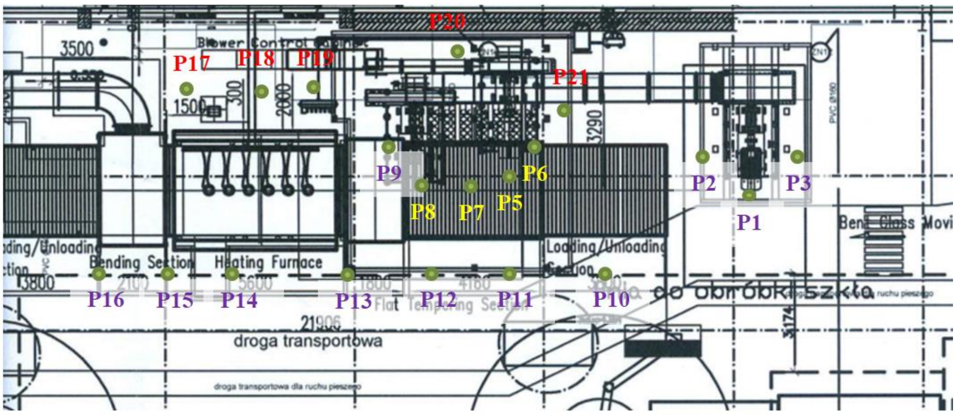

Figure 2. Layout of noise measurement points

All noise measurements were made using the SVAN 971 sound level meter. The measurement results were used to assess the noise hazard at all work stations in the hall, as well as to calibrate the acoustic model of the hall.

Table 1. Noise measurement results (measuring points shown at Fig. 2)

No	No measurement point	A-weighted sound pressure level L_{Aeq} [dB]	A-weighted sound pressure level MIN L_{Amin} [dB]	A-weighted sound pressure level MAX L_{Amax} [dB]	Noise background level L_{Abg} [dB]
	FAN MOTOR W1				
1	P1	**93.2**	91.0	94.8	64.5
2	P2	**95.4**	94.0	96.5	
3	P4	**93.1**	91.5	94.3	
	FAN MOTOR W2				
4	P5	**94.6**	91.1	96.2	64.5
5	P6	**96.1**	91.7	98.0	
6	P7	**93.2**	81.3	98.9	
	FAN MOTOR W3				
7	P7	**93.2**	81.3	98.9	64.5
8	P8	**95.0**	89.4	97.5	
9	P9	**95.7**	90.9	97.4	
Emission A-weighted sound pressure levels (PN EN ISO 11202)					
10	P10	**92.1**	74.3	97.3	64.5
11	P11	**94.0**	74.0	99.0	
12	P12	**95.7**	78.6	100.3	
13	P13	**93.0**	76.6	98.1	
14	P14	**89.7**	75.3	95.0	
15	P15	**88.3**	75.8	93.3	
16	P16	**87.6**	74.1	92.8	
17	P17	**91.6**	72.7	91.6	
18	P18	**92.9**	72.6	99.8	
19	P19	**94.7**	73.3	101.2	
20	P20	**96.2**	74.3	103.2	
21	P21	**96.2**	76.0	101.4	

Noise at the workplaces

Table 2 contains the noise risk assessment at operator workplaces SP1 and SP2 of the glass hardening furnace:

Table 2. Noise hazard assessment for 8 hours of working time shift in the operator workplace at the glass hardening furnace

No	No work station	Equivalent sound level for 8 h of work L_{Aeq8h} [dB]	Maximum value sound level L_{Amax} [dB]	Peak sound level L_{Cpeak} [dB]	Background sound level L_{Abg} [dB]
		Limit value L_{Aeq8h} = 85 dB	Limit value L_{Amax} = 115 dB	Limit value L_{Cpeak} = 135 dB	
1	SP1	90.6	100.3	116.3	64.5
2	SP2	93.9	103.2	120.4	64.5

The timetable of 8 hours work day of the furnace operators consist of:

– 105 cycles (one cycle 4 minutes) = 420 minutes,
– 30-minutes – breakfast break (background sound level L_{Abg} = 64.5 dB),
– 30 minutes-preparing for the shift begining and end of the shift (background sound level L_{Abg} = 64.5 dB).

3.2. *Acoustical model of the industrial hall and noise distribution computer simulation*

Geometrical acoustics are used as a standard model for room acoustic design and predicting. Research on room acoustic simulation focuses on a more accurate modelling of propagation effects such as diffraction and other wave effects in rooms [10]. Odeon Combined 15 was used as a software for acoustic analysis of this hall. This software allows to provide sound pressure calculations for selected sources both in single points and grid of points using hybrid method based on Image Source Method and Ray-Radiosity.

