Acoustic and Flow Analysis to Reduce Boiler Hum

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Abstract: A client of LBPSIGHT was confronted with a serious problem of low frequency noise, caused by a forced draft boiler installation. The boiler has a steam production of 220 ton/hr. Measurements showed high noise levels around the boiler, with 30 Hz as dominant frequency. This hum caused serious annoyance in the surrounding, and therefore the problematic load range was avoided as much as possible.

The objective of the study was to reduce the noise emitted by the boiler, and therefore to make it possible to run the installation on every desired load.

With an acoustic study with Comsol, several acoustic resonances were found, including strong resonances at 30 Hz. This acoustic study did not explain the cause of excitation. Therefore, further study towards possible causes of the hum was needed. A review of the design gave rise to the suspicion that poor flow conditions existed at the inlet and outlet of the forced draft fan. It was decided to study the flow patterns with CFD calculations.

The CFD calculations of the turbulent flow (k-ε) indeed showed that both the inlet and outlet flow contained large vortices, which could cause the strong hum. Extra calculations were performed to compare different possible solutions to reduce these vortices, therewith reducing the hum. Necessary changes in the design were determined. The finally proposed changes consisted of changing the overall shapes of the inlet and outlet duct in combination with several flow guiding vanes.

In order to have more assurance that the boiler hum would disappear, additional absorptive silencing was designed with the acoustic module of Comsol. A large absorbent section directly behind the fan was designed. The acoustic response with absorption showed a reduction of 5 dB at the strongest resonance at 30 Hz.

In July 2014 the changes in the installation were completed. Preliminary measurements showed a reduction of 7 dB at 30 Hz. A full test will be performed later. This reduction causes a large decrease of annoyance due to the installation.

Keywords: Boiler Hum, acoustic measure; flow analysis.

1. Introduction

A forced draft boiler showed a serious problem at low frequencies. The boiler has a steam production capacity of 220 ton/hr, using a forced draft fan (a radial fan with max air flow 44 m3/s; power 0,7 MW). The force draft fan supplies combustion air to the boiler. An overview of the installation is shown in figure 1 with the air intake, silencers, fan, air ducting, furnace and the stack with the exhaust at 40 m above ground level. Noise measurements showed that the problem occurred between 66% and 80% boiler load, with 30Hz as dominant frequency. This hum caused serious annoyance in the surrounding, and therefore the problematic load range was avoided as much as possible.

The objective of the study was to reduce the noise emitted by the boiler, and therefore to make it possible to run the installation on every desired load.

2. Initial acoustic analysis

As a start of the study, several possible causes of the noise were summarized. These possible causes are mentioned here.

Vortex shedding of the flue gas behind the heat exchanger tubes in the boiler can cause high noise levels at low frequencies, especially when they coincide with acoustic resonances of the duct. Based on the Strouhal number of the pipe configuration, the gas velocity and the dimensions of the heat exchanger ducts, the occurrence of such resonances can be predicted, and the frequency thereof can be calculated. Such calculations showed that these vibrations were not likely to occur in this installation, and if they occurred, the frequency would be above 50 Hz. Therefore this mechanism was excluded as main cause of the problem.

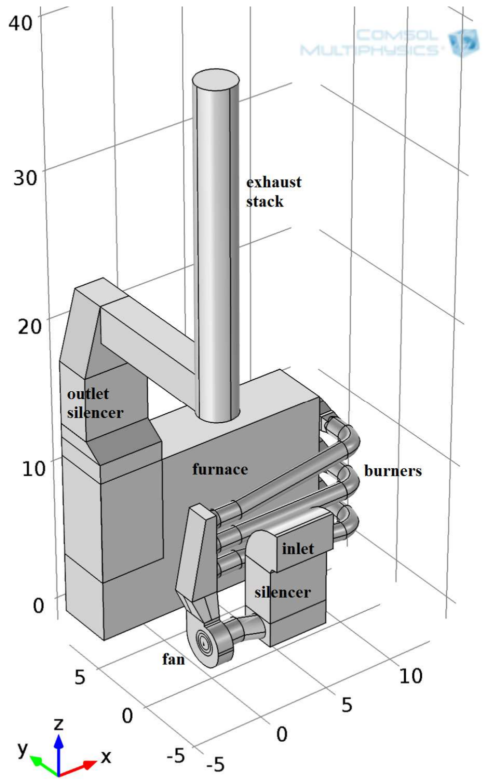

Figure 1. Overview of the boiler (distance: m)

