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NOISE PREDICTION AT POWER PLANT SITES AND AT CHEMICAL PLANTS

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The prediction of noise by industrial installations stretches from local workshops to huge industrial sites covering several square kilometers. The standard ISO 9613-2 is the world-wide accepted and applied engineering method to predict the noise from industrial sites and also from other types of sources. Experience with the application of this standard has shown that these procedures provide reasonable results for mid-range distances and in case the meteorological conditions are not of dominating influence within the assessment interval. Tasks to handle are the setting up of the model's geometry, importing and updating the acoustical data for numerous sources using external data sheets and databases, performing the calculation, and reporting the results for several scenarios considering different zones within or different planning stages of a plant or factory. Results should be transparent with respect to the source-receiver-relation offering emitted sound power and receiver levels quantifiable for each sub-structure of a plant. The paper addresses objectives and solutions with large industrial sites, focusing on the energy and chemical sector, using software representing the current state of the art.

1. Introduction

Increasing conflicts between industrial sites and neighboring housing areas require a clear and structured planning process to identify possible noise reduction strategies already in the early planning stage. Due to legal requirements existing in a number of countries a noise study needs to be reliable, reproducible, and well documented in order to pass the final examination by the local authorities being involved. Also in case where no legal requirements have to be met the providing manufacturer has to prove frequently whether the installed facilities fulfill the requirements as fixed by contract. By including the acoustical concept already in the early stage of a project, where the general layout and design of a plant or installation is still modifiable, avoids a costly and time-consuming redesign.

2. Objectives of an integrated acoustical design concept

An acoustical computer model of a any industrial installation allows to investigate the specific correlations between the noise emission of relevant sources and the noise impact at distinct receiver points or even on a grid. By such a model a reasonable and complete concept with regard to design specifications of individual units can be drawn up. Objectives provided by a computer model are:

- A calculation model enables a reasonable overall assessment of all relevant sources and operating conditions.
- The partial level of a specific sound source at a certain receiver cannot be evaluated by measurements in all cases.
- The assessment focuses on the evaluation of the long-term average level, mostly for an entire year, assuming that meteorological effects are not of dominating influence.
- Instationary sources or operating conditions and their effect on the average level can be evaluated just by calculation.
- An acoustical model allows to create and compare design specifications for noise protection measures (e.g. insertion loss of screening barriers/silencers, noise reduction index of facades/roofs etc.).
- Possible design alternatives and their effect on the sound pressure level in the neighborhood can be studied in advance.
- The results of a study can be reported to an authority in charge of final inspection and approval of a planned industrial installation.

In the power plant business, the prediction of prospective noise levels is an essential part of contractual warranties. On the one hand, legal requirements (e.g. "make good clauses" or penalties of up to some hundred thousands of Euros/Dollars per day when noise limits are exceeded) must be considered, on the other hand, the noise protection costs may sum up to 6% of the total investment. Moreover, devices for noise protection may have considerable effect on the power plant's performance data (e.g. pressure drop due to silencer baffles or cooling tower efficiency due to limited fan speed). Therefore, an acoustic model needs to be accurate, efficient and must consider all requested operating conditions. Moreover a planning process may change to different plant configurations and scenarios which requires a model having a clear and flexible structure.

In principle, the same holds for other large industrial sites and installations, such as chemical plants, steel and coal industrial sites, mining or refinery areas.

3. Setting up the acoustical model

The required steps to create an acoustical model with all relevant noise sources are:

- data acquisition
- check of data (when necessary, conversion and modification of the data)
- import of data and setting up of the computer model
- check and validation of the model
- calculation of noise levels at relevant receivers
- calculation of noise grid (as required)

The efforts and the time to spend on these individual steps depends on the features offered by the software used and also - an often disregarded aspect when comparing different software - how an individual task is executed and achieved. This includes so-called "weak" aspects like user-friendliness, easy to remember control structures, comfortable import filters, and back-traceable results with protocol-features enabling to assess ray paths and their contribution to the final result.

4. Planning scenarios at power plants

The handling of planning scenarios is discussed for a fossil fired power plant (Figure 1) and a combined cycle power plant (Figure 2). For acoustical modeling the software CadnaA was used [1], offering features to arrange objects in groups in order to structure the input data (emitted sound power of sources) and of output data (receiver levels in the plant's vicinity).

