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SOUND INTENSITY MEASUREMENT USING A 6D ROBOT

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1. INTRODUCTION

This paper deals with the development of an acoustical test bench, intended for the study of industrial noise sources.

The adequate treatment of the noise abatement problems in power plants requires, among other elements, a precise knowledge of the acoustical characteristics of those industrial noise sources (acoustic power spectrum, directivity pattern)
The development of an acoustical test bench, intended for the experimental characterisation of sources, may be a way to acquire this necessary knowledge.
A modern design of such a test bench naturally leads to important technical choices :
1) the choice to perform the measurements through a robotized system.
2) the choice of intensity techniques for the acoustic measurements.

The automatisation of the measurements leads, in the principle, to two main advantages, which are : perfect reproducibility of the measurement locations, limitation of the inconvenience of repetitive work for the measurement operators.
The use of intensity techniques also leads, in the principle, to a number of significant advantages, compared to more conventional measurement techniques, i. e. pressure-based methods : independence to environmental conditions (existence of perturbing sources, independence to reflection conditions in the measurement room).

However difficult problems are encountered in the development, and even in the later utilisation, of an intensity-based measurement system. It is thus interesting to try to establish, after some time of utilisation, the technical and economical assessment of such a system.

2. GENERAL DESCRIPTION OF THE MEASUREMENT BENCH

The measurement facility is based on a laboratory room in which a robot has been installed. The test room itself is of average size ; its walls are fitted with an inexpensive and summary acoustical material.

The bench equipment is composed of an intensity probe, a robot which manipulates the probe, and a host micro-computer equipped with a digital signal processing (DSP) board. The computer alternately controls the positioning of the robot and the processing of the acoustic signal.

The robot has six degrees of freedom : three translations and three rotations. Most of electrical noise sources are of piecewise parallelepipedic form. The intensity probe is set at the end of the robot's manipulating arm. The probe's operating volume is 2.0 meters in length, 2.0 meters in width and 1.9 meters high. The probe moves along a trajectory situated on the measuring surface which is automatically defined by the program for a given noise source [1]. *Figure 1 gives a general view of the facility. Figure 2 allows to see the mobile arm of the robot and the probe near to a tested device. Figure 3 shows the operator's working place.*

The choice of intensity techniques for the bench was, at least partly, due to the fact that the application of these techniques is expanding rapidly for acoustic power measurements. This current trend of expansion can be attributed to a number of standards recently developed in this field. The most important of these is the ISO 9614 which allows uniformity of the accuracy obtained with this method. (The standard deals with the discrete point version of the method.)

The intensity measurement is performed by a DSP board installed in the host computer. The control of the robot, signal acquisition, standardised calculations and data storage are closely linked, allowing an increased manipulation speed. The robot's precision allows for an extremely dense grid definition, down to a few centimetres, which is impossible in manual measurement.

The facility is thus suited for both acoustic intensity field analysis and acoustic power measurements.

3. SOFTWARE DESCRIPTION

3.1. Presentation

The software consists of two main parts : acoustical measurement processing and robot control.

The acoustical part was designed to measure acoustic power according to the NF-31100 standard (French equivalent of ISO 9614) using a point-by-point technique.

Establishing a link between the robot and an existing computer-based intensity measurement program appeared to be the best solution. Both elements, the intensity program, as well as the robot link, are described below.

The program may run on a standard PC computer. All measurement operations are performed here by a special DSP processor, the host computer also has a high level processor (386/387 with a 200 Mb disk) and a rapid display.

3.2. Acoustic functions

The acoustic functions of the software are close to those of a standard PC-based system, described in several recent papers [2], [3]. The principle of this software is to combine the

measurement of sound intensity with all the necessary calculations defined in sound power measurement standards such as ISO 9614. From the standard it appears clearly that an efficient way to process the measurements is to handle data from the analyser by means of a computer. In the system used here the analyser is itself a computer. On the one hand it controls measurement using an implemented DSP board, and on the other hand it carries out calculations, plots spectra, prints tables and maps, stores data, etc.
Figures 4, 5, 6, and 7 present some examples of diagrams on which measured data can be displayed.
The software had to take into account certain geometrical restrictions concerning the robot's trajectories.

