1990

A New Experimental Method for the Identification of the Transmission Paths

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A NEW EXPERIMENTAL METHOD FOR THE IDENTIFICATION OF THE TRANSMISSION PATHS.

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1 ABSTRACT

This manuscript deals with a new experimental approach for investigating the various transmission paths.

In reciprocating compressors the major excitation force can be considered along the piston axis and the vibrations generated are tranferred to the shell via the transmission paths and then radiated in the surrounding.

Usually the estimation of each path is made by measuring how much the single paths transfer from inside to outside the shell.

Practical reasons make this procedure difficult and consequently a new proceeding has been developed.

This method , called INDIRECT METHOD, is the subject of these papers

To complete the description, detailed information about the practical carrying out of the tests is included.

2 INTRODUCTION

The need for less and less noisy compressors has required a continuous research about the potential causes of noise and the ways for cutting it down .

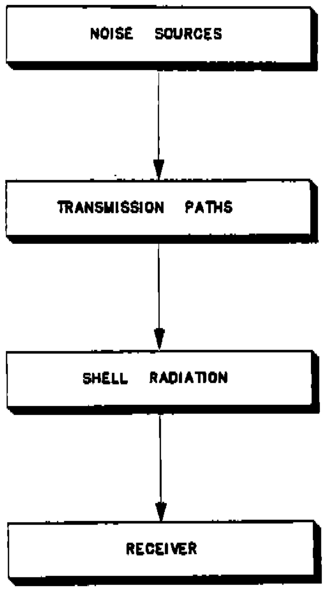
A first analisys and a very convenient way to illustrate how the compressor noise is generated and transmitted to the external surrounding is shown in fig.1.

The diagram is extremely simplified but it emphasizes the importance of the three factors, noise sources, transmission paths and shell radiation.

Noise sources consist in all mechanisms concerning with the compression cycle.Compressor components are excited by the pressure change in the cylinder and could be brought in resonance.Additional noise sources could be the valve impact against seats and stops, the electrical motor and the gas pulsation in the discharge and suction lines.

The transmission paths represent the connection between the internal structure and the shell.

These connections are mechanical (support springs and discharge pipe) and not, like for instance the lubricant and gas paths.



Finally, the acoustic energy reaches the shell which radiates the sound outwards and partially again to the compressor structure via the transmission paths.

It appears clear from this general introduction, that each of this three factors is extremely important and must be subject of a serious investigation.Aim of this paper is to illustrate how the transmission path analisys is possible.

3 TRANSMISSION PATH ANALISYS WITH A CONVENTIONAL MEASURING METHOD

.Generally the transmission path analisys is made by measuring the contribution of the single paths.

A complete and not running compressor is taken and only one of the transmission lines is kept (for instance the support springs without oil,gas and discharge pipe).Then the compressor crankase is excited by a random force excitor.

As the main excitation in the compressor is the gas force in the cylinder, the force excitor is connected to the crankase along the piston axis (for example acting on the cylinder head).

The vibrations are transferred to the shell via the only existing connection and the noise radiated in the external surrounding will represent the sound power due to the selected transmission path.The behaviour of the structure can be described with a transfer function H that relates the excitation force to the radiated sound power.This relationship can be expressed as follows.

The excitation force F produces the vibration of the compressor housing.

This force is transmitted to the shell via the selected transmission path and the housing area around this connection starts vibrating with a velocity V1.

The relation between cause (F) and effect (V1) is defined by a transfer function Z called mechanical impedance :

$$F = Z * V1 \qquad (3.1)$$

Naturally, the vibrations propagate over the whole structure and the housing begins to vibrate with a velocity V2.The relationship between V1 and V2 is linear and it is controlled by the transfer function of the shell (H1) :

$$V2 = H1 * V1 \qquad (3.2)$$

The radiated sound power (W) can be written as :

$$W = R * V1 \hat{} 2 \qquad (3.3)$$

where R is the mechanical radiation resistance of the structure.

Finally the relationship between excitation force F and radiated power W is determined by the combination of equations (3.1),(3.2)and (3.3) :

$$\begin{aligned} W &= R * V1 \hat{} 2 = R * (H1 * V1) \hat{} 2 = \\ &= R * (H1 * F / Z) \hat{} 2 = \\ &= H * F \hat{} 2 \end{aligned} \qquad (3.4)$$

Thus the relationship between force and sound power is controlled by the function H , taking into account the superimposition of a few effects (transmission of vibrations to the housing, propagation over it and radiation in the surrounding).

The measure of this function is very difficult experimentally because of the impossibility to have available so small and powerful excitors to be fixed inside the shell.

Hence the application of the INDIRECT METHOD.