Fan noise, amplified by the burners, resonating in the system, is a possible cause. The highest noise peak of a fan is the blade passing frequency. This frequency is much higher than the problem frequency and therefore not the cause of this problem. A fan also generates a broad spectrum of flow disturbances which manifests as noise. For similar installations, this noise usually doesn't cause strong low frequency noise and it is therefore not likely the main cause of the problem.

As a result, the fan noise, the fan inlet valves, the burner control valves were excluded. Another possible cause of the hum could be flow instabilities in front of the fan and directly behind the fan. Therefore, it was decided to optimize the flow at the inlet and outlet of the fan, in order to prevent the hum.

The burners in the system can also play an important role. Air is heated from ambient temperature to approximately 1000°C, giving a large increase in volume flow. Therefore, the burners act as acoustic amplifiers, with directly behind them a large volume that can resonate at several low frequencies.

In the study, both the inlet and outlet ducting of the fan were studied. The flow pattern of the original design was visualized. It was decided to aim the study on improving the inlet and outlet of the system. The flow inside the fan was not part of this study.

3. Flow study of fan inlet in COMSOL

For the study of the inlet, the system was studied from the air intake until the inlet of the fan, as shown in figure 2. At the inlet, the total flow was imposed; at the outlet a zero pressure was imposed.

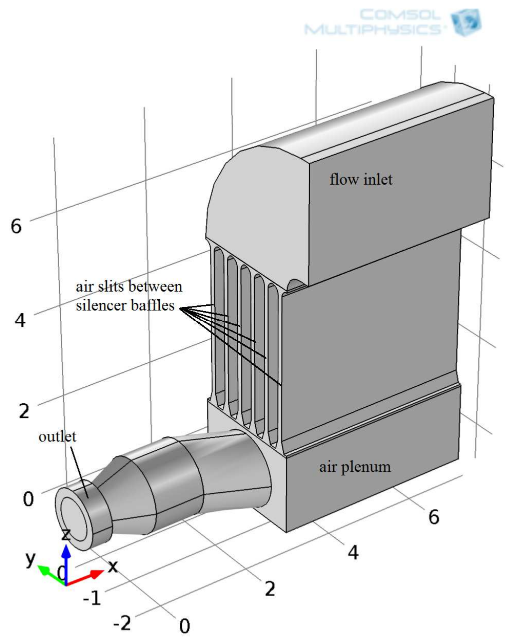

Figure 2. Geometry of fan inlet study

The calculations were made in Comsol 4.3b, with the Non Isothermal Flow model; turbulence model type RANS, k-ε model. Although thermal effects were not part of the study, the use of the model including heat transport (Kays-Crawford) gave good convergence.

3.1 Results flow study fan inlet

The calculations showed a large vortex in front of the fan. This is shown in figure 3.

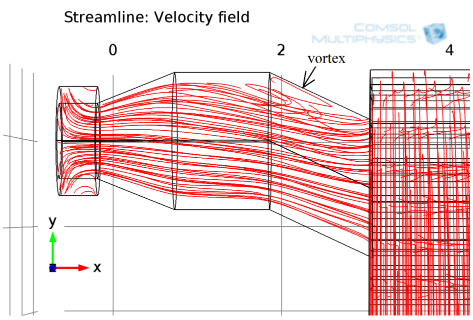

Figure 3. Vortex at fan inlet (top view)

A vortex at such short distance before the fan can cause large instabilities, with an uneven fan inlet flow. This should be avoided. Therefore an adapted inlet design was proposed.