3.2.1. Intensity measurement

The intensity measurement is carried out primarily by the DSP board. The acquired data are transformed into numbers and all further processing is performed digitally. The signal originates from a conventional two-microphone probe. The phase correction technique is applied, thus allowing the pressure-residual intensity index to reach 20 dB at 100 Hz for a microphone spacing of 12 mm. Real-time processing enables the user to view the measurement process.

3.2.2. ISO 9614

All ISO 9614 features are implemented. The program defines a meshing surface according to the source dimensions entered by the operator. This surface definition may be stored on the disk to be used for future measurements. This allows an identical measuring surface to be applied for a wide range of sources.

The standard time variability test is performed automatically at a representative point and the F1 field indicator is then calculated. A preliminary calibration check is also performed using probe inversion.

Intensity and pressure levels are measured for all relevant frequency bands, typically from 80 Hz to 6.3 kHz third-octave bands. The measurement is done at all points of the surface or over a chosen subset of points, in a specified order. For example, when transformer noise was measured, the surface was not entirely "covered" : the upper square was not taken into account. The standard field indicators (F2, F3 and F4) are calculated after each point.

The measurement is usually fully automatic : after each measurement point, the spectra are stored, the probe moves to the next point and the next measurement is performed. The procedure may be suspended at any given point. All the spectral data may be examined at this time (the current point, the previous points, the partial sound power and all field indicators). The two standard criteria are checked : dynamic capability is compared to the F2 indicator and the measuring surface is compared to the spatial variance of the energy flow. This may lead to a repetition of the measurement at all points or at chosen points or, in the extreme case, to a redefinition of the surface. A thorough check of the standard diagram may be carried out at any moment. If the standard's conditions for a desired precision class have not been fulfilled, the program displays the list of actions to be taken to improve the result.

3.3. Robot control

To ensure the safety of robot's functioning, all its moving parts (including the probe) must be kept within the space limited externally by the robot's maximum displacement and internally by the measuring surface. Flying over the noise source has also been forbidden, except when explicitly requested by the user. This was due to the danger of an electric interaction between the probe and high-voltage equipment submitted to testing.

Within the above conditions the probe is allowed to move between any two points of the surface. The technique applied is based on four refuge points placed in four upper corners of robot's maximum space. The path between two points placed on two opposite sides of the surface always passes via two refuges. A single refuge is always used between two points on two adjoining surfaces. In certain combinations of points a refuge must be used even between two points on the same plane. This is due to the fact that the probe is fixed at the extreme end of a 60 cm-long horizontal arm turning around the vertical axis. This arm must change its orientation by 180 degrees whenever the probe crosses the vertical axis of symmetry of each lateral surface. An unrestricted rotation is rarely possible on robots, and in fact is not necessary. To reach the opposite direction, the arm must turn by 180 degrees to the left or to the right, depending on the relative position of the idle angle. The problem is that one (or both) of these rotations may conflict with the free space limits. The probe would then have to be sent to the nearest refuge, turn there, and then go to the programmed point.

In all lateral movements the horizontal arm is parallel to the displacement to ensure the lowest possible surface swept by the volume of the robot. In this way, the threat of possible overhead movement is avoided.

One important problem had to be solved concerning the "home" position. This is a default position where the robot is sent by its own hardware when it is turned on. This "home" position falls inside the measuring surface in most cases. In other words, the probe is placed in a position which is forbidden in normal measurement conditions, and which can be dangerous. The program sends the probe to the closest refuge after the power-on "home" command, but the execution of this command can also be dangerous for particular equipment. The presence of an experienced operator is required in this case. The situation can become even more dangerous if the robot is reset from an arbitrary point, on the opposite side of the source, for example. For security reasons, the presence of an experienced operator is again recommended.

