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# CONVERGENCE OF GAS PULSATION SIMULATIONS WHEN COMBINING TIME AND FREQUENCY DOMAINS ITERATIVELY

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## ABSTRACT

In models which combine both time and frequency domains iteratively, the thermodynamic process of compression and valve flow is solved numerically in time utilizing in iterative steps improved estimates of suction and discharge cavity gas pulsations, which are obtained from frequency domain models. While no problems have been reported for discharge side simulations, the process has shown occasional convergence problems on the suction side in part due to the increased sensitivity of valve motion to pressure fluctuations at valve closing time. This paper shows how iterations can be slowed down for satisfactory convergence behavior and presents a case study to illustrate the point.

## MATHEMATICAL MODEL

The overall philosophy is illustrated in Fig. 1. The standard approach relies on certain laboratory measurements, for example prototype valve measurements are used to identify effective damping.

The key to the typical program is the calculation of the instantaneous mass in each cylinder, m(t), by

$$m(t) = \dot{m}_s - \dot{m}_d \qquad (1)$$

where $\dot{m}_s$ and $\dot{m}_d$ are suction and discharge mass flows. The cylinder pressure can then be determined utilizing a polytropic process or the basic form of the first law of thermodynamics. The instantaneous volumes are provided from kinematic equations. Mass flow rates are computed using the concept of equivalent orifices and quasi-steady flow. The procedure is well documented in a large number of publications [1].

The model is formulated and solved in the time domain, provided suction and discharge pressures are given or formulated in the time domain. This can be done in case of lumped paramter models of the suction or discharge dynamics, of which many examples exist, one of the earliest by Soedel, Padilla-Navas, and Kotalik [2].

Linearized continuous gas dynamic models, on the other hand, are best solved in the frequency domain. This creates a problem of model incompatibility. It was solved first by Elson and Soedel [3] by an iterative approach, illustrated in Fig. 2. First, the mass flow rate history of the suction and discharge ports is calculated as if suction and discharge pressures are constant, and transformed into the frequency domain. The spectral response of the suction and discharge system is then obtained and back pressure spectra for each valve are calculated. These spectra are synthesized by inverse Fourier transformations into time domain pressure oscillations. The second iteration recalculates the mass flow rate histories of the valves on the basis of these pressure oscillations. The recalculated mass flow rate is Fourier transformed into new excitation spectra and new back pressure spectra are obtained. Inverse Fourier transformation allows the third iteration to proceed.

Convergence of this process cannot be guaranteed in advance. However, all studies by the author and his students, which tended to concentrate on discharge system pulsations, showed very satisfactory convergence, until recently. It was found that this iteration process would not converge for the suction system for the case of a fractional horse power refrigeration compressor of the reciprocating type. Because of the relatively small coupling between suction and discharge oscillations, the discharge process still showed satisfactory convergence.

## SLOWING DOWN THE ITERATION

The solution to the convergence difficulty lies in physical interpretation of the iterations. It was assumed in all past applications that the calculated back pressure oscillation from the (i–1)th iteration is an improvement to be used fully for the ith iteration. However, the pressure difference between the suction plenum and the cylinder is very small at the time of the final suction valve closing. Even a very small deviation in suction plenum pressure oscillations has a relatively large influence on suction valve closing behavior. It is therefore possible that the pressure oscillations from the (i–1)th iteration are an over correction.

Therefore, the pressure calculation for the ith iteration is modified to

$$P^*_{s,i} = \eta P_{s,i} + (1 - \eta) P^*_{s,i-1} \tag{2}$$

where $\eta$ is a convergence factor which is less than unity, $P^*_{s,i}$ is the suction pressure which will actually be used for the numerical procedure of the ith step, $P_{s,i}$ is the pressure calculated for the ith step by the original uncorrected procedure, and $P^*_{s,i-1}$ is the suction pressure which was actually used for the (i–1)th iteration. That is, only a fraction $\eta$ of the newly calculated pulsation pressure is used as estimate for the next iteration, added to a fraction $(1-\eta)$ of the previous pressure.

When convergence is achieved, $P^*_{s,i-1} = P_{s,i} = P^*_{s,i}$ subject to a permissible small deviation $\varepsilon$.

The identical iteration can of course be used for the discharge process, should it be necessary.

The schema is an adaption from an application involving the prediction of stresses in nonlinearly deflected membranes [4].

## CASE STUDY

The compressor for which the numerical convergence problem was noted is relatively standard as far as valve design is concerned. The schemas of the suction and discharge systems are shown in Fig 3. The suction system includes the gas in the hermetic shell. The analysis of the suction system with three-dimensional shell cavity is described in references [5,6].

Figure 4 shows typical successive iteration results (as example the fourth and fifth iterations) for the suction and discharge plenum pressures when the iterative process is not slowed down. Typically, the discharge pressure shows a relatively fast convergence, but the suction pressure has obviously not converged. A way to study convergence is to plot the mass in the cylinder after the suction valve has closed, as shown in Fig. 5. Once the iteration has been modified, converged results are also achieved for the suction process as shown in Fig. 6.