4 INDIRECT METHOD

The INDIRECT METHOD is based on the reciprocity principle formulated by J.W.RAYLEIGH about one century ago.

The application of this principle to acoustical experiments means that the transmission of sound is measured in the reciprocal direction, i.e. a sound source is placed at the original receiving position and the response of the system is measured at the original source position.

The use of this method for determining the transfer function H, requires some mathematical sequences and a few definitions {1}, {2}.

This theory, without entering into its detailed, can be observed for practical experiments as follows.

The sound source and the receiver can be regarded as two terminals.

For each terminal two variables are defined, so that their product represents the power fed into the system via the terminals.

For an electrical terminal these variables are the voltage E and the current I, for an acoustical terminal the sound pressure p and the volume velocity Q and for a mechanical terminal the force F and the velocity V.

In the homogeneous system the variables at each terminal are the same (for instance in an electrical terminal they will be E1 , I1 and E2 , I2).In the heterogeneous system these variables will be a function of the considered system.

In our case a mechanical-acoustical system has been assumed, therefore the variables will be F and V for the mechanical terminal and p and Q for the acoustical terminal.

As following figures will shows, the mechanical terminal (compressor) has been placed in position 1 and the acoustical terminal (point in the reverberating room) in position 2.

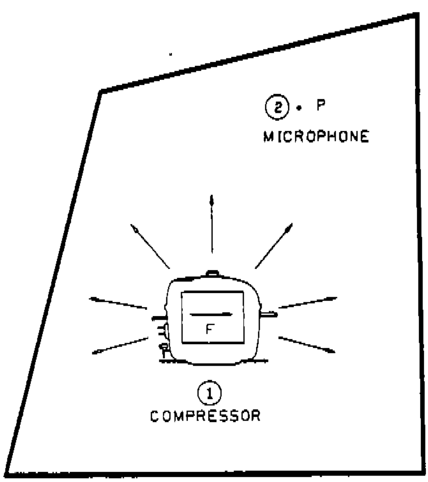
According to the reciprocity principle, two simple experiments are required {3}.

In the first experiment the sound source is placed at the position 1 and the pressure level is measured at the position 2 (fig 2).

The sound power is defined as :

$$W = H * F^2 = A * p^2 \tag{4.1}$$

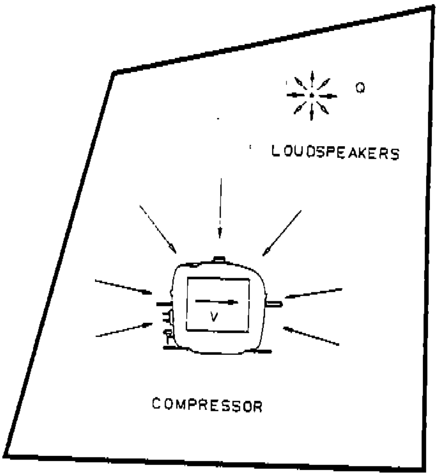
where H and A are proportionally constant



In the second experiment the sound source is placed at the position 2 and the variable V is measured in the position 1 (fig.3).

In this case the sound power diffused in the reverberating room is :

$$W = (\rho * \pi * f^2 * Q^2) / 2c = \\ = A * p^2 \tag{4.2}$$



In the former case the unknown sound source is the force F, while in the latter case the sound source is expressed by the volume velocity Q.

The reciprocity principle formules four relations, one of which can be applied to our case.

This relation is :

$$p2 * Q2 = - F1 * V1 \tag{4.3}$$

where p2 = sound pressure at the position 2 when the sound source is in 1

Q2 = volume velocity at the position 2 when the sound source is in 1

F1 = force at the position 1 when the sound source is in 2

V1 = velocity at the position 1 when the sound source is in 2

From the equation (4.3) it can be written

$$p / F = - V / Q \quad \text{and}$$

$$(p / F)^2 = (V / F)^2 \tag{4.4}$$

and consequently

$$p^2 = (F * V / Q)^2 =$$

$$p^2 = (F * a / w * Q)^2 \tag{4.5}$$

From the equation (4.1) it is

$$p^2 = H * F^2 / A \tag{4.6}$$

and combining with the equation (4.5) it can be written :

$$p^2 = (F * a / w * Q)^2 =$$

$$= H * F^2 / A \tag{4.7}$$

therefore

$$H = A * a^2 / (w * Q)^2 \tag{4.8}$$

Substituting in Q its own expression from the equation (4.2) it gets :

$$Q = A * p^2 * 2c / \rho * \pi * f^2$$

$$H = W / F^2 = \rho * a^2 / 8c * p^2$$

$$= C * a^2 / p^2 =$$

$$= 1.41\ 10^{-4} * a^2 / p^2 \qquad (4.9)$$

From here it is shown as the function H is determined by measuring the acceleration a on the compressors and the sound pressure p in the reverberating room.