4. UTILISATION EXPERIENCE

4.1. general

In terms of utilisation purposes, this measurement robot can be considered as suitable for a wide scope of applications :

- pure industrial production needs, such as acoustic power measurement of noise sources.
- utilisation as a help to scientific work i.e. providing experimental support to

calculation programs or methods. This can be the case for sound radiation, or sound source location from intensity field measurement methods. In such cases, it is necessary to go much further than a simple acoustic power measurement i.e. to determine the directivity pattern of the device tested.

- an intermediate case is represented by comparison studies between a set of sources, or parametric studies for a unique source placed in different operating conditions. In this last case, the use of an automated system should be especially rewarding.

In practical, the system has been used till now mainly for studies entering in this third category. The devices studied have been mainly of two types :

- electrical transformers, in the range of 400 to 630 kVA
- air conditioning systems, of small or intermediate power range.

The case of electrical transformers is particular. The sound radiation spectrum of this type of devices (for electrical powers under 1000 kVA) is composed of pure frequencies in the range 100 Hz - 1000 Hz [4]. The case of air conditioning system is different, the noise spectrum includes at the same time pure frequencies (rotating components) and wide band noise (from fans, fluid flow inside heat exchangers, etc.). Noise of both types of devices is stationary, but highly dependent on their operating conditions.

It has been confirmed by the utilisation that intensity measurements are especially difficult for sources with a pure frequency noise. This has been especially visible not for the overall acoustic power measurements, which are always achieved with a good accuracy (.5 dB), but for the determination of the directivity patterns. This is especially a drawback for all studies aimed at the improvement of the acoustical design of the electrical devices under test.

4.2. additional equipment

The equipment of the facility had to be complemented on several aspects, some of which are quite foreign to acoustics :

- the operation safety of the facility had to be carefully organised, some of the noise sources handled may be intrinsically dangerous : electrical transformers generate high voltages, etc.
- for the significance of the measurements, devices have to operate under normal (and controlled) conditions. This implies, for instance, that for the test of air-conditioners, the thermal energy retrieved or provided by the device should be permanently compensated by an other conditioning system, working conversely. This compensating system must obviously be much less noisy that the equipment under test, which has not been so easy to obtain.

4.3. Measurement difficulties

The difficulties encountered within the utilisation of the measurement system have been of several kinds, some of which had to be clearly awaited, some others much less :

1) the stationarity of perturbing sources : the facility is located in a laboratory building, where various research and other activities are under course. These activities generate all sorts of noises such as slamming doors, lawn-movers outside, etc. The facility had to be modified after some time to take this into account, by improving the acoustical

isolation of the measurement room.

2) the influence of environmental conditions had to be considered. The acoustic power of a given source itself is theoretically dependant from the environment (i.e. equal to 0 in a totally reflecting environment) but this may be neglected in almost all practically encountered situations. The determination of this acoustic power from intensity values under stationarity conditions should also not depend from the environment. However, it was observed at the bench, in the case of electrical transformers, that on a single frequency the directivity pattern was hardly reproducible.

This difficulty has been especially analysed. Noise levels maps in the measurement room have been realised, along with numerical calculations. Both showed that due to the poor absorption properties of the wall coatings in the low frequencies domain, stationary waves took place in the room. These stationary wave fields are very sensitive to small changes in boundary conditions, or changes in the vibration pattern of the source. These changes themselves may result from slight modifications in the source supply voltage, temperature, etc.). It has since been difficult to make accurate directivity analyses for transformers.

4.4. utilisation assessment

The utilisation of the test bench has let some difficulties appear, which had not all been anticipated. Most of them had been analysed and solved. Some improvements to the installation remain to be done, for an optimal efficiency of the facility. However, it should be observed that this approach of acoustical measurements, due to the corresponding costs and development delays, was most useful in the framework of research activities.

A number of specific technical programs, concerning air-conditioning systems and electrical transformers, have been successfully completed, thanks to the availability of thé system.

5. CONCLUSION

The constitution of an acoustical measurement facility, based on the use of intensity techniques has been described. The experience of utilisation has lead to observe that some of the awaited advantages of this type of system had been obtained. Some new problems have also been observed. The utilisation assessment shows that one has to consider very carefully the global prospects of utilisation, before to decide the implementation of such a facility.

