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Vibrational Design Criteria in Small Reciprocating Compressor

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VIBRATIONAL DESIGN CRITERIA IN SMALL RECIPROCATING COMPRESSOR

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ABSTRACT

This work is to show some criteria on reducing the vibrational energy transmitted by the pump assembly to the compressor shell, and then by the shell to the structure connected to it.
During the conceptual phase, in fact, it is important to have calculation tools which allow an easy analysis of several alternative solutions, in order to optimize the vibrational design of the compressor.
The pump behaviour during its running it has been firstly investigated; then its interaction with the shell was deeply studied. Finally a comparison between experimental and theoretical data is discussed.

INTRODUCTION

The compressor is considered as working at the normal condition,and the studied criteria are the following :

1) criteria in order to optimize the pump assembly
   - how to investigate the pump assembly motion, caused by the forces and the torques generated by the alternating mechanism
   - how to define and compute the Vibrational Intensity Index (I.V.I.) of the pump assembly
   - how to compute the sensitivity of the IVI to the characteristic parameters variation

2) criteria in order to optimize the whole system, composed of the pump assembly and the shell
   - how to evaluate the local energy transmittability of the shell
   - how to choose the position and the physical characteristics of the mounts (used to join the pump assembly to the shell, and the shell to the structure) in order to minimize the local energy flux, and then the vibration amplitude on the structure.

THE PUMP

Pump loads reduction

In this phase, loads producing by the pump during its running (due to gas pressure and inertia) are computed, together with their armonic composition. In order to design pumps which produce very low level of loads, it often is not enough to restrict the value of alternate mass or act on the crank mechanism geometry, but it is necessary to define pump balancing systems which use auxiliary appropriate counterweights. A computational tool has been developed which, together with a parametric CAD system, enables the balance of the shaft to be designed automatically with minimum of weight and respecting dimansional constrains and structural strenghts.

Vibrational Intensity Index (I.V.I.)

Once the force and the torques acting on the pump have been calculated we are forced with the problem of minimize the displacements which the the pump generates (particulary on the points of the pump fixing points).
They depends not only on the forces and torques above, but on inertia characteristics of the pump body too.
A computational tool has been developed in order to define the intrinsic vibrational attitude of the pump; the following are the phases which leads to the definition of the Vibrational Intensity Index of the pump:

1) Computation, on the points of a volume surrounding the pump, of the displacements (in absolute value) which will be here generated if there is an infinitly rigid connection with the pump (see figure 1)

COMPUTING VOLUME

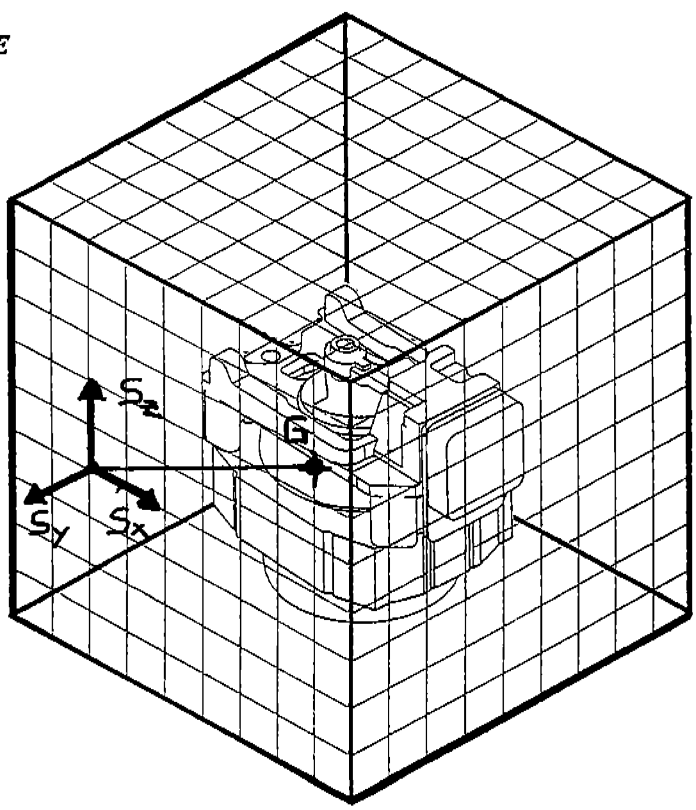


figure 1

- Calculation of the probability distribution of the displacements values (one for each direction, see figure 2)

