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Analytical Modeling of Helical Screw Machine for Analysis and Performance Prediction

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ANALYTICAL MODELING OF HELICAL SCREW MACHINE FOR ANALYSIS AND PERFORMANCE PREDICTION.

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ABSTRACT

In this paper a numerical method for prediction and analysis of oil-free and oil-flooded screw compressor performance is presented. The model includes inlet and discharge dynamics, leakage throughout the machine, and the thermodynamics within the thread volumes and leakage paths.

Calculation results are presented and compared to results from laboratory tests.

INTRODUCTION

In order to get a powerful tool for analysis and development of screw compressors and expanders a computer simulation method has been developed at Svenska Rotor Maskiner AB, Stockholm, Sweden.

This development work has been made possible by the calculating capabilities of the digital computer and the great amount of laboratory tests and experience that Svenska Rotor Maskiner AB has gathered during all the years since the screw compressor was invented by Alf Lysholm.

The advantages of using a simulation method in the development work are:

- Gives the possibilities for detailed analysis and better understanding of the screw compressor performance.
- Reduction of experimental costs.
- Better control of parameters than in laboratory tests. It is almost impossible to hold a parameter completely constant in laboratory tests.

To obtain a tool which can serve the above mentioned purposes, certain demands must be fulfilled. The computer program must be able to calculate the effects of the variations of the following parameters:

- Clearances.
- Design of inlets and outlets.
- Rotor profile.
- Wrap angle.
- Length/diameter ratio.
- Lobe-combination.
- Rotor speed.
- Working medium.
- Cooling.
- Oil-injection rate.
- Oil viscosity.
- Solubility of refrigerant in injected oil.
- Viscous losses.

THEORY

The following processes have been considered in the physical model:

(1) Expansion through the inlet during filling phase and adjustment for enthalpy flow through inlet and leakage paths. Flow losses and inlet pipe dynamics are considered.

(2) Compression in the thread volume by using equations for polytropic process adjusted for mass and enthalpy leakage flows into or out from the thread as well as heat transfer losses.

(3) Expansion through discharge with adjustment for enthalpy flow. Flow losses and outlet pipe dynamics are considered.

(4) Mass and enthalpy flows in leakage paths by using isentropic flow equations for dry compressors or 2-phase viscous flow equations for oil-injected compressors. For oil-injected compressors, heat exchange between oil and gas in leakage paths is considered.

(5) Mass and enthalpy flows caused by solubility of working fluid in the injected oil.

(6) Friction losses due to oil in the leakage paths by using equations for flow friction combined with path geometry.

A short description of the physical modelling is presented in table 1.

The physical formulas describing these processes are arranged to a set of interrelated differential equations coupled by mass and enthalpy flows between control volumes. These equations are of the form

$$\frac{d\underline{x}}{dt} = \underline{f}\ (\underline{x},\ \underline{u},\ t)$$

where $\underline{x}$ is a vector of state variables, $\underline{u}$ is the system inputs, and $\underline{f}$ is a vector of nonlinear state functions.

The equations are computer coded and solved numerically on a digital computer.

TYPICAL RESULTS

To carry out these calculations it was necessary to determine all coefficients describing leakage, heat transfer and dynamic losses by comparison with SRM laboratory test results. After determining the coefficients the calculations below were performed for different types of screw compressors and the results are shown in figs. 1, 2, 3 and 4.

Fig. 1.: This figure shows the pressure transient in one thread of a small oil-injected refrigeration compressor working with R12. It can be seen clearly that the calculated and measured values are in good agreement.

Fig. 2.: This plot shows how the refrigerant dissolved in the oil affects the compression as it evaporates. The oil is injected between 200^o and 280^o position of the male rotor angle. Numerical integration of the increased torque will give the decrease in adiabatic efficiency.

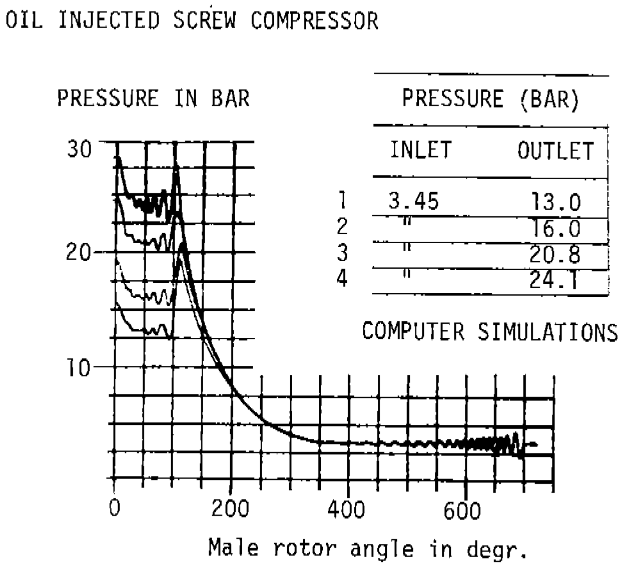
Fig. 3.: This shows the effect of the amount of oil injected into an air screw compressor at three different rotor tip speeds.

As shown, there is an optimum point for each rotor tip speed - at low tip speeds the adiabatic and volumetric efficiencies decrease due to increased leakage, but also at high tip speeds the adiabatic efficiency decreases due to increased dynamic losses arising from the oil injection.

	DRY	OIL INJECTED
LEAKAGE		
Clearances	Isentropic flow	Viscous 2-phase flow
DYNAMIC LOSSES		
Inlet/outlet resist.	abs-square law	2-phase abs-square law
Flow pulsations	Momentum equation	Momentum equation
Viscous friction	----------	Newtons law for friction
Mechanical	Empirical	Empirical
HEAT TRANSFER	Polytropic process with correction	Polytropic process with correction

Table 1.