Measurements

The carrying out of the tests needs a reverberating room, a powerful sound source and a transducer.

The reverberating room allows to simplify the practical application of the reciprocity principle.

The reciprocity relation requires the same direction characteristic for the microphone and the sound source.

As in the reverberating room the sound field is diffused, the direction characteristic of the microphone is not important.

Besides, even the geometrical dimensions of the sound source are not important and this allows to consider it as a point source that radiates the same amount of sound power.

The set of loudspeakers must enable to reach a pressure level of at least 100 dB with a random signal included between 100 - 200 Hz and 5000 Hz.

This high level is necessary in order to have a good response signal at the accelerometer mounted on the compressor.

As already said, the main force excitation in the compressor is along the piston axis and consequently the accelerometer has been connected on the cylinder head.

The measurements have been carried out with a complete and not running compressor set in a welded shell with the only variable concerning the transmission paths.

Then, one path a time is let connected and the transfer function H is measured by means the ratio a^2 / p^2 multipied by the constant C.

Five different configurations have been assumed :

a) A complete compressor with all paths connected

b) A compressor without oil, gas (vacuum) and discharge i.e. with only support springs.

c) A compressor without oil and gas (vacuum),i.e with only discharge pipe and support springs.

d) A compressor without oil and discharge pipe,i.e. with gas and support springs.

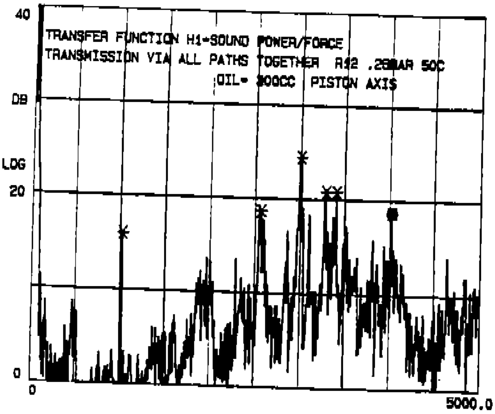
e) A compressor without discharge pipe and gas (vacuum), i.e. with oil and support springs.

For practical reasons the support springs were always present but the results have shown that their contribution can be neglected.

Evaluation of the results

a) Compressor with all paths connected. (standard configuration).

As it is shown in fig.4 the spectrum presents sharps peaks in a broad frequency range (2500-4000 Hz).

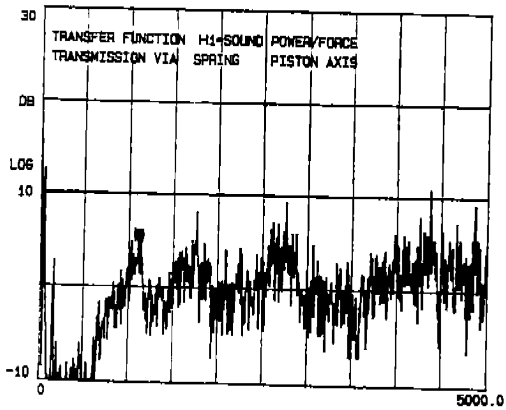


The measure has been carried out at the usual noise test condition with 0.26 bar of pressure inside the shell and 50 ^C on the top shell.

Comparing this spectrum with the next ones it will be possible to go back to the causes of these peaks with a fairly good precision.

b) Compressor with only support springs.

The compressor has been set in the welded shell without discharge pipe, oil and gas.



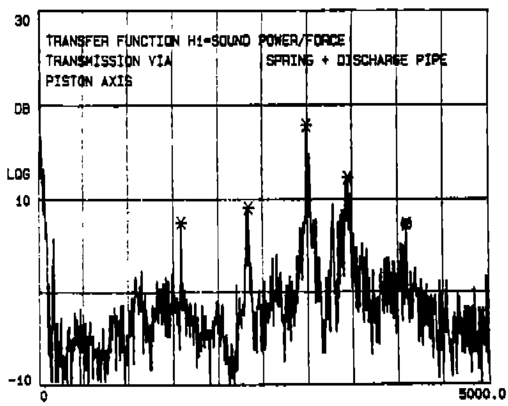
With a pump a strong vacuum has been made in order to avoid the transmission via gas.The spectrum is shown in fig. 5.

As expected, the response signal transmitted via the support springs only has been very low (see the change of the vertical scale) and with a very slight influence on the general spectrum of figure 4.

For this reason in the next measurements the contribution of the springs will be neglected.

c) Compressor with discharge pipe and support springs.

