Analysis of noise sources in the acoustic field of a combine harvester’s rotating thresher drum

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Abstract. The main goal of the current research is to analyze the acoustic field of the threshing unit of a combine harvester. This research implements a numerical simulation of gas flow based on the Navier-Stokes equations with discretization of equations by the finite volume method. The finite element mesh used in the idealized model allows one to adequately analyze noise sources up to a frequency of 2500 Hz based on the broadband noise source models of Curl and Proudman. In this paper, the analysis of the flow around the threshing unit at two rotation speeds of 500 rpm and 980 rpm was performed in order to point out elements contributing the most to the noise environment of a combine harvester in operation. As a result of the analysis, the spectra of maximum acoustic pressure and intensity were obtained. Based on this data, there were obtained design refinement areas and areas of increased technological control of a typical thresher drum for the practical implementation in the noise reduction strategies.

1. Introduction
The principle of mechanical separation of grain from the grain mass by dragging the mass between the drum and the concave is common to all combine harvesters. The difference lies in the way the mass is fed to a threshing unit - there exists a transverse and a longitudinal axial flow method (for the rotary threshing devices). In the transverse axial flow method, the threshing speeds of a drum lie in between 290 and 1250 rpm. The diameter of a drum, depending on the manufacturer, can be from 600 to 800 mm. When rotating at such speeds, the linear flow velocity on the drum’s rotor beater plates can reach 100 m/s.

2. Formulating the research problem
In the process of harvesting crops a thresher drum performs the task of separating grain from the grain-mass directly, thus making a significant contribution to the overall noise environment of a combine harvester [1]. The rotating drum of a combine harvester’s threshing unit generates a stream of air, which by interacting with the drum’s elements and the housing’s walls creates areas of significant pressure differences, these being the sources of increased noise. For this reason the thresher drum of a combine harvester was chosen as the focus of the present research [2].

The air resistance of the thresher drum’s elements, such as the rotor beater plates, the drum frame with its structural and technological cuts, and the fasteners with their extremely irregular aerodynamic
shapes, lead to the formation of many discontinuous vortices which are the sources of aerodynamic noise. The interaction of the air flow with the parts of the housing of a threshing unit creates additional sources of noise as well.

3. Choosing the research method
The flow of a gas or fluid stream around bodies is described by the equations of hydrodynamics, and the flow mode (laminar or turbulent) depends on the shape of the bodies inside the stream, the flow rate and the characteristics of the stream itself. Depending on the flow mode, the formation of sound wave sources is possible. The laminar mode is characterized by a jet, continuous flow, without sharp changes in pressure and speed whereas the turbulent mode is characterized by the separation of the boundary layer, the formation of vortices and sharp changes in speed and pressure [3].

This research utilizes a 3D model of a thresher drum with a diameter of 800 mm, a length of 1400 mm with a number of beaters 10 as the object for calculation. The research was conducted at rotational speeds of 1050 rpm and 500 rpm in the housing without the concave. A general view of the thresher drum is shown in Figure 1. The following parameters of the elements of a drum located in the aerodynamic flow must be sources of noise: the beater plates with multidirectional channels with a width of 5 mm, pins of bolts for fastening the beater plates with a diameter of 12 mm, rivets for fastening brackets for beater plates with locking spherical heads with a radius of 8 mm.

![Figure 1. Thresher drum harvester.](image)

To determine the noise-generating sources, the techniques of the computational aeroacoustics were implemented. At the first stage of the research, in the stationary mode, the reinforced areas of noise sources were determined on the basis of a turbulence model with Reynolds Averaged Navier-Stokes or RANS, a method based on solving averaged Navier-Stokes equations [4].

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j} - \rho u_i u'_i)$$

where Equation 1 is the continuity equation, Equation 2 is the equation of motion of a liquid (gas), and $\rho u'_i u'_j$ is the Reynolds stress tensor (contribution of large energy-containing vortices).

According to the results of the first stage, the contours of flow velocities and pressure created by a solid surface in the stream were obtained.

At the second stage, a study in the unsteady mode was conducted to determine noise sources using the Detached Eddy Simulation (or DES) and the F1owcs Williams-Hawkings Unsteady acoustic models. The DES hybrid turbulence model includes the RANS turbulence model in the near-wall flow area and the LES (Large Eddy Simulation) in the external flow region. The main principle of the Large
Eddy Model is to divide (“filter”) the turbulent flow characteristics average over time by the spatial average over regions into small-scale and large-scale structures [5-9].

\[
\frac{\partial u_i}{\partial x_i} = 0
\]

(3)

\[
\rho \frac{\partial \bar{u}_i}{\partial t} + \rho \frac{\partial (\bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} (\mu \frac{\partial \bar{u}_i}{\partial x_j} - \tau_{ij}^{SGS})
\]

(4)

where Equation 3 is the continuity equation, Equation 4 is the "filtered" equation of motion of a liquid (gas), and \( \tau_{ij}^{SGS} \) is the subgrid scale tensor.