6. REFERENCES

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[3] Pépin H., Rozwadowski A. *"Mesure de la puissance acoustique par intensimétrie selon la norme NFS 31 100"*, 1er Congrès Français d'Acoustique, Lyon (France) 04/1990

[4] Fanton J.P., Adobes A. *"Simulations numériques de la mesure de la puissance acoustique de transformateurs électriques"*, 1er Congrès Français d'Acoustique, Lyon (France) 04/1990

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Figure 1 : general view of the facility : robot and tested device

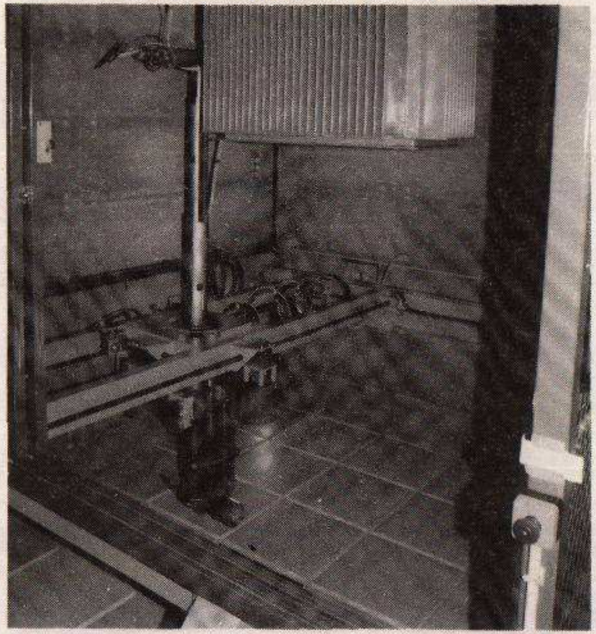

Figure 2 : mobile arm of the robot

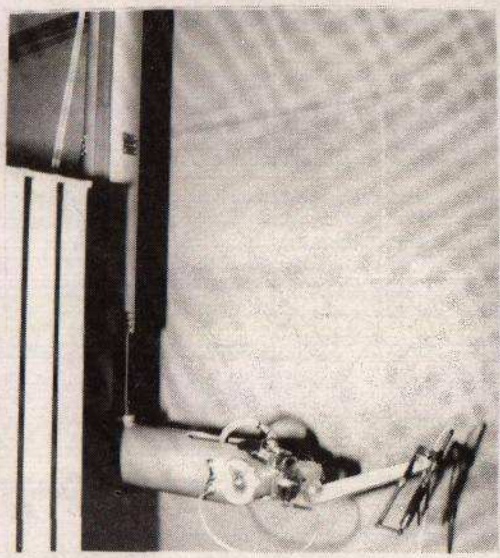

Figure 3 : operator's working place

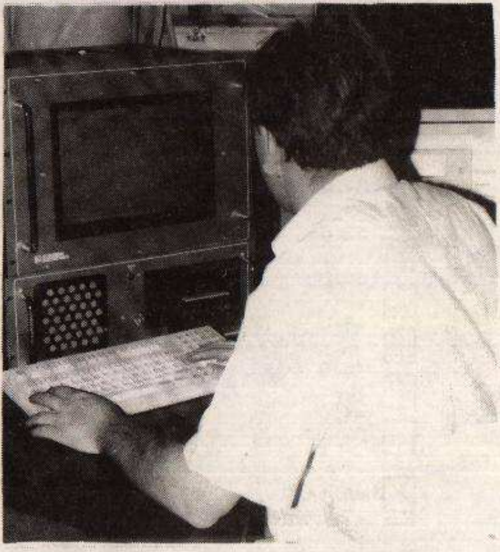

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Figure : developed surface of a tested device : intensity isovalues