3.2 Adapted fan inlet design

The best way to avoid the vortex would be to straighten the duct from the plenum to the fan inlet. This was not possible due to mechanical restrictions outside the duct. Three changes were made: the inlet area was increased by making the connection with the plenum a rounded square instead of round. A guiding plate was placed inside the plenum, and a guiding vane was placed in the duct. These changes and the resulting streamlines are shown in figure 4.

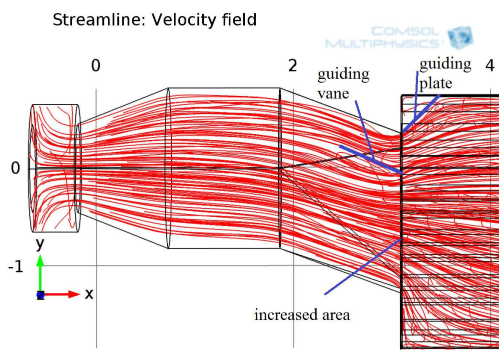

Figure 4. Improved fan inlet with streamlines

4. Flow study of fan outlet in COMSOL

Flow analyses after fans usually start with a given flow pattern as starting condition. In this case, the duct behind the fan has a shape that significantly influences the flow pattern at the fan outlet plane. Therefore, it was decided to start the calculation at the outlet of the radial fan impeller. The starting condition there consisted of two components; a tangential flow component which equals the rotational speed of the impeller (1490 rpm): $v_{tan} = \omega \cdot r_{imp}$, and a radial velocity due to the total flow amount, defined by the equation $v_{rad} \cdot \pi \cdot r_{imp} \cdot w_{imp} = W_{tot}$.

The fan outlet system was studied from the fan impeller outlet, until 2 m after the dividing plenum above the fan. The geometry is shown in figure 5.

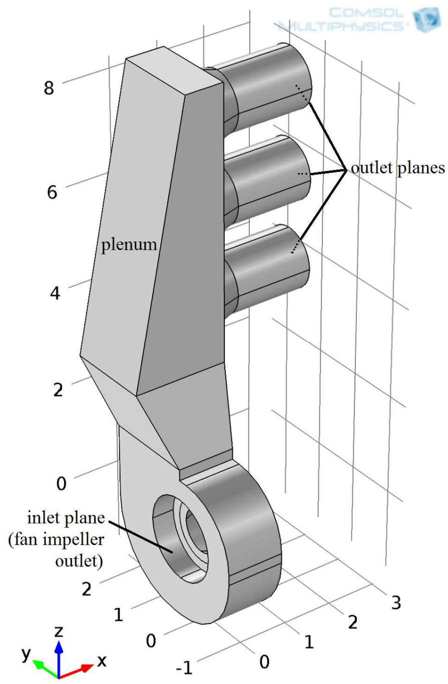

Figure 5. Geometry of fan outlet study

The COMSOL model type for the fan outlet study was the same as for the fan inlet study.

4.1 Results flow study fan outlet

The resulting streamlines for the given design are shown in figures 6 and 7.

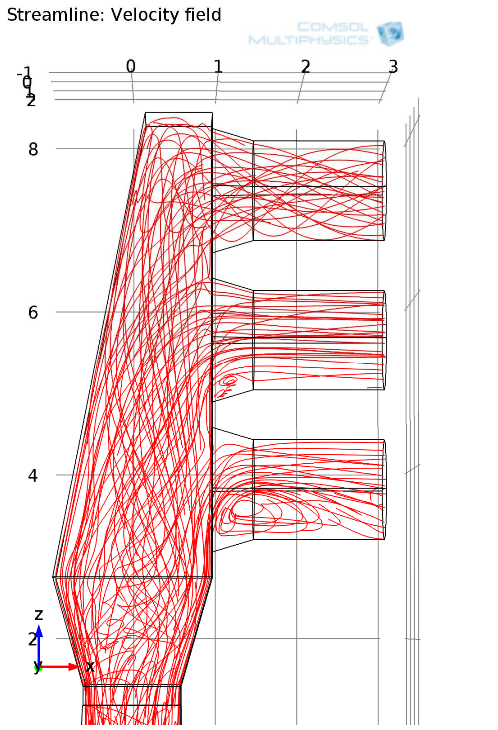

Figure 6. Original fan outlet with streamlines (xz-view)