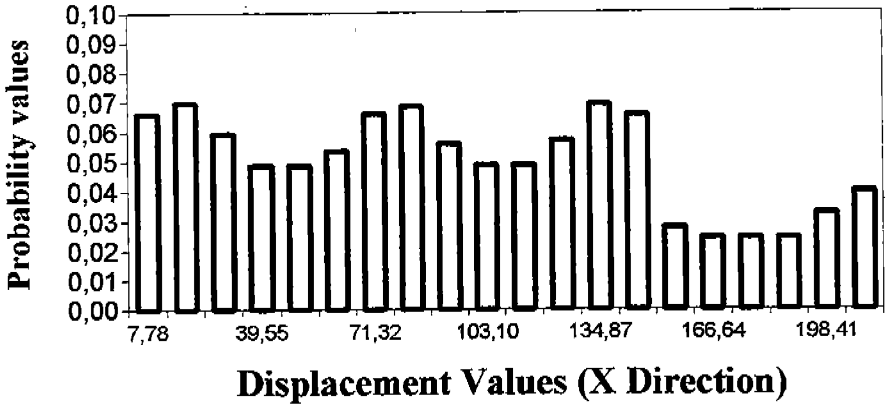


figure 2

2) Calculation the probabilistic average value (one for each direction) and then of the I.V.I., according to the following formula (referred to X direction):

$$\overline{S_{Px}} = \int S_x \varphi(S_x) dS_x$$

$\varphi(S_x)dS_x$ = *probability to have a displacement value between Sx and Sx+dSx*

3) Computing the I.V.I. value

$$\text{I.V.I.} = (\bar{S}_{Px}^{\,2} + \bar{S}_{Py}^{\,2} + \bar{S}_{Pz}^{\,2})^{1/2}$$

This kind of average permits a more appropriate information about the vibrational attitude of the pump, according to the choice of max four points to connect the pump.

Experimental computing values comparison

The displacement values of a reference pump have been computed; the comparison with the experimental data is showed in the figure 3; the following tables describes the position of the measurament points.

Measurement Points	Description
POINT 1	Cilinder head
POINT 2	Crankcase
POINT 3	Stator (Piston direction)
POINT 4	Stator (Piston ortgogonal direction)

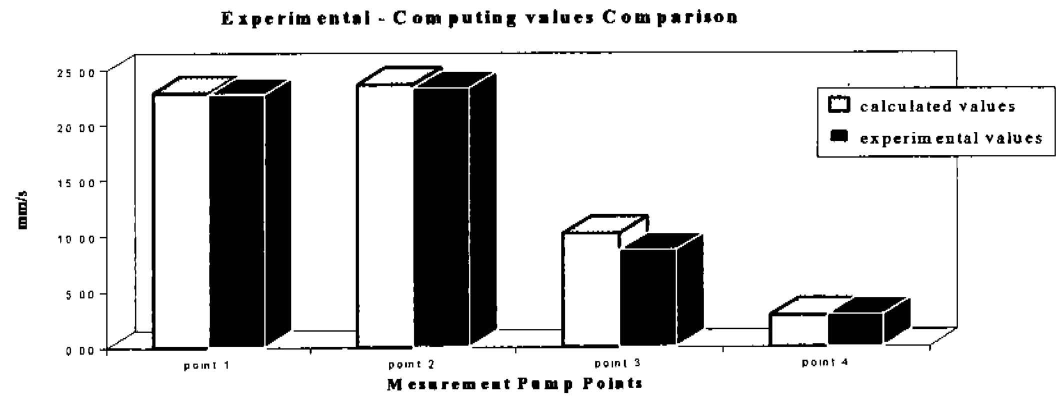
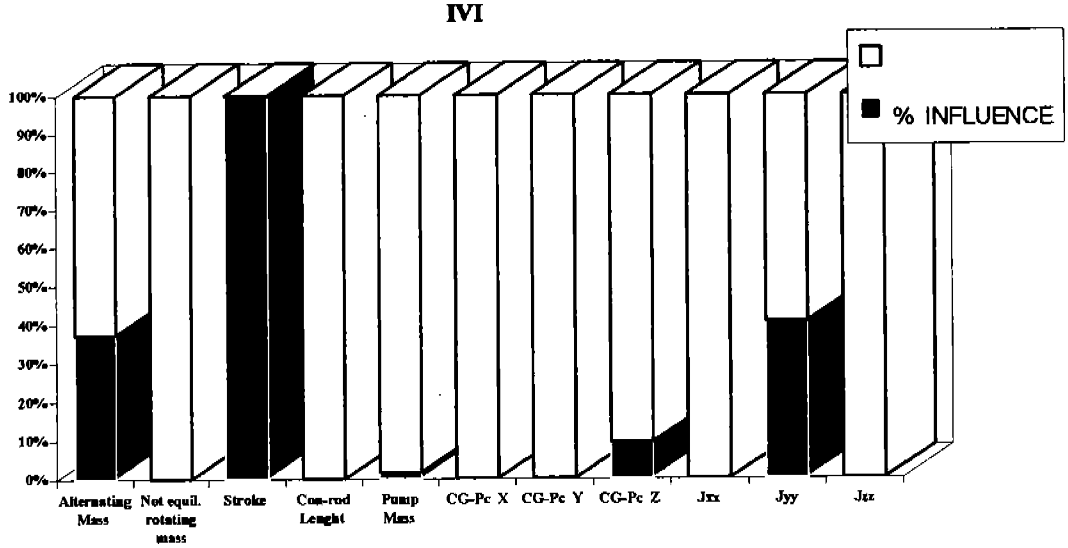


figure 3

Pump Sensitivity Factors

In order to better investigate the intrinsic vibrational pump behaviour another computing tool allows to define the sensitivity of the pump I.V.I. with respect to variation of the pump parameters (alternating mechanism values and inertia values); the results obtained analyzing some compressor pumps show the great influence of the stroke but alsoof the pump inertia too on the I.V.I. value as shown in the figure below.