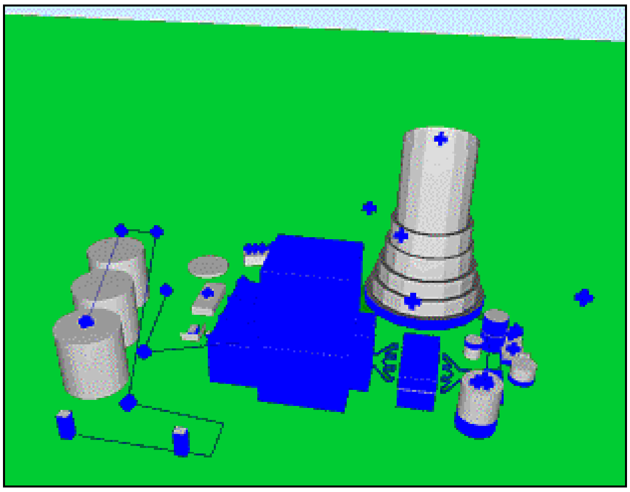


Figure 1. Model of a coal fired power plant.

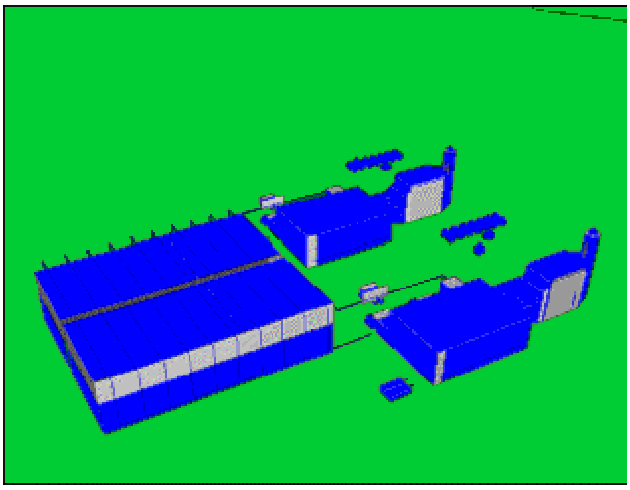


Figure 2. Model of a two unit combined cycle power plant.

The coal fired power plant (Figure 1) consists of a huge turbine building and a boiler house, and a natural ventilated wet cooling tower. The solid fuel is transported by a coal supply system with ship unloading jetty and coal bunkers. Devices to reduce environmental impact comprise an electrostatic precipitator system, waste water cleaning systems, transformers, gypsum recycling, pump houses and other facilities. Each functional group is modeled using point, line and area sources. For example, the turbine building consist of area source for walls, gates, doors and ventilation openings, line noise sources for ventilation systems and point sources for safety valves and steam discharge systems (Figure 3).

The two unit combined cycle power plant (Figure 2) consists of a heat recovery steam generator, a turbine building, transformers, a fin fan cooler, two large air cooled condensers and supporting equipment. In the software model, each functional group is modeled using point, line and area sources. For example, the air cooled condenser consist of area sources for each air intake (6 sides), area sources for each air outlet (60 fans), furthermore 60 line sources for the different parts of the steam piping system and point sources underneath representing pumps and motors (Figure 4). The model includes different operating scenarios for the air cooled condenser, each having the same above described structure.

In both cases, the model includes some hundred single noise sources for the different scenarios. Moreover, obstacles and reflective surfaces are modeled using cylinders, 3D-reflectors, buildings and barriers.

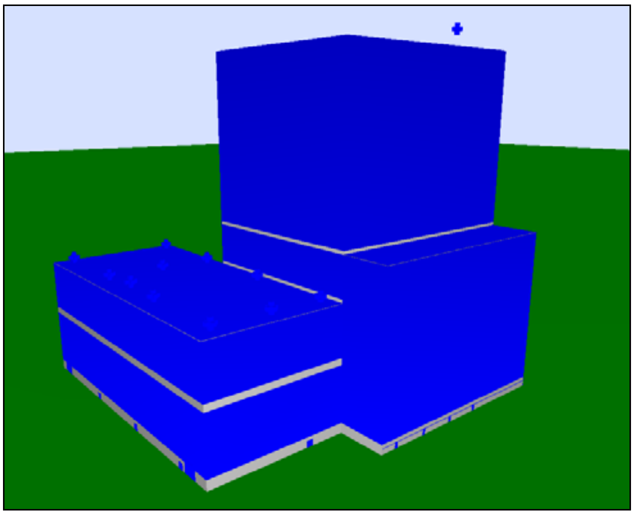


Figure 3. Model of a turbine building .

