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NOISE CONTROL FOR A BETTER ENVIRONMENT

Russian Experience of Power Plants Noise and Vibration Estimation and Reduction

Vasilyev Andrey V.[1]
Samara State Technical University
Molodogvardeyskaya str., 244, Samara, Russia, 443100

ABSTRACT

Power plants (compressors, pumps, internal combustion engines etc.) are using in different branches: machinery, transport, energetic production, chemical industry etc. Significant noise and vibration levels generated during power plants operation may cause not only serious problems of workers heals, but also for power plants productivity, durability, reliability, exploitation time etc.
Russian experience of power plants noise and vibration characteristic estimation is described. Russian standards, sanitary norms as well as personal author's methods are considered. Experimental results of power plants noise and vibration characteristic measurements results are discussed.
Some approaches to power plants noise and vibration reduction and results of it approbation are described. Results are showing significant effects of noise and vibration reduction.

Keywords: Power plant, Noise, Vibration
I-INCE Classification of Subject Number: 46

1. INTRODUCTION

Power plants of different kinds (compressors, automobile internal combustion engines, pumps, ventilators, heat-exchanges, stationary engines etc.) are widely used in different branches (mechanical engineering, transport, energetic, chemical industry etc.) during gas and liquids transporting in pipeline systems, in housing and communal services [6, 11, 12]. Vibration and related with it mechanical noise of power plants and joining mechanical systems (pipelines, aggregates etc.) may cause significant influence to reliability, durability, productivity and other parameters during exploitation [6, 13]. It impact may cause a number of negative sequences: power plants and pipelines parts and bodies destruction, damage of joining of pipelines and devices, the seal seals etc. Moreover, intensive noise and vibration during exploitation of power plants and mechanical noise may cause reduction of attention and increasing of number of mistakes during work. In result together with human health damage also reduction of labor safety, productivity and quality is occurs.

[1]avassi62@mail.ru; vasilyev.av@samgtu.ru

There are different kinds of compressors, and every compressor type has some peculiarities of vibration generation and diagnostics. Screw compressors are variety of rotor compressors type.

This paper is devoted to presentation of results of Russian experience of power plants noise and vibration estimation and reduction.

2. POWER PLANTS AS NOISE AND VIBRATION SOURCES

Let us describe briefly the main power plants kinds as noise and vibration sources.

1. Compressors.

Depending on the kind of compressor mounts, conditions of operation and of noise and vibration generation compressors have different acoustical characteristic. E.g., in the intake spectrum of turbo-compressors (high-speed aggregates) high frequency sound harmonic are dominating. Volume compressors are subdivided as piston, rotor and membrane types. In the intake spectrum of rotor compressors the frequency of shaft rotation and it harmonic are dominating. Due to the fact that rotation speed of rotor compressors usually is high, again we have high frequency sound domination. The most of piston and membrane type compressors are low-rotating machines, so in it spectra low frequency sound harmonic are dominating. One of the main vibration sources of compressor bodies and pipelines are low-frequency gas pressure oscillations (pulsations) spreading along pipeline main and appearing during alternating gas suction into the cylinder due to the pressure drop between cylinder recess and abutting pipeline.

2. Pumps.

Pumps are machines using for transportation of liquids and for transmission of energy to it. Pimps are subdivided to blade (centrifugal, vortex, axial, diagonal), volume (piston and rotor), pneumatic, stream. The most often used are blade pumps. Noise and vibration spectra of pumps are widely different and complicated.

3. Engines.

Engines are devices transforming some kind of energy to mechanical operation. The most often used kind of engines is heat engines, transforming heat energy to mechanical operation. Engines are subdivided to stationary and moving kinds. Moving machines are often using also in industry. Noise and vibration spectra of engines are widely different and complicated. For automobiles equipped with internal combustion engines forming of external noise, especially in low frequency range, is mainly caused by intake and exhaust noise [6, 11, 12]. Low frequency range of engine noise is significantly determined by gas dynamic pressure oscillations (pulsations) in intake and exhaust manifolds [10, 15, 17, 19]. Acoustical discomfort in automobile passenger compartment is mainly caused with cancellation of low frequency “boom” noise, main source of which is vibration transmitting from the automobile engine through the mounts to the front panel.