The vibrations mainly transferred via the discharge pipe are reported in fig. 6.



Although the response signal level has been rather low a few peaks are very well correlating with the general spectrum of fig.4.

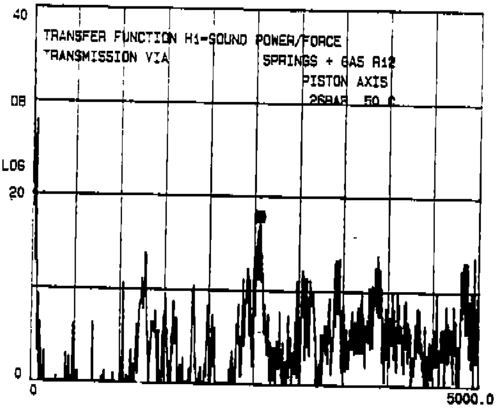
This concerns in particular the peak at 3KHz, even if the range of influence is characterized by sharp peaks between 2 and 4 KHz.

d) Compressor with gas R12 and support springs.

The figure 7 gives the spectrum determined by the transmission mainly via gas paths.

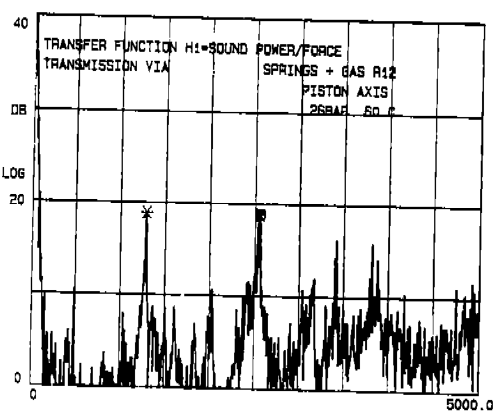
As it is shown, several peaks are present but only a few have some influence on the general spectrum.

The only remarkable peak is at 2540 Hz,where the amplitude is pratically the same reported on the general spectrum.



Because of the strong dependence of the gas resonances with the temperature, another measure has been carried out with warmer gas (from 50 to 60 ^ C).

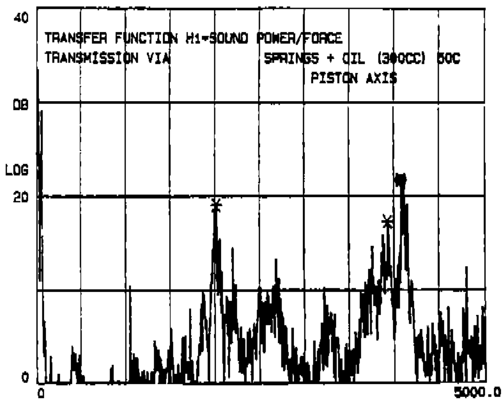
This second test is reported in fig.8, where it is evident a new peak at 1275 Hz and a slight rise of amplitude in the rest of the range.



e) Compressor with oil and support springs.

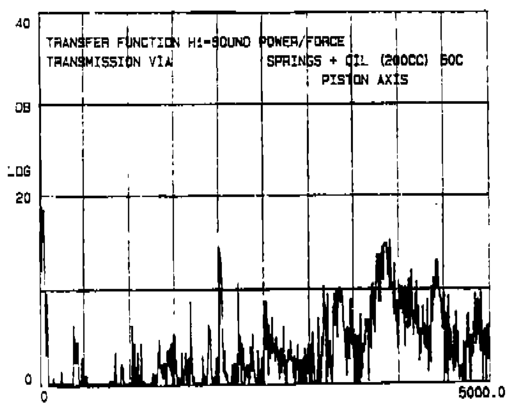
The compressor with two different oil levels and support springs has been placed in a welded shell.

Figure 9 points out a few high peaks ,whose amplitude is pratically coincident with the corresponding peaks of the general spectrum (2KHz and 4KHz).



The peak at 2KHz is particularly critical because it coincides with the first resonance frequency of the shell and then with a range having a very high transmissibility of vibrations outwards.

A remarkable drop of the peaks amplitude can be observed in fig.10, where a lower oil level has been used (200 cc instead of 300 cc).



5 CONCLUSION

All previuos figures have shown interesting behaviour for the different transmission paths.

It should be noted that the interpretation of the results is often rather complicate because each transfer function presents a great number of peaks not always referable to specific causes.

Clear indications have been obtained from the oil path and from the discharge pipe.

As a consequence many efforts have been made in this direction with good practical results.

In conclusion, considered the great importance of the transmission paths, the INDIRECT METHOD can be suggested as a very useful tool for a detailed investigation.

6 REFERENCES

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