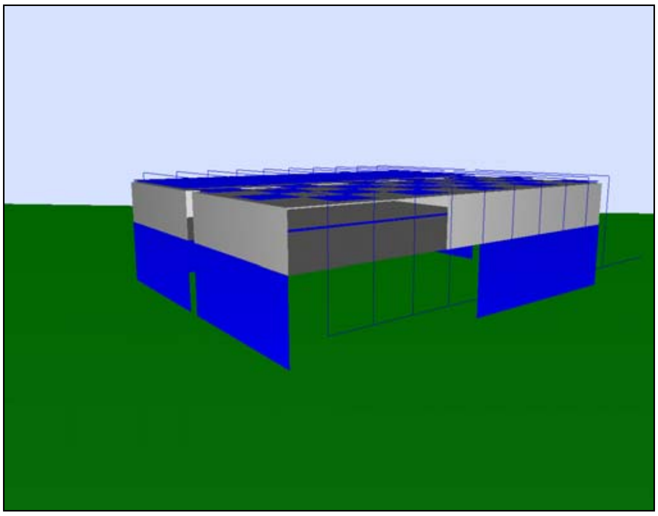


Figure 4. Model of an air-cooled condenser (for better visibility of the structure some elements were set inactive).

5. Project organization

5.1 ObjectTree

In order to achieve a flexible project organization when assessing complex noise scenarios the software applied has to offer comfortable editing and control structures to handle this task is in a time-efficient and acoustically useful way. The software CadnaA offers the so-called "ObjectTree" to sort individual noise sources into functional groups defined by the user. With regard to power plants as described above some functional groups can be seen from Figure 5. Objects sorted as, for example, sorted into group "Unit 20, subgroup Gas and Steam Turbine Building" can be seen from Figure 6. Basically, these functional groups may not just contain sources, but may also include other kinds of objects (e.g. buildings, underlying bitmaps, auxiliary polygons, text boxes). For sure, the software offers flexible and easy to handle control structures to address not just individual objects to such a group, but also groups of objects by just a single command sequence.

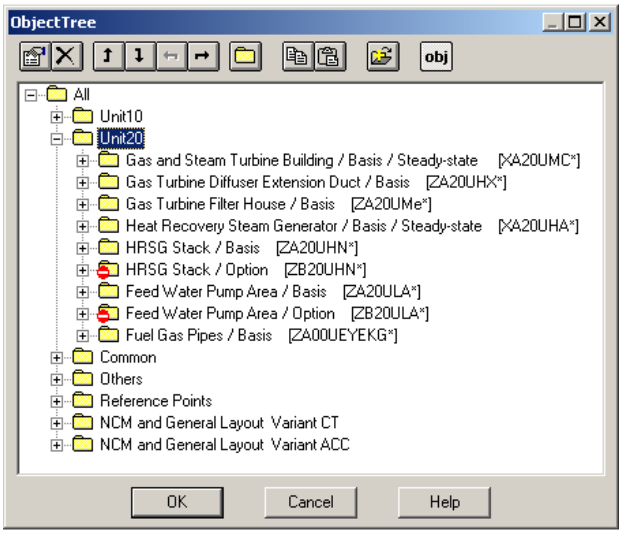


Figure 5. Functional groups defined in the ObjectTree of a power plant model (for two units).