4. Ventilation plants.

Ventilation plants are widely used as in industry as in domestic conditions for delivering of air volumes and may be subdivided as ventilators for general purposes, fans blowing boiler rooms, smoke exhausters, mine fans etc. According to the air flow in operation wheel ventilators are subdivided as axial, radial (centrifugal), diagonal, diametrical; according to construction – one- and multistage, reverse, one- and bidirectional suction; according to displacement of driving wheel – horizontal and vertical; according to the kind of driver – with electrical engine, with air turbine, with internal combustion engine etc.; according to performance – standard, gastight, for transportation of combustible and explosive gases, corrosive gases etc.

Sources of ventilators noise are any oscillation effects arising during it operation. Ventilators noise is usually spreading by the following ways:

- Through the air intake device of air suction device (way 1);
- Through the discharge air duct device (way 2);
- Through the housing of radial fan (way 3) and discharge or air suctioning devices (ways 2 and 1).

It is possible also to point out noise radiation by open intake or exhaust manifolds of radial ventilator and by axial ventilator directly to the atmosphere. Noise of ventilation plants is often exceeding admisible levels in wide frequency range. Serious problem is impact of tonal components of ventilators noise mainly in low frequency range.

3. RUSSIAN EXPERIENCE OF POWER PLANTS NOISE AND VIBRATION ESTIMATION

Noise levels in Russia are evaluated according to hygiene requirements, stated by valid sanitary norms (Sanitary Norms 2.2.4/2.1.8.562-96, Russian State Standards, Building Norms and Rules etc.). Normative parameters for unstable noise are equivalent sound levels L_{Aecv} and maximal sound levels $L_{A\max}$, dBA. There are different noise values norms for different operational processes, but in any case noise levels must be lower than 80 dBA.

According to the requirements of Russian Building Norms and Rules building projects must include the measures for protection from noise. In part "Technological solutions" (for industrial enterprises) during choosing of technological equipment it is necessary to prefer low noise equipment. Disposition of technological equipment it is necessary to carry out taking into consideration noise reduction at workers positions in buildings and on the territories by application of rational architectural-planning solutions. In part "Building solutions" (for industrial enterprises) on the basis of acoustical calculations of expected noise at workers positions it is necessary to calculate and design building-acoustical measures for protection from noise.

In part "Architectural-building solutions" (for objects of housing-civil construction) project solutions should be stated on the basis of calculations of sound insulation of protecting buildings constructions.

In part "Engineering equipment" project solutions should be stated on the basis of calculations of vibration and sound insulation of engineering equipment.

Town planning documentation must include part "Protection from noise".

For industrial and energetic enterprises with maximal linear dimensions up to 300 metres it is necessary to take into consideration equivalent levels of sound power L_{Wecv} and maximal levels of sound power $L_{W\max}$ in 8-octave frequency bends with mean geometrical frequences 63 - 8000 Hz and factor of source directivity for the point of observation Φ (we admitting $\Phi = 1$, if factor of source directivity is not known).

Vibration levels in industry in Russia are evaluated according to hygiene requirements, stated by valid sanitary norms (Sanitary Norms 2.2.4/2.1.8.562-96). Hygienic vibration estimation parameters are vibration velocity v and it logarithm levels L_v and vibration accelerations in octave and 1/3 octave frequency bands. It is also admitted integral vibration estimation for all frequency range of vibration and estimation of vibration dose D according to the time of vibration impact. For estimation of vibration levels of technological equipment also vibration displacements and it amplitudes are using as normative parameters.

Recently technical regulations are also developing.