4. Deducing the research solution

Based on the preliminary graphs of flow velocities and pressure, a cloud of probes and probe lines were created in the proposed areas of noise sources. The probes and the probe lines are shown in Figure 2. Based on the results of the unsteady calculation stage, the dependence of pressure changes at the probes over time and the acoustic pressure spectra as a function of frequency at each probe were obtained. A similar approach was used in researches [10-15].

![Probed areas](image)

**Figure 2.** Probed areas.

Figures 3 - 5 show the dependence of changes in the sound pressure level at probes over the frequency spectra for a drum rotation frequency of 980 rpm. Figures 6 - 8 show the dependence of changes in the sound pressure level at probes over the frequency spectra for a drum rotation frequency of 500 rpm. “Probe Front” and “Probe Back” are the probes in front of and behind the drum in an unperturbed flow and are situated in the plane of the section \( Z = 0 \) at a distance of plus 0.5 m and minus 0.5 m respectively. The probes 1 to 12 are holes in the drum discs, the probes 13 to 22 are the upper beater plates.

Sound pressure level (PSL) represents the sound pressure value referred to the control value:

\[
PSL = \log_{10} \frac{p_{rms}}{p_{ref}}
\]

(5)

where \( p_{rms} \) stands for the root mean square pressure; and \( p_{ref} \) stands for the control value (20 \( \mu \)Pa).
Figure 3. Frequency spectra of maximum acoustic pressure at the Front and Back Probes at a drum rotation speed of 980 rpm.

Figure 4. Frequency spectra of maximum acoustic pressure for the probes 1-12 at a drum rotation speed of 980 rpm.

Figure 5. Frequency spectra of maximum acoustic pressure for the probes 13-22 at a drum rotation speed of 980 rpm.
Figure 6. Frequency spectra of maximum acoustic pressure for the Front and Back Probes at a drum rotation speed of 500 rpm.

Figure 7. Frequency spectra of maximum acoustic pressure for the probes 1-12 at a drum rotation speed of 500 rpm.

Figure 8. Frequency spectra for maximum acoustic pressure for the probes 13-22 at a drum rotation speed of 500 rpm.
Figures 9-17 represent the contours of the rms value of the instantaneous sound pressure from the frequency spectra for drum speeds of 980 rpm and 500 rpm, selected from the peaks of graphs 3-8.

Figure 9. Acoustic pressure distribution contour at a frequency of 77 Hz and a drum rotation speed of 980 rpm.

Figure 10. Acoustic pressure distribution contour at a frequency of 308 Hz and a drum rotation speed of 980 rpm.

Figure 11. Acoustic pressure distribution contour at a frequency of 462 Hz and a drum rotation speed of 980 rpm.
**Figure 12.** Acoustic pressure distribution contour at a frequency of 1000 Hz and a drum speed of 980 rpm.

**Figure 13.** Acoustic pressure distribution contour at a frequency of 1154 Hz and a drum rotation speed of 980 rpm.

**Figure 14.** Acoustic pressure distribution contour at a frequency of 62 Hz and a drum rotation speed of 500 rpm.
Figure 15. Acoustic pressure distribution contour at a frequency of 312 Hz and a drum rotation speed of 500 rpm.

Figure 16. Acoustic pressure distribution contour at a frequency of 435 Hz and a drum rotation speed of 500 rpm.

Figure 17. Acoustic pressure distribution contour at a frequency of 833 Hz and a drum rotation speed of 500 rpm.
Figures 3 - 5 and 6 - 8 represent the sound pressure levels at twenty-four probes at a drum rotation speed of 980 rpm and 500 rpm, respectively. Figures 3 - 5 make it clear that the peaks of maximum sound pressure are at frequencies of 77, 308 and 462 Hz. At a drum rotation speed of 500 rpm (figures 6 - 8), the frequencies of maximum sound pressure are in the same range, namely, 62, 312 and 435 Hz. From the resulting frequency spectra of the maximum sound pressure there were obtained the acoustic pressure contours in order to determine the noise sources, which are shown in Figures 9-17.

5. Discussing the obtained results
1. The broadband noise of a rotating thresher drum must be related to the stall, turbulent flow characteristics of the air stream.
2. The sources of broadband noise must be the channels of beater plates, the backsides of the beater plates, the elements of cutouts in the disks of the drum and the upper plate of the threshing unit’s housing.
3. In the course of the current research it has been established that the highest acoustic pressure intensity falls on the maximum speed of rotation of the thresher drum at 980 rpm.
4. The maximum sound pressure level falls in the range between 60 and 350 Hz with a maximum component of 118 dB.
5. The frequency spectrum emitted by the top plate of the threshing unit’s housing lies in the range of 800 to 1600 Hz.
6. A loose rivet head may be a source of noise in the range of 450 to 1500 Hz.

6. Conclusions
In the course of the present investigation, there was performed the aero-acoustic analysis of the rotating drum of a combine harvester’s threshing unit for two operating modes: with the drum rotation speed 980 rpm and 500 rpm. The sources of broadband noise and their intensity according to frequency spectra were revealed. The specific areas requiring refinement in order to reduce the noise of the threshing unit were identified.

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