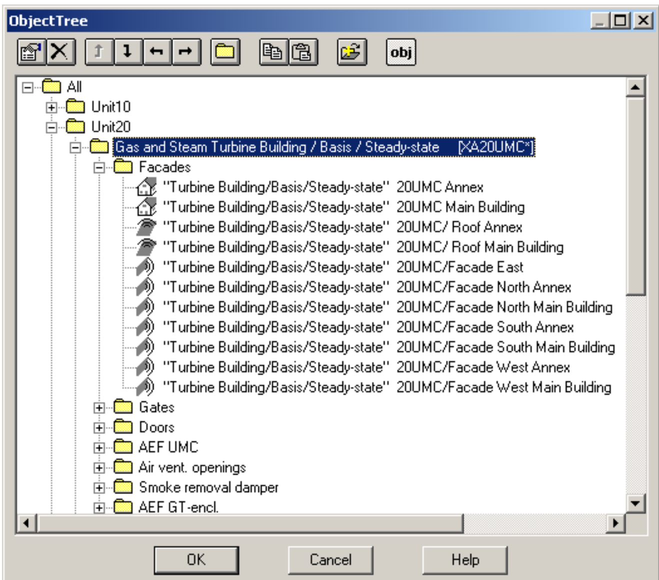
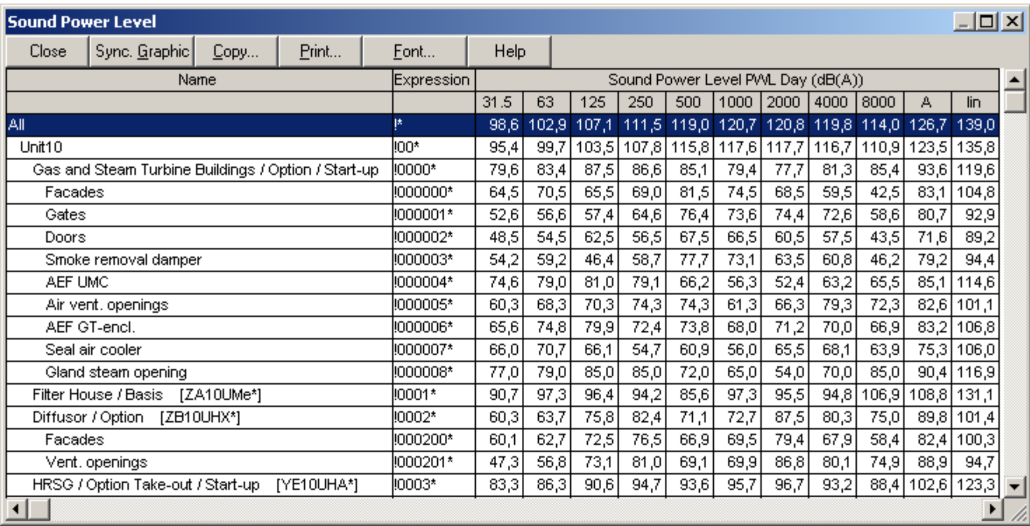


Figure 6. Sub-group "Facades" in the functional group "Unit 20, Gas and Steam Turbine Building".

Different scenarios (also called "variants") can be defined by addressing the respective sources to a specific group. Applying this variant feature to different plant operation scenarios (e.g. base load conditions, start up conditions, by-pass operation, safety valve operation) or different noise protection classes (e.g. standard design, low noise design and end of technical feasibility designs) brings a clear, but flexible structure in the model. Finally, the group table can be used to control the activity of the different functional and sub-functional groups related to active and inactive variants.

5.2 Sound power per facility unit

The emission of relevant noise sources the functional groups can be ranked based on the emitted sound power (Figure 7). For each functional group the table lists the spectral data in octave band width and of the A-weighted and linear sum levels. Alternatively, the emitted sound power of each individual sound source within each functional group can also be displayed. For some structures it may even make sense to create subgroups, e.g. if within the building group noise data emitted from facades, gates, or ventilation systems are of interest. Moreover, subgroups can also be used to split different design or construction scopes, e.g. the facades are provided by a civil contractor and the ventilation system is designed by the architect engineer. These subgroups can be used even to define and agree on noise limits by a consortium.