ODEON is an energy-based room acoustic modeller, but sound waves are represented by rays, straight lines connecting sources and receivers. Reflections are represented by image and secondary sources, where the sound is still considered as rays. These simplifications make it possible to calculate the acoustic response in large spaces, while maintaining a short computation time with a high level of accuracy [5]. All calculations in ODEON are performed in the energy domain - not in the pressure domain. We use not only point sources for proper simulation of noise sources. Point, line, surface and multi surface sources are available in Odeon. For each source in the model could be assigned a certain radiated sound power in octave bands. The geometry of the noise sources should be approximately modelled, and the surfaces should be used as sources radiating sound [7].

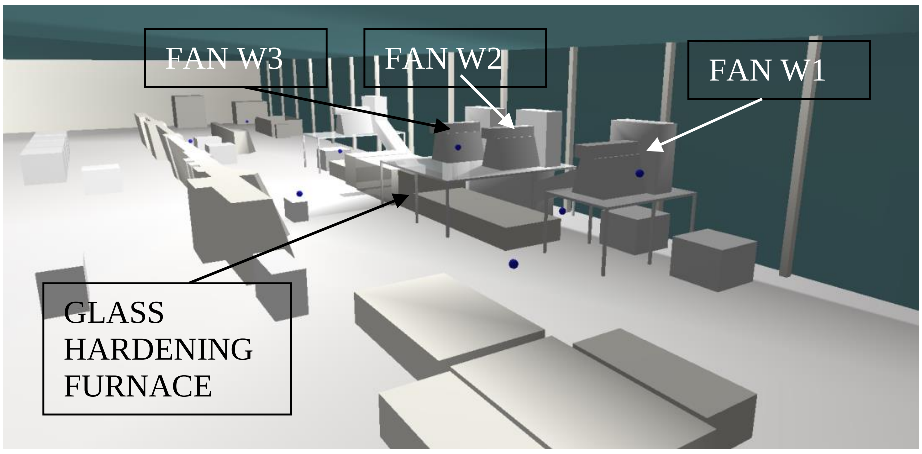

Figure 3. View of 3D model of hall with the glass hardening furnace

The geometrical model of hall was created in SketchUp software and then exported to ODEON (Fig. 3) using SU2ODEON plug-in recommended by ODEON developer, what allowed to simplify geometrical preparation of hall as well as later added models of noise protection solutions [5].

The receivers are placed exactly at the workplace and represented by 3D Models. As input data to the model, the designated sound power levels of individual devices and the measured the Emission Sound Pressure Levels. Calibration of the sound power level of noise sources is done using the measurement results. For selected workplaces, full noise analysis is provided to take into account the impact of each hypothetical operating noise source (including reflections from walls).

4. Discussion

Using the Odeon software, a series of computer simulations and calculations were made that gave the possibility to choose the best anti-noise solution for use in in situ conditions. Among the proposed solutions, calculations of the semi-open sound-absorbing and sound insulating enclosure of the ventilators were made, acoustic panels hang from the ceiling above the furnace, acoustic adaptation of the back wall behind the furnace, increased acoustic insulation of the air supply ducts to the furnace, soundproofing curtain separating the back wall of the furnace.

Different configurations of the proposed anti-noise measures were also analyzed by plotting maps of the A-weighted sound level distribution above the floor surface of the hall. The distribution of A-weighted sound level on 1.5 m over floor of the hall in the present state, without noise protection means has shown on Figure 4 and after the simulation of the application of soundproofing enclosures to the fan motors has shown on Figure 5.