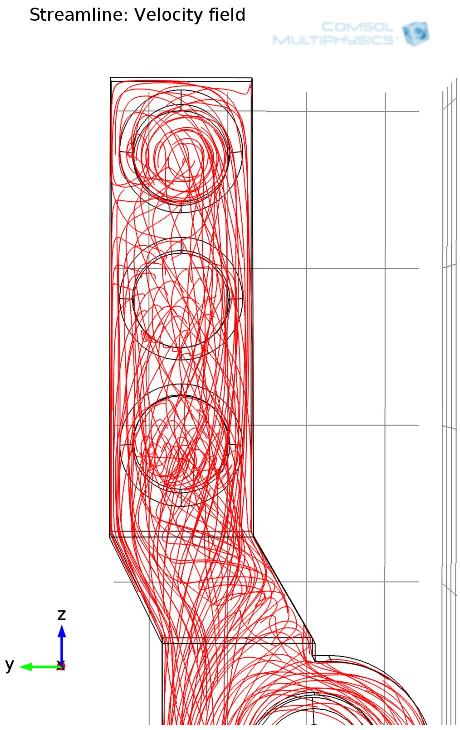

Figure 7. Original fan outlet with streamlines (yz-view)

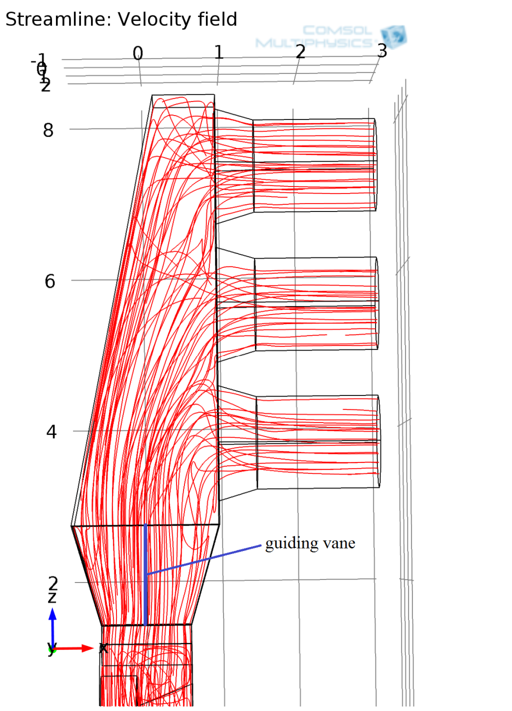

Figure 8. Adapted fan outlet with streamlines (xz-view)

Figure 9. Adapted fan outlet with streamlines (xz-view)

Figures 6 and 7 show unstable flow with vortices directly behind the fan. Such flow instabilities can cause noise, especially since these instabilities can interact with the fan, which can add energy to the system. Also the interaction with the whole system, including the noise amplifying burners and resonances of the system, can cause high noise levels. Therefore such flow instabilities directly behind the fan should be avoided.

4.2 Flow improving measures fan outlet

At the outlet of the fan, the use of guiding vanes alone did not give sufficient improvement of the flow pattern. Therefore, the shape of the fan casing needed redesigned. The changed shape of the fan casing, the added guiding vanes and the resulting streamlines are shown in figures 8 and 9.

Figures 8 and 9 show a significantly improved flow behind the fan. Based on this study, it was decided to make the described improvements on the inlet and outlet ducting of the fan. It was expected to give a significant improvement of the noise; but the improvement could not be quantified.