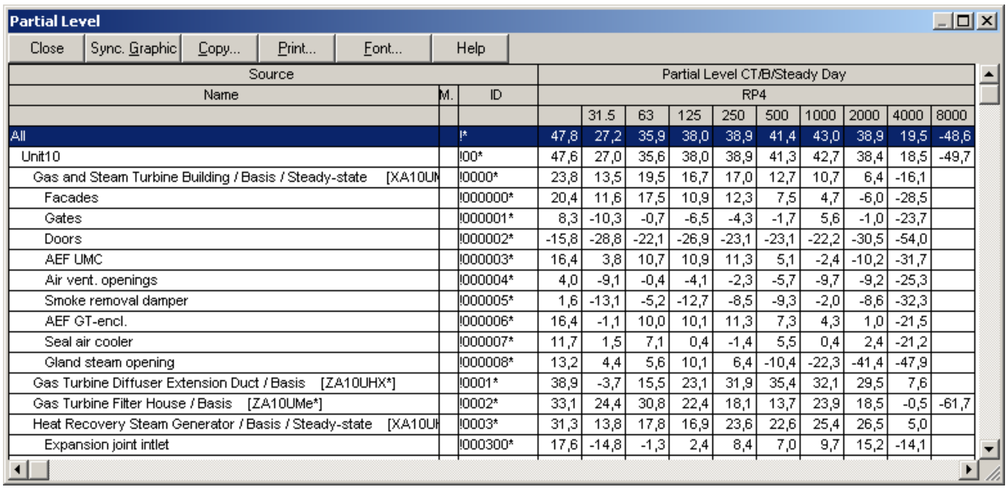


Name	Expression	Sound Power Level PWL Day (dB(A))										
		31.5	63	125	250	500	1000	2000	4000	8000	A	lin
All	!*	98,6	102,9	107,1	111,5	119,0	120,7	120,8	119,8	114,0	126,7	139,0
Unit10	!00*	95,4	99,7	103,5	107,8	115,8	117,6	117,7	116,7	110,9	123,5	135,8
Gas and Steam Turbine Buildings / Option / Start-up	!0000*	79,6	83,4	87,5	86,6	85,1	79,4	77,7	81,3	85,4	93,6	119,6
Facades	!000000*	64,5	70,5	65,5	69,0	81,5	74,5	68,5	59,5	42,5	83,1	104,8
Gates	!000001*	52,6	56,6	57,4	64,6	76,4	73,6	74,4	72,6	58,6	80,7	92,9
Doors	!000002*	48,5	54,5	62,5	56,5	67,5	66,5	60,5	57,5	43,5	71,6	89,2
Smoke removal damper	!000003*	54,2	59,2	46,4	58,7	77,7	73,1	63,5	60,8	46,2	79,2	94,4
AEF UMC	!000004*	74,6	79,0	81,0	79,1	66,2	56,3	52,4	63,2	65,5	85,1	114,6
Air vent. openings	!000005*	60,3	68,3	70,3	74,3	74,3	61,3	66,3	79,3	72,3	82,6	101,1
AEF GT-encl.	!000006*	65,6	74,8	79,9	72,4	73,8	68,0	71,2	70,0	66,9	83,2	106,8
Seal air cooler	!000007*	66,0	70,7	66,1	54,7	60,9	56,0	65,5	68,1	63,9	75,3	106,0
Gland steam opening	!000008*	77,0	79,0	85,0	85,0	72,0	65,0	54,0	70,0	85,0	90,4	116,9
Filter House / Basis [ZA10UMe*]	!0001*	90,7	97,3	96,4	94,2	85,6	97,3	95,5	94,8	106,9	108,8	131,1
Diffusor / Option [ZB10UHX*]	!0002*	60,3	63,7	75,8	82,4	71,1	72,7	87,5	80,3	75,0	89,8	101,4
Facades	!000200*	60,1	62,7	72,5	76,5	66,9	69,5	79,4	67,9	58,4	82,4	100,3
Vent. openings	!000201*	47,3	56,8	73,1	81,0	69,1	69,9	86,8	80,1	74,9	88,9	94,7
HRSG / Option Take-out / Start-up [YE10UHA*]	!0003*	83,3	86,3	90,6	94,7	93,6	95,7	96,7	93,2	88,4	102,6	123,3

Figure 7. Sound power levels of functional groups.

5.3 Calculated sound pressure level per facility unit

In order to determine the contribution of all sources within all functional groups those can be ranked based on the receiver level at all receivers as well (Figure 8). This table of partial levels may include also the spectral data, but the size of the table enlarges heavily with a number of receiver points listed. This structure becomes very effective during project execution, when the planning scope becomes reality and real data are available. For example, the civil contractor provides a test certificate for the insulating properties of the facades. The façade attenuation data can easily be implemented in the corresponding sound reduction table and the influence on of the real facades can be checked directly just by pressing the calculation button.