For stationary power plants in low frequency range according to the requirements of Russain state standards main acoustical characteristic are octave levels of sound power in octave bands with average geometric frequences 63, 125, 250 Hz and frequency-weighted sound level (dBA).

For power plants, sound power of which cannot be determined and also for power plants which are equipped only in enterprises-manufactures it is allowed to use as noise characteristic sound pressure levels in octave bands and frequency-weighted sound level (dBA) in control points. In a numper of control points (at least three) it is necessary to include working place (places) of operator.

The meanings of admitted noise characteristic of power plants and technically achieved meanings of noise characteristic are determined according to the Russian state standard GOST 12.1.003-2014.

Analysis of pipelines failures is showing that it occurs, as a rule, due to fatigue of materials of pipe, therefore as criterium of pipeline safe work it is reasonable to use the value of permissible stress in the most dangerous section. Pipelines failures under vibration load are occuring mainly under impact of longitudinal stresses (cross-section rapture), and therefore it is necessary to standardize first of all these stresses. For selection of parameter of rationing of pipelines vibration in this case it is more convenient to use vibration displacements. Admissible amplitude of vibration displacement is determined by the following equation:

$$A = \frac{k}{n^2} \sigma_a \frac{l^2}{r}, \quad \text{mm}, \tag{1}$$

where k - coefficient depending from the condition of securing the ends of the pipeline;

n - oscillations form;

σ_a - admissible amplitude of longitudinal stress;

l - span length;

r - average radius of pipeline.

During constant stresses admissible amplitude of vibration is increasing directly proportionally to ration $\frac{l^2}{r}$. The meanings of coefficient k are depending from the kind and the constructions of supports.

During the selection of points of measurement of pipelines vibration the author of paper is suggesting to include the places of connection of support flanges to the pipe because fatigue rupture of pipelines is occurring, as a rule, in pipe itself at the site of joining of the flange. In addition, it is necessary to take into consideration that pipeline vibrations are transmitting through the supports to foundation and also to attached units (cooler, the oil separator), therefore during the measurements it is necessary to include all above mentioned objects.

In order to receive the most full presentation about the character of vibration load as from the point of view of personnel safety as for provision of non-destruction of equipment in the process of measurements it is reasonable to register all three kinematic vibration parameters: vibration displacement, vibration velocity, vibration acceleration.

For low rotated piston compressors it is necessary to do the measurements of vibration characteristic in 1/3 octave range, beginning from 2 Hz octave.

Measurements of noise and vibration of different kinds of power plants were done.

For low-rotated piston compressors high low frequency vibration levels were observed. For example, for 4-stage compressor having productivity Q = 6500 m^3/h, installed in KuibyshevAzot public joint stock company, Togliatti, Russia (figures 1 and 2 and table 1) analysis of measurements results is showing that in low frequency range high oscillations on the main frequency f = 12,5 Hz are occurs. In total the most intensive is vibration behind the second stage of the compressor.