5. Acoustic study of boiler and absorptive measures

The flow study had given sufficient confidence to change the installation, but extra insurance on a sufficient result was desired. Therefore in addition an acoustic study was made of the complete system.

The goal of this study was first to explain the acoustic resonances of the system, and secondly to define ways for additional acoustic reduction in the system.

In order to make a complete model, several simplifications had to be made.

The first simplification was the level of detail in the inlet- and outlet silencers. Therefore, in separate models, the amount of low frequency reduction of the silencers was calculated. The reduction was implemented in the total model as a frequency dependent formula in the acoustic calculation as an attenuation coefficient with the following values at 30 Hz:

0,6 dB/m for the inlet silencer

0,3 dB/m for the outlet silencer

In a similar way, the noise reduction of the boiler heat exchanger pipes was modelled as 0,5 dB/m. This was determined with a calculation model for noise reduction by heat exchanger pipes.

The influence of flow in the system was neglected. Typical average flow speeds in the main air and exhaust gas ducting is up to approximately 15 m/s, and thus the Mach number is smaller than 0.05. Therefore flow influence on acoustics is small. In some small regions with local high velocity, a certain error would be made, but this was taken for granted.

Since the hum occurs at low frequencies, relatively large elements could be used for the study, making it possible to model the complete boiler.

The source of the noise was positioned at the centre of the fan.

Different temperatures in the system were taken into account. This gives, due to mass conservation at the furnace entrance, a first order approach of the noise amplification at the burner. The following temperatures were used:

- ambient from inlet till burners: 15°
- furnace: 1000°C
- average in heat exchanger: 570°C
- exhaust silencer and stack: 140°C

The boundary conditions at the air intake and at the stack exhaust were modelled with the end impedance formulas according Levine and Schwinger.

5.1 Results acoustic study

With this model the average sound pressure level in the furnace was calculated, at a given strength of the flow source. This transmission showed clearly a number of resonances present in the system, with three different peaks close to 30 Hz. This demonstrates the sensitivity of this installation for disturbances around 30 Hz.

5.2 Acoustic measures

Several modifications were studied. The proposed modifications must be practically possible. It was possible to add large absorbers to one side and the top of the plenum directly behind the fan. The thickness of the top absorber is 1 m, the thickness of the side absorber is 0.5 m. The connection consists of a perforated plate and a glass wool lining in order to protect the wool from flow influences.

In figure 10, the calculated sound pressure spectra in the furnace is shown without and with the absorbers (for comparison; absolute values are arbitrarily chosen).

Figure 10 shows that the amount of noise reduction varies much with the specific frequency. Especially the peaks around 30 Hz are of interest. The peak at 28.5 Hz is reduced by more than 20 dB. The peak at 30 Hz however, is only reduced with 5 dB. The peak at 33 Hz is reduced by almost 10 dB.

This difference in effectiveness is caused by the modal shape of each resonance. If the pressure wave at a resonance has a local pressure maximum near the absorber, the absorber will be less effective, since absorption acts on the acoustic particle velocity. Figure 11 shows the modal shapes at 30.25 Hz for the situation without and with absorption. It shows that the absorption has little effect on the shape of the mode. The amplitude of the mode has become is smaller. Since the highest peak will determine the overall effect, the effectiveness of the added absorbers around 30 Hz is expected to be 5 dB.

This reduction of noise does not apply for noise of the fan which is emitted directly by the inlet and also not for noise caused by burners and furnace which is emitted by the stack. Therefore, the total reduction due to absorption would be at maximum 5 dB.