## ACKNOWLEDGEMENT

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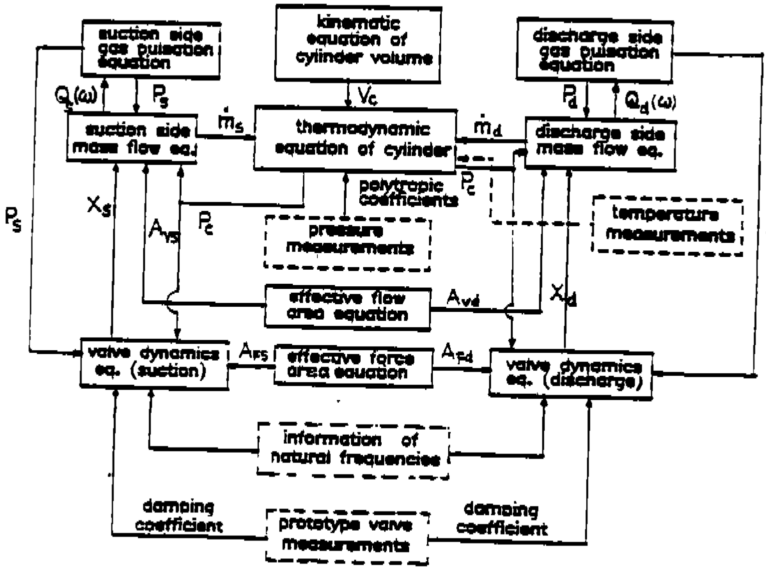


Fig. 1. Combination of Theoretical Information with Laboratory Experiment for Compressor Analysis.

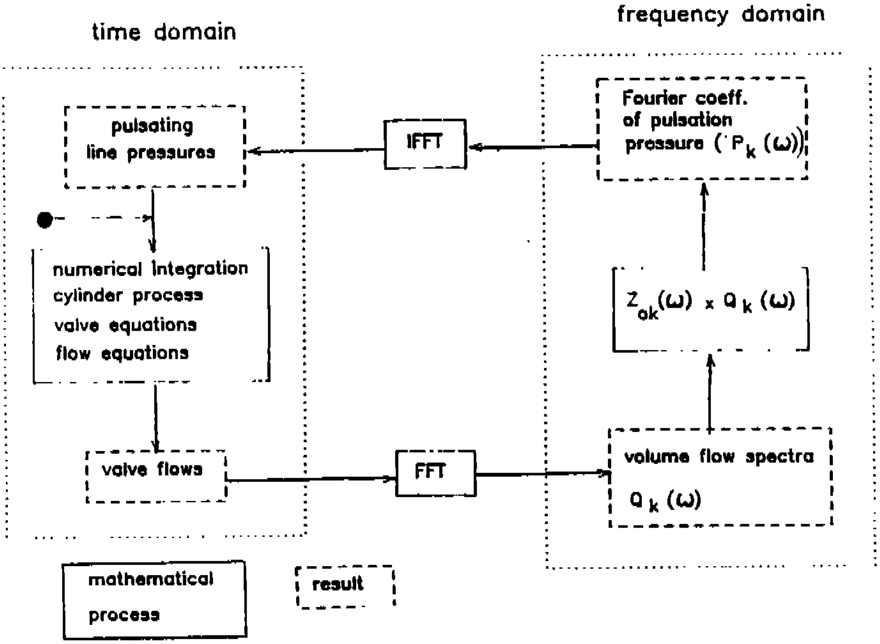
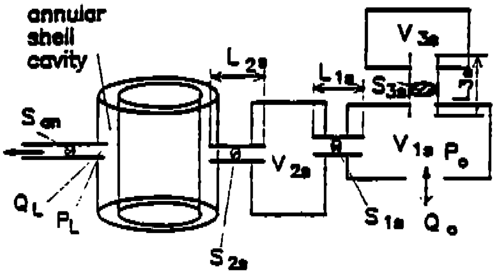
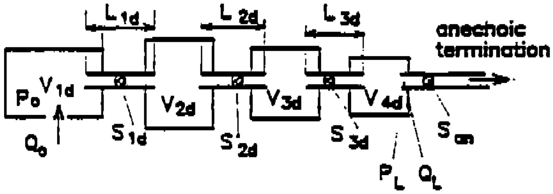


Fig. 2. Calculation of Pulsating Pressures.