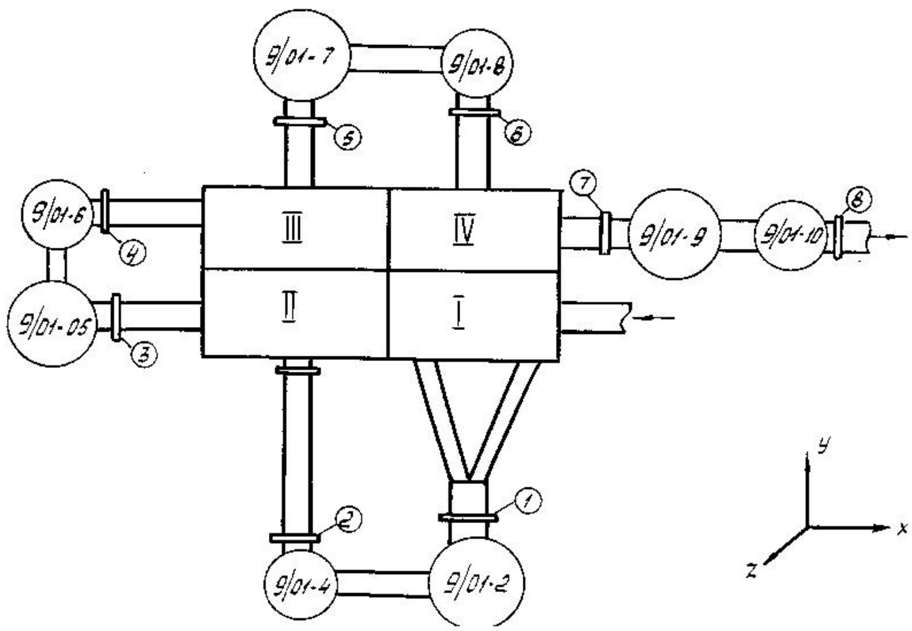

Figure 1. Displacement of points of measurement of vibration of 4-stage piston compressor

Table 1. General levels of vibration acceleration of pipelines of compressor N 9/01 KuibyshevAzot public joint stock company under 100% load (dB)

№ of points	x	y	z
1.	89	90	92
2.	79	90	82
3.	94	89	90
4.	90	88	88
5.	89	89	87
6.	89	87	82
7.	86	97	88
8.	78	85	76

Figure 2. 1/3 octave spectrum of vibration displacement of compressor N 9/01 KuibyshevAzot public joint stock company in point 3, direction y (during operation load and without load)

Researches of vibration characteristic of pumps of "Grundfos" company which are installed in shop of industrial enterprise in Russia. Measurements of vibration levels were carried out on pump mounting beams, on supports, on foundation, and also in characteristic points of pipelines in three mutually perpendicular directions. Single-number and spectral values of vibration acceleration levels were measured. In tables 2-4 and on figures 3-5 example of presentation of measured values of vibration accelerations in octave frequency bands and octave spectrum for different directions of measurements.

Table 2. Levels of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis x)

Axis X								
	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
10 s max	80.64	60.77	61.71	65.97	78.21	97.45	128.32	105.55
Lecv	65.16	59.62	60.68	65.09	77.53	97.07	126.40	103.73

Table 3. Levels of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis y)

Axis Y								
	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
10 s max	80.16	57.90	57.56	59.99	69.38	82.79	109.05	98.75
Lecv	63.45	56.73	56.37	59.32	67.90	82.38	108.04	97.98

Table 4. Levels of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis z)

Axis Z								
	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
10 s max	79.18	59.09	59.91	64.70	76.34	91.67	121.52	105.70
Lecv	79.18	59.09	59.91	64.70	76.34	91.67	121.52	105.70

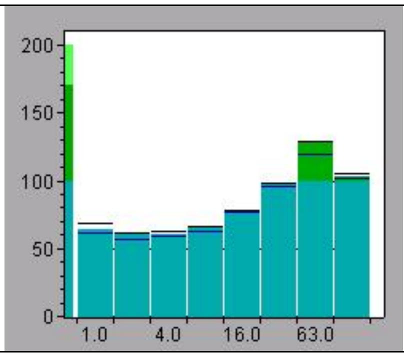

Figure 3. Spectrum of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis x)

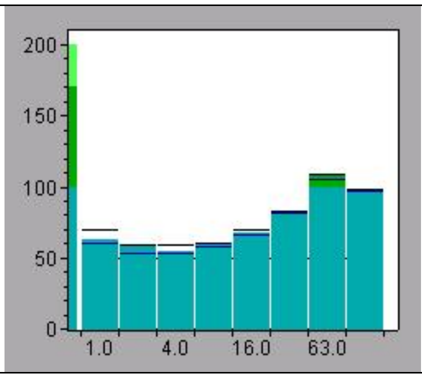

Figure 4. Spectrum of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis y)