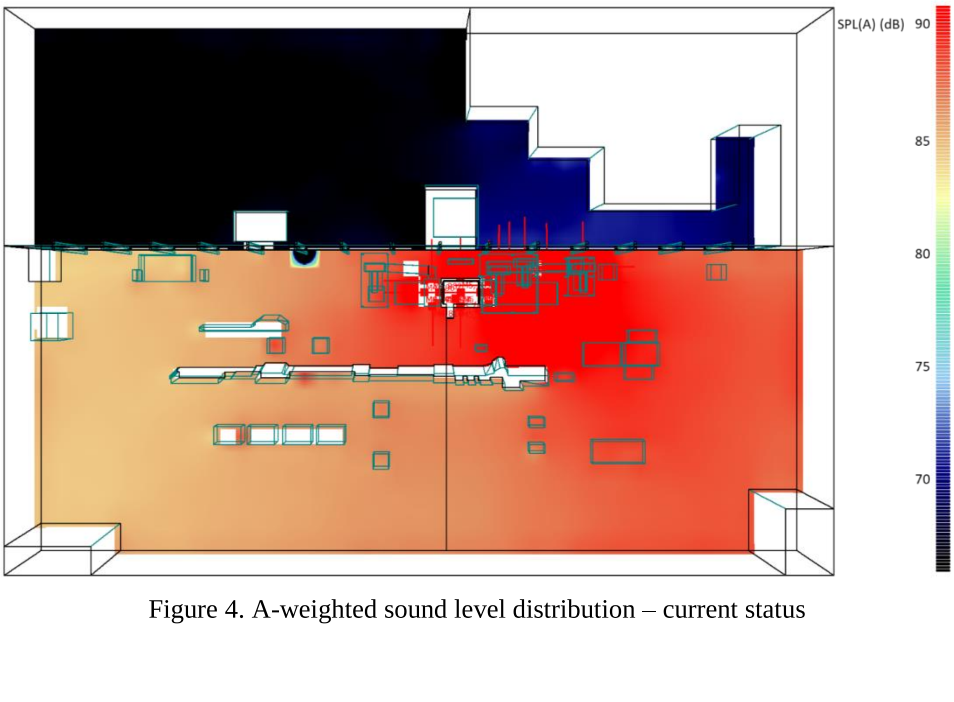

Figure 4. A-weighted sound level distribution – current status

Noise maps obtained from the simulation of sound level distributions in the hall for individual configurations of the proposed noise abatement protections point at the possibilities of noise reduction at workplaces at the furnace as well as at sites adjacent to the furnace. Analysis of the expected effects allows for the selection of measures that are acoustically effective and estimating the costs of their application. In the present case of the hall, taking into account the amount of exceeding the admissible values, it is necessary to apply measures with high acoustic efficiency, such as soundproofing enclosures for fan motors, but it isn't insufficient. The reduction of the A-weighted sound level at workplace SP2 is over 3 dB (A). In addition, adaptation of the back wall should be used (acoustic efficiency is about 1.5 dB (A) and sound insulation enhancement of air duct (about 0.8 dB (A). The same applied noise protections, in the work place on the neighboring machine, give more than 6 dB (A) acoustic effectiveness. Discussion with the plant owner will allow you to choose the most effective from the point of view of acoustics and the most economical solution.

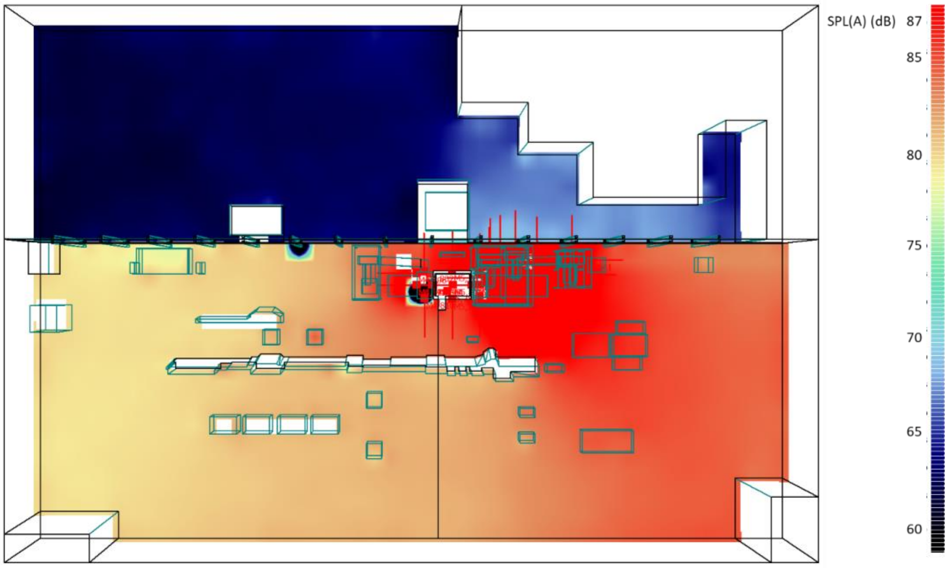

Figure 5. A-weighted sound level distribution after applied enclosures for fan motors No1, No2, No3

5. Conclusions

The reliability of computer modeling is confirmed by comparing the calculated and measured sound pressure levels at reference points. We created the 3D acoustic model of the hall, then calibrated it with the results of measurements and finally received a tool to solve the noise problems that we set at the beginning. Our project was created in order to analyze various scenarios of many possible solutions for noise reduction, calculating their acoustic efficiency and choosing the most effective variant.

One of the most valuable simulation results is the comparison of the share of individual noise sources in the values of A-weighted sound level at the reference points. These values allow estimating the acoustic efficiency of each proposed anti-noise solution. Noise maps showing the distributions of A-weighted sound levels above the floor surface of the hall enable the estimation of noise hazards at workstations located in this hall.

Acknowledgments

Work has done as part of the statutory work 16.16.130.942 of the Department of Mechanic and Vibroacoustic of the AGH-UST in Krakow

The authors would like to thank J. Wiciak, B. Borkowski and R. Trojanowski for their support in carrying out research tests on the furnace for glass hardening.

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