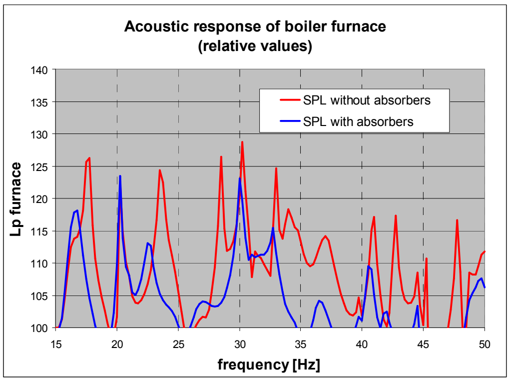

Figure 10. Boiler furnace response from fan without and with absorbers

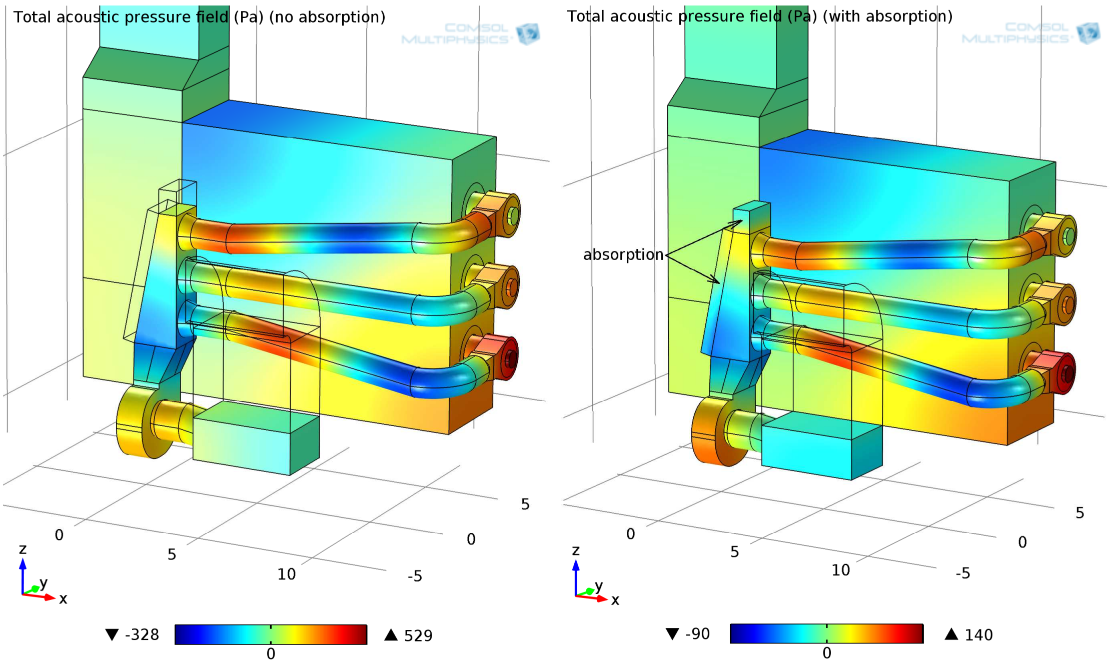

Figure 11. Acoustic mode at 30.25 Hz without absorption (left) and with absorption (right) (note the different scales!)

6. Results in practice

In July of 2014, the changes in the installation were completed, according the results of the study. The measures are summarized as:

- flow optimisation at fan inlet, consisting of a change in duct shape and a flow guiding vane,
- flow optimisation at fan outlet, consisting of a change in duct shape and several flow guiding vanes,
- an absorptive section directly behind de fan outlet.

The installation was started and directly used for production, up to loads above the formerly problematic load range of the installation. The noise emission of the boiler, which is constantly monitored, proved to be 7 dB lower around 30 Hz compared to the original situation (measurement of 31.5 Hz ⅓rd octave band). A test of the boiler at all loads will be done later. The reduction with 7 dB is a serious improvement, and probably sufficient to avoid annoyance for the neighbourhood.

7. End remarks

The acoustic and flow analyses proved to be a successful engineering tools in this trouble shooting case of reducing boiler hum. It helped in understanding the causes of the problem and was used for both the flow optimization as for the design of the noise reduction measures.