Source			Partial Level CT/B/Steady Day									
Name	M.	ID	RP4									
				31.5	63	125	250	500	1000	2000	4000	8000
All		!*	47,8	27,2	35,9	38,0	38,9	41,4	43,0	38,9	19,5	-48,6
Unit10		!00*	47,6	27,0	35,6	38,0	38,9	41,3	42,7	38,4	18,5	-49,7
Gas and Steam Turbine Building / Basis / Steady-state [XA10UI		!0000*	23,8	13,5	19,5	16,7	17,0	12,7	10,7	6,4	-16,1	
Facades		!000000*	20,4	11,6	17,5	10,9	12,3	7,5	4,7	-6,0	-28,5	
Gates		!000001*	8,3	-10,3	-0,7	-6,5	-4,3	-1,7	5,6	-1,0	-23,7	
Doors		!000002*	-15,8	-28,8	-22,1	-26,9	-23,1	-23,1	-22,2	-30,5	-54,0	
AEF UMC		!000003*	16,4	3,8	10,7	10,9	11,3	5,1	-2,4	-10,2	-31,7	
Air vent. openings		!000004*	4,0	-9,1	-0,4	-4,1	-2,3	-5,7	-9,7	-9,2	-25,3	
Smoke removal damper		!000005*	1,6	-13,1	-5,2	-12,7	-8,5	-9,3	-2,0	-8,6	-32,3	
AEF GT-encl.		!000006*	16,4	-1,1	10,0	10,1	11,3	7,3	4,3	1,0	-21,5	
Seal air cooler		!000007*	11,7	1,5	7,1	0,4	-1,4	5,5	0,4	2,4	-21,2	
Gland steam opening		!000008*	13,2	4,4	5,6	10,1	6,4	-10,4	-22,3	-41,4	-47,9	
Gas Turbine Diffuser Extension Duct / Basis [ZA10UHX*]		!0001*	38,9	-3,7	15,5	23,1	31,9	35,4	32,1	29,5	7,6	
Gas Turbine Filter House / Basis [ZA10UMe*]		!0002*	33,1	24,4	30,8	22,4	18,1	13,7	23,9	18,5	-0,5	-61,7
Heat Recovery Steam Generator / Basis / Steady-state [XA10UI		!0003*	31,3	13,8	17,8	16,9	23,6	22,6	25,4	26,5	5,0	
Expansion joint intlet		!000300*	17,6	-14,8	-1,3	2,4	8,4	7,0	9,7	15,2	-14,1	

Figure 8. Sound pressure levels (partials levels) of functional groups at receiver locations.

Furthermore, the identification column (column "ID") can include the coding according to the Power Plant Classification System (KKS) used for identification and classification of the equipment of power stations [2]. For reasons of simplicity this has been omitted in this example.

6. Refinery alarm system

For a refinery an alarm speaker system had to be designed assuring that a minimum level increase of 3 dB above the background level is ensured with respect to the alarm function. In this case, the sound levels produced by the refinery itself have to be regarded as background noise disturbing the alarm signal from the loudspeakers (Figure 9). The question to answer was whether for a given set-up of loudspeaker positions within the plant, and based on the emitted sound power and directivity of the loudspeaker systems a reasonable alarm level is obtained at all locations inside the plant.