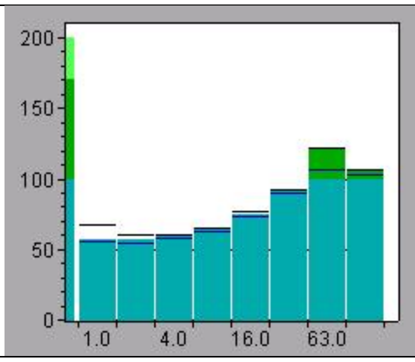

Figure 5. Spectrum of vibration acceleration in octave bands during operation of pumps of "Grundfos" company (point 1, axis z)

Analysis of results of measurements is allowing to conclude that there is significant exceeding of existing norms both for pumps and technological equipment and personnel impact. Maximal levels of vibration acceleration for all coordinate directions were measured in points of measurements on pump mounting beams and on supports and were fixed on frequencies 50 Hz and 100 Hz for pump mounting beams and 50 Hz for supports. In total the most significant values of vibration were observed for direction of measurements z.

The spectra of noise or vibration may be very differ for different kind of transport or transport systems. E.g., the peculiarity of intake or exhaust noise of automobile internal combustion engine is the presence of one or several maximal tonal harmonics of engine crankshaft rotation frequency [10, 12, 17], see, e.g. figure 6. So, in order to reduce significantly external engine noise it is enough often to reduce noise only for one or two harmonics.

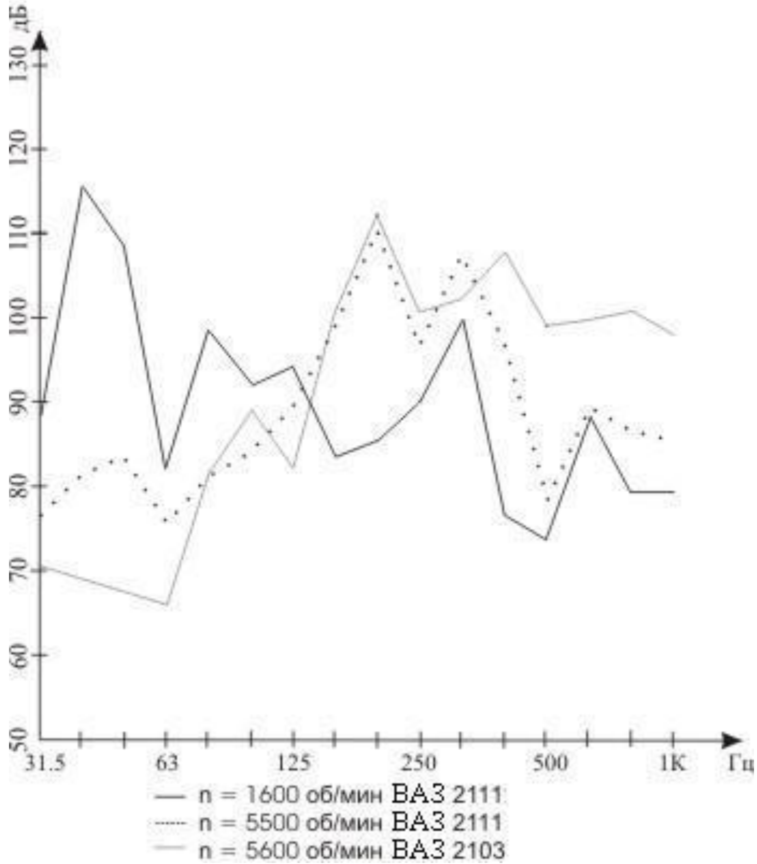

Figure 6. 1/3-octave spectrum of SPL of VAZ engines, measured in the distance of 0,06 m (VAZ 2111) and 0,10 m (VAZ 2103) from the air-suctioning pipe open end