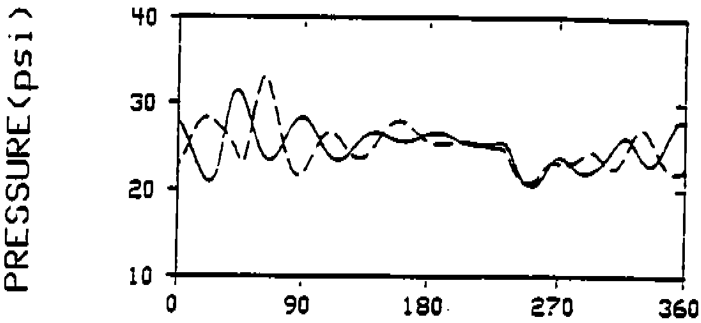


(a) Suction Side

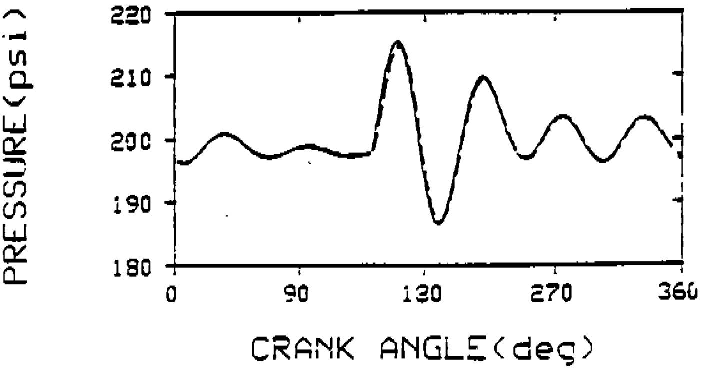


(b) Discharge Side

Fig. 3. Compressor Gas Manifolds.



(a) Suction Pressure



(b) Discharge Pressure

Fig. 4. Example of Successive Iterations Showing Satisfactory Convergence of the Discharge Plenum Pressure and Unsatisfactory Convergence for the Suction Presure: ——, 4th Iteration, - - - - -, 5th Iteration.

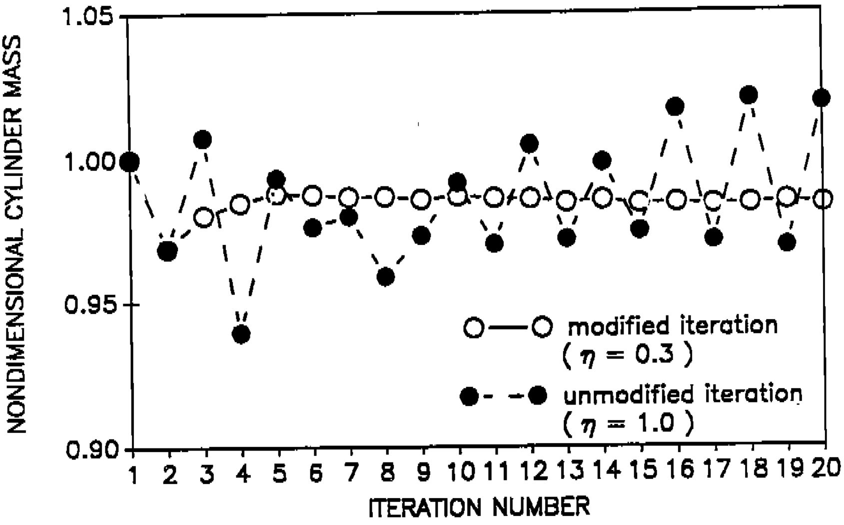


Fig. 5. Mass in Cylinder After Suction Valve has Closed.

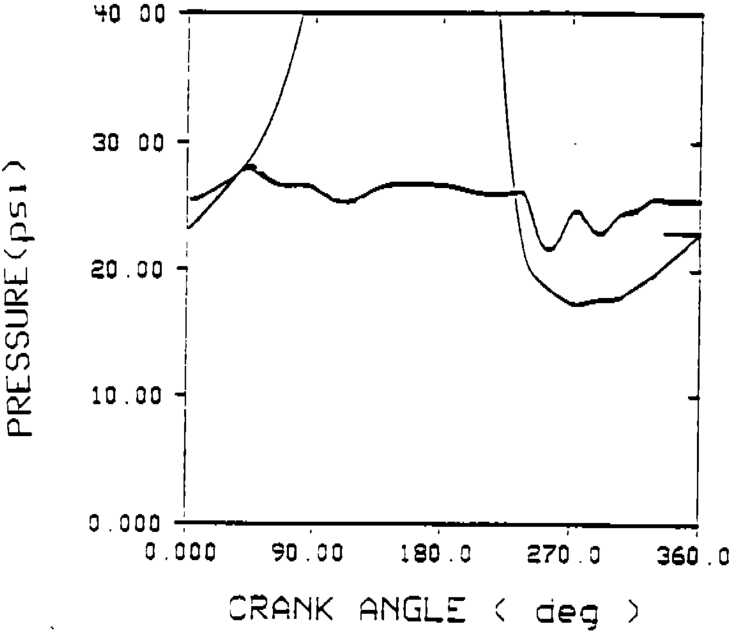


Fig. 6. Modified Iteration Results for the Suction Process for the Eleventh, Thirteenth and Fifteenth Iteration.