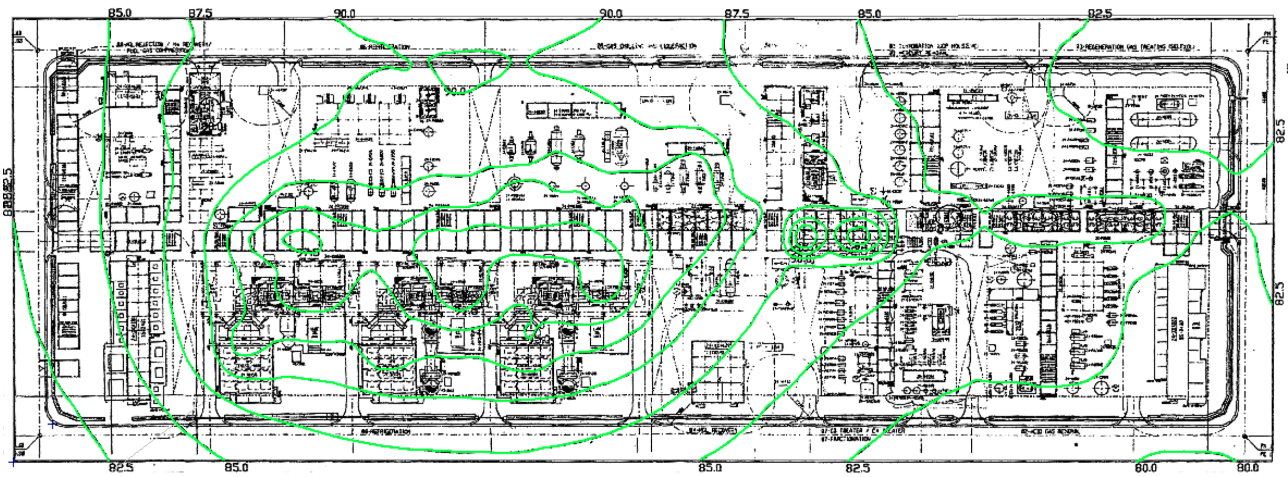


Figure 9. Sketch of a refinery with overlapping background noise contours (in green).

6.1 Sound power and directivity pattern

Input data of the loudspeaker was the sound pressure level vs. angle for octave bands 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz (Figure 10). The continuous directivity pattern was converted into directivity indices in steps of 15-degrees for input into the noise modeling software (Figure 11).

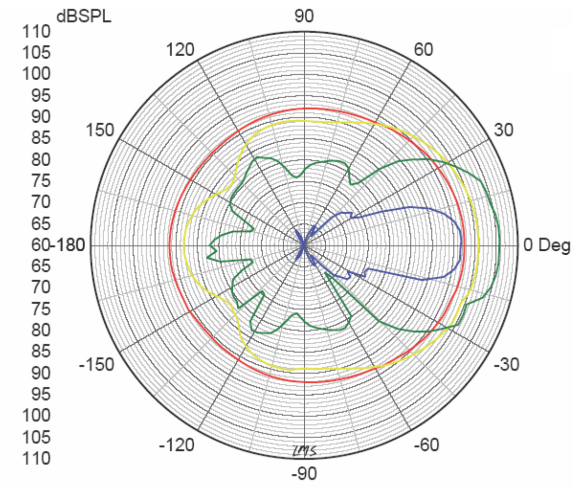
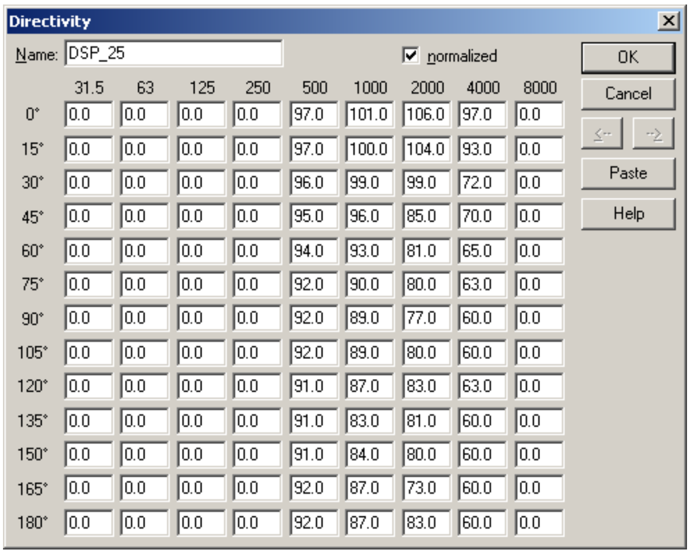


Figure 10. Directivity pattern of the loudspeaker used for an alarm system used (SPL vs. angle).