4. APPROACHES TO POWER PLANTS NOISE AND VIBRATION REDUCTION

Classification of methods of noise and vibration reduction of power plants may be based on the different principles. Widely the means of protection from noise and vibration it is possible to divide on means of collective and individual protection. Firstly it is necessary to use collective methods and means which may be classified as following:

1. Architect-planning methods:
- rational vibration and acoustical solutions of planning of industrial buildings and of general plans of objects;
- rational displacement of technological equipment;
- rational displacement of working places;
- creation of noise and vibration protective zones.
2. Vibration and acoustical means:
- means of noise and vibration isolation (including vibration isolating mounts);
- means of noise and vibration damping;
- pulsation damping etc.
3. Organization-technical means:
- application of technological processes with low level of vibration;
- equipage of vibration dangerous power plants by means of distant and automatic control;
- perfection of technology of energetic plants repair and service;
- using of power plants with low level of noise and vibration, variation of constructive parameters of power plants;
- using of rational regimes of labor and rest.

Energetic approach is taking into consideration costs of additional energy for noise and vibration reduction. According to energetic criterion it is possible to pint out the following groups of methods of power plants noise and vibration reduction: passive, active and hybrid (active-passive) methods.

Passive methods are assuming using of only passive elements which are not adding energy into the system. They may only absorb energy or change source impedance to not create undesirable energy. Therefore during using of passive methods stable systems are not converted in unstable. It is possible to point out many examples of using of passive methods (e.g. using of vibration dampers, resonators etc.). Using of passive methods is developed in details. Presently there are a number of efficient and not expensive passive solutions for reduction of noise and vibration.

A number of passive technical solutions for noise and vibration reduction of power plants was developed by author [1-5, 7, 9, 13, 14, 18 etc.]. E.g., constructions of vibration dampers have been developed using hydraulic resistance occurring e.g. during punching of working fluid through the small calibrated holes. Such constructions allow to change the coefficients of resistance in wide range. Using of silicon oil as working fluid provides stability of the coefficients in wide temperature diapason of exploitation.

Adaptive-passive methods are assuming using of passive elements which may be selected in a way to optimize it characteristics for the certain range of conditions. The most efficient adaptive-passive decisions are developed for narrow band applications. Pulsations dampers with deformable walls may be considered as adaptive-passive constructions (e.g. oscillations damper in intake manifold of internal combustion engine, bottom and cap of which are made from elastically deformable material). Adaptive-passive constructions may be as narrow band as wide band.

Adaptive pressure oscillations damper of suction system of piston machine developed by author is consists of capacity of variable volume supplied with rigid walls on one of which at least one imputing manifold is mounted connecting cavity of capacity with atmosphere, and on the other – at least one outlet branch connecting cavity of capacity with cylinder of piston machine [15].

Active methods are assuming using of additional energy and bringing it into the system [8]. For operation of systems of active compensation source of energy and electronic unit of transforming of characteristic of active source are required. In modern practice of reduction of noise and vibration it is assumed that using of active compensation is reasonable only when passive methods are insufficiently efficient. As example of active compensation of vibration may be used active vibration isolating mount for reduction of vibration during operation of automobile internal combustion engine.

Hybrid active-passive systems are the most promising kind of devices of vibration reduction. In practice systems of active vibration control are used in its pure form rather seldom. The most of so called active systems are combination of active and passive systems, or active-passive hybrid. For example, active vibration isolating mounts are usually consists of active and passive elements. Often so called active mount is to the optimum of passive system with added active system. In Institute of building physics of Fraunhofer Gesellschaft (Stuttgart, Germany) under supervision of prof. Ph. Leistner a number of hybrid ventilation noise dampers were developed and implemented.

A separate and well-investigated field is active vibration control (AVC) of transport. For cars AVC may be used for vibrations reduction of engine body, pan, steering wheel, seats etc., see e.g. developments of "Lotus Engineering", "Carl Freudenberg" etc. There are also developments on active vibration reduction spaceships by using of piezoelectric polymer materials.