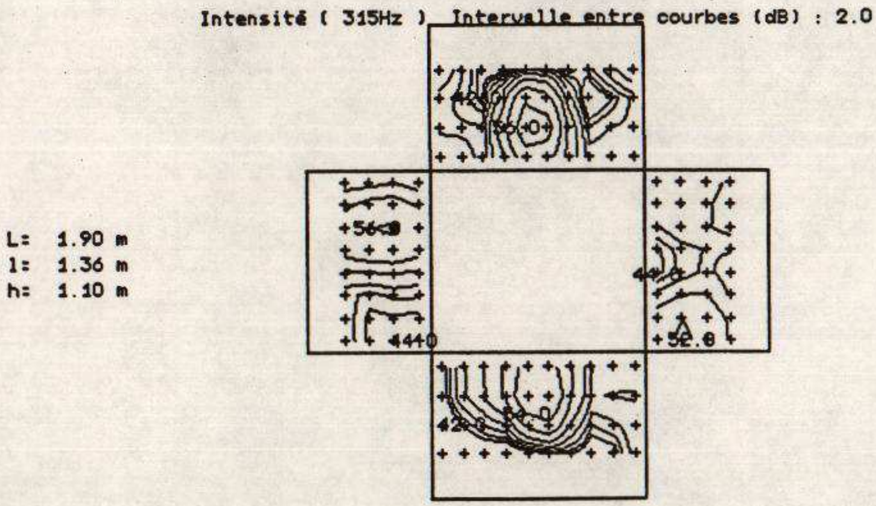

Figure : developed surface of a tested device : local intensities

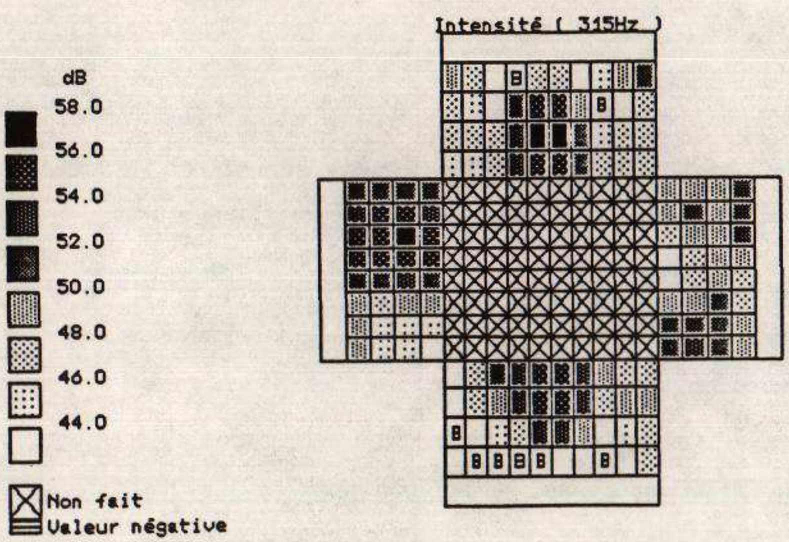

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Figure : directivity pattern

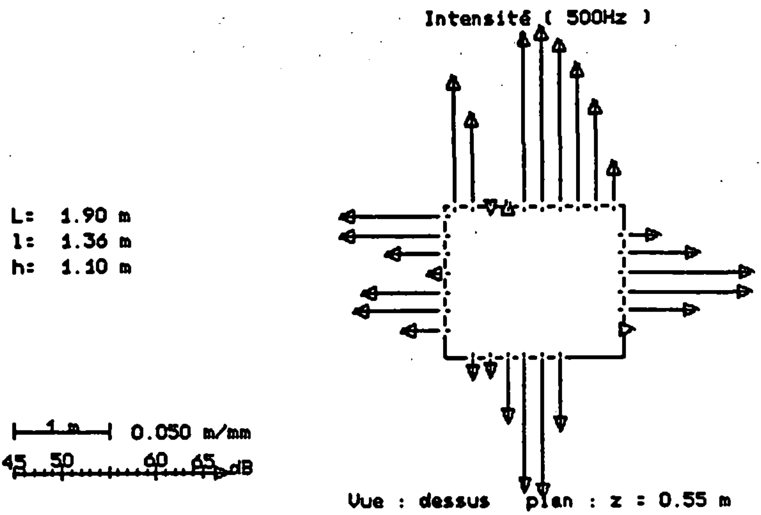

Figure : sample of sound spectra