——500 Hz, —— 1000 Hz, —— 2000 Hz, —— 4000 Hz



Directivity

Name: DSP_25 ☑ normalized

	31.5	63	125	250	500	1000	2000	4000	8000
0°	0.0	0.0	0.0	0.0	97.0	101.0	106.0	97.0	0.0
15°	0.0	0.0	0.0	0.0	97.0	100.0	104.0	93.0	0.0
30°	0.0	0.0	0.0	0.0	96.0	99.0	99.0	72.0	0.0
45°	0.0	0.0	0.0	0.0	95.0	96.0	85.0	70.0	0.0
60°	0.0	0.0	0.0	0.0	94.0	93.0	81.0	65.0	0.0
75°	0.0	0.0	0.0	0.0	92.0	90.0	80.0	63.0	0.0
90°	0.0	0.0	0.0	0.0	92.0	89.0	77.0	60.0	0.0
105°	0.0	0.0	0.0	0.0	92.0	89.0	80.0	60.0	0.0
120°	0.0	0.0	0.0	0.0	91.0	87.0	83.0	63.0	0.0
135°	0.0	0.0	0.0	0.0	91.0	83.0	81.0	60.0	0.0
150°	0.0	0.0	0.0	0.0	91.0	84.0	80.0	60.0	0.0
165°	0.0	0.0	0.0	0.0	92.0	87.0	73.0	60.0	0.0
180°	0.0	0.0	0.0	0.0	92.0	87.0	83.0	60.0	0.0

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Figure 11. Directivity pattern for octaves 500, 1000, 2000, and 4000 Hz derived from the line pattern in Figure 10 (0-degrees representing forward direction).

The sound power level spectrum is estimated from this directivity pattern as well. As the sound pressure level was measured at a distance of 1 m under free-field conditions the relevant area is obtained by integrating over the area of constant sound pressure levels in sections of 7.5°-width or 15°-width respectively.

6.2 Alarm levels above background levels

The arrangement of loudspeakers is modeled from point sources receiving the PWL and directivity as evaluated from the laboratory measurement and the noise grid calculated. The final level difference is obtained by so-called "Grid Arithmetics", i.e. subtracting the background noise grid from the noise grid representing the loudspeaker's emission (Figure 12). Thus, the requirement of at least 3 dB above background noise level could be met and proven.

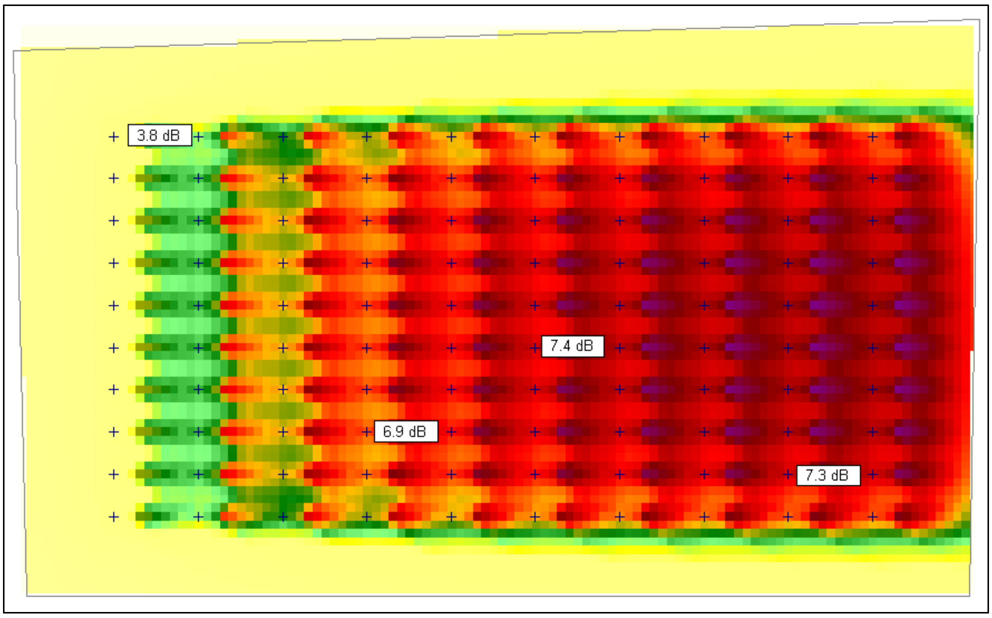

Figure 12. Level increase above background level due to an alarm system.

REFERENCES

[1] DataKustik GmbH, "CadnaA – Software for Environmental Noise", www.datakustik.com

[2] see http://www.vgb.org/en/db_kks_eng.html