% INFLUENCE OF THE PUMP PARAMETERS IN ORDER TO EXPLAIN THE IVI



THE SHELL

The first problem we are forced with after the intrinsic pump optimisation is to choose the correct point of the pump fixing points.The correct positioning of these can in fact considerably contribute to the vibration reduction on the shell. In relation to this, the criteria that we have choosen for their definition are essentially two:

a) to choose the point in relation to the minimum forces generated from the pump (at this level considered to be a rigid body)
b) to choose the point in which the structure presents the lowest level of dynamic sensitivity and, therefore,the greatest obstacle to the propagation of the vibrational energy.

Study of the shell mobility

To quantify the b) criteria we can use the **mobility** of the points of the shell structure, defined by the following formula:.

MECHANICAL IMPEDANCE IN A POINT:

$$\underline{z} = c + J\left(\omega M - \frac{K}{\omega}\right), \quad \omega = 2\pi f$$

Where:
c = Damping
M = Local mass
K = Local stiffness

$$\boxed{\underline{F} = \underline{z}\,\underline{v}}$$

MOBILITY $\underline{m}$:

$$\underline{m} = \frac{1}{\underline{z}} = \frac{c}{z^2} - J\frac{X}{z^2}$$

$$X = \left(\omega M - \frac{K}{\omega}\right) \longrightarrow \textit{Dynamic reactance}$$

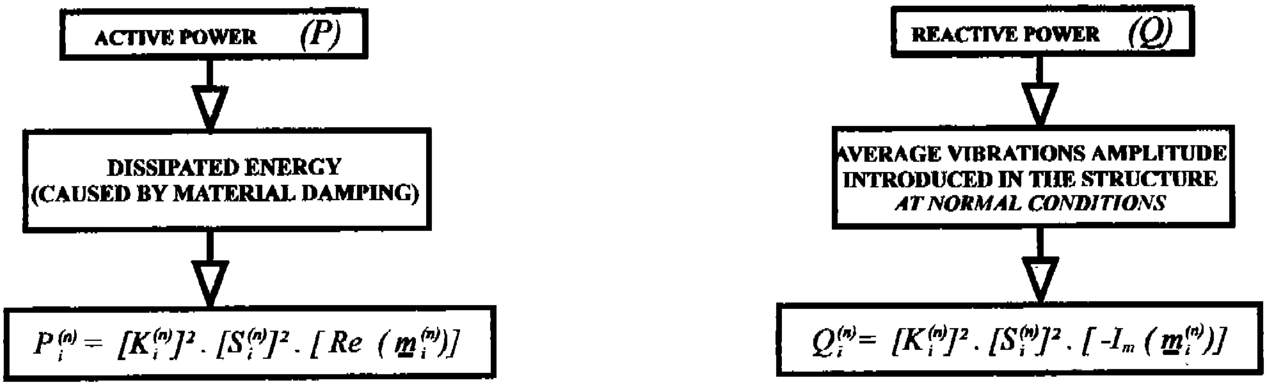
The point mobility are generally dependent on the frequence of the exiting forces, that is on the RPM of the electric motor.

PUMP-SHELL VIBRATIONAL INTERACTION

To quantify the b) criteria we can use the displacement values that the pump generates in relation to the points of the shell, based on a completely rigid connection
It should be noted that the two criteria aboved mentioned, don't lead to, in general, to final coincident points or areas; to make good use use of both pieces of information, one has then to use a third physical quantity, which would rapresent their total contribution.

Power exchanged between the pump and the shell

This is how :



i = 1,2,3 (direction)
(n).=. n° structure point where is supposed exisisting an pump anchorage point
Ki = stiffness value of the connecting spring

From the formulas above one can see that the quantity obtained multilying the square of the displacement generated by the pump in a point by the mobility of the shell in the same point represents (exept a constant function of the stiffness of the connecting support) the energy flux (power) exchanged by the two systems.
Since the stiffness of the supports is defined once the position of the supports themselves are fixed (according to the specifications which garantee the functional hold of the pump in the standard reference conditions), it is possible to assign to every configuration a number which represents the total exchanged power.
It is also possible to prove (and can be easily seen) that such quantity is proportional to the amplitude of the vibration which are induced on the shell, thus being able to syntesize the effects of generated displacements and induced vibrations.

CONCLUSIONS

A possible methodology to improve the vibrational behaviour of a small reciprocating compressor has been developed. It leads to the computation of the exchanged power between pump and shell referred to a possible configuration of the placing of the supports (times a constant which is a function of the stiffness of the above points); the evaluation of the support static stiffness and then the computing of the real total exchanged power corrispondent to the assumed configuration leads to, using optimization techniques, effectively explore in a systematic fashion all of the resonable alternatives.The numerical results (referred to the computing of the pump displacement) has given a good agreement with the experimental data.

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