A number of compact active noise control units were developed and approbated by the author [10-17, 19, 20]. For the first unit receiver of sound pressure is installed directly at the field of air oscillations excitation (in the zone of low interferences of air-cleaner chamber volume), and through the power amplifier and the element of adaptive control is connected with the sources of emission of compensating oscillations. For another unit construction attenuating signal is delivered into the air-cleaner intake manifold open end area through the special pipe, frequency characteristics of which repeats the frequency characteristics of intermediate intake collector manifold.

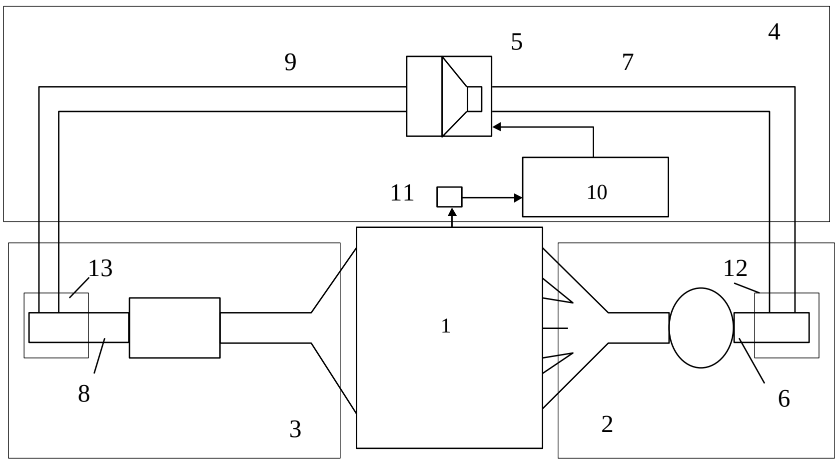

Figure 7. Combined ICE intake & exhaust noise active muffler (from Vassiliev, Mokrinsky [19]).

For reduction of low frequency vibration of pipelines of power plants also a number of other measures was developed and implemented, including the following measures: installing of different types of pipelines fastening, supports gain of pressure pipeline; reduction of pipelines turns; installing of throttle orifices in flange connections of pipelines etc.

For reduction of "Grundfos" pumps vibration the following recommendations were developed:
1. To strengthen pipelines supports and pumps mounts:
- To firmly secure by the clamps pipeline coming from the pump;
- To strengthen support of the pipeline, not attached to the main beams;
- Rigidly link pipelines supports with the bottom of the tank (to put spacers or tightening mechanism).
2. To calculate the strength of the bottom of the tank taking to account pump mass, it productivity and pump head, it is necessary to strengthen the bottom of the tank by installing of metal constructions, allowing to increase the rigidity of system.
3. To install additional supports directly под насосами – vibration sources and additional concrete supports in points with maximal vibration levels.
4. To change pump construction by увеличения of radial clearance δ between blades of working wheel and blades of the diverting device.
5. To improve anti-cavitation properties of pumps etc.

Implementation of recommendations was allowed to reduce pumps vibration level up to normative requirements.

4. CONCLUSIONS

Different kinds of power plants as noise and vibration sources were considered: compressors, pumps, engines, ventilators.

Russian experience of power plants noise and vibration characteristic estimation is described. Russian standards, sanitary norms as well as personal author's methods are considered. Analysis of pipelines failures is showing that it occurs, as a rule, due to fatigue of materials of pipe, therefore as criterium of pipeline safe work it is reasonable to use the value of permissible stress in the most dangerous section.

Experimental results of power plants noise and vibration characteristic measurements results are discussed.

Some approaches to power plants noise and vibration reduction and results of it approbation are described. Energetic approach to power plants noise and vibration reduction was considered. In total, efficient reduction of power plants noise and vibration may be achieved by complex using of different methods: Architect-planning methods; vibration and acoustical means; organization-technical means etc.

5. ACKNOWLEDGEMENTS

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