Basis for physical model of screw compressor.



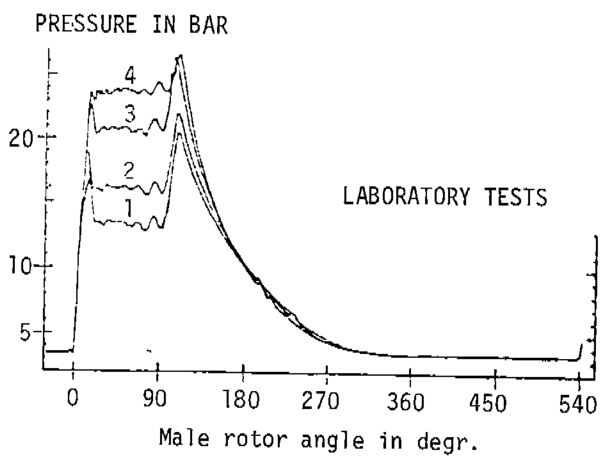


Fig. 1. Comparison between computer simulations and laboratory test results for a small refrigeration compressor.

Fig. 4.: The computed performance for two different rotor profiles is here presented. The calculations are made with the assumption that all clearances are of the same magnitude for the two profiles. The results show that the newly developed profile gives better screw compressor performance than the asymmetric profile.

Fig. 5.: A comparison between computed and measured results for the above mentioned profiles (fig. 4) is here presented. As can be seen a good agreement between theory and laboratory results is obtained.

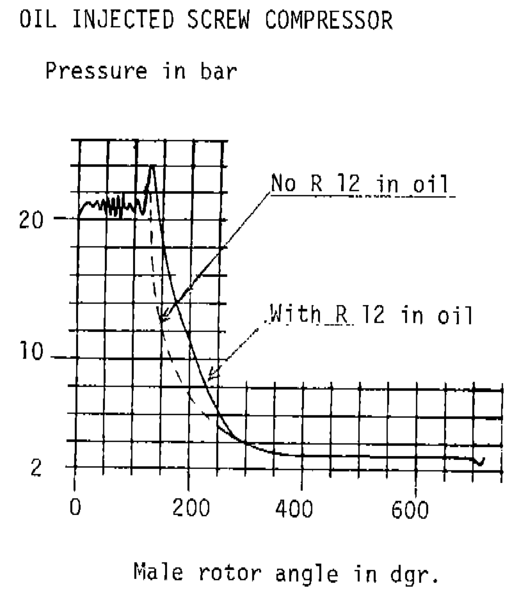


Fig. 2. Effect of evaporation of dissolved R 12 in injected oil on a small refrigeration screw compressor.

CONCLUSIONS

The presented simulation method is a useful tool for the analysis and development of screw compressors.

The method is especially useful in evaluating machines for which experience is limited.

By using this simulation model the cost and time of development work can be considerably reduced.

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COMPUTER SIMULATED PERFORMANCE OF AN
OIL-FLOODED AIR COMPRESSOR

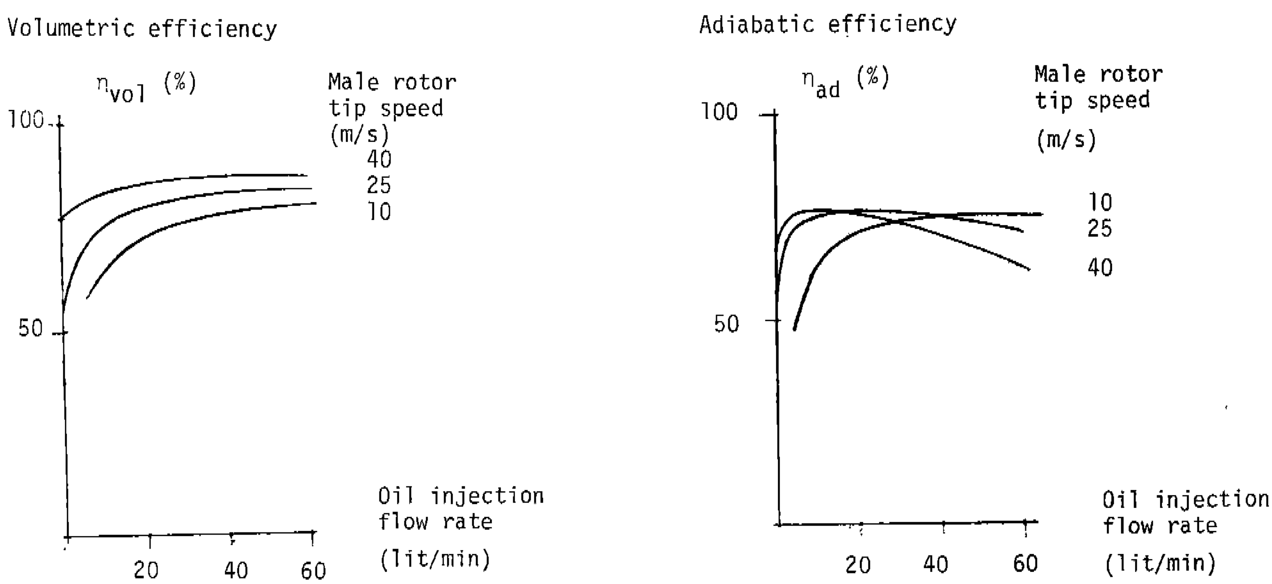

Fig. 3

Effect of injected oil on an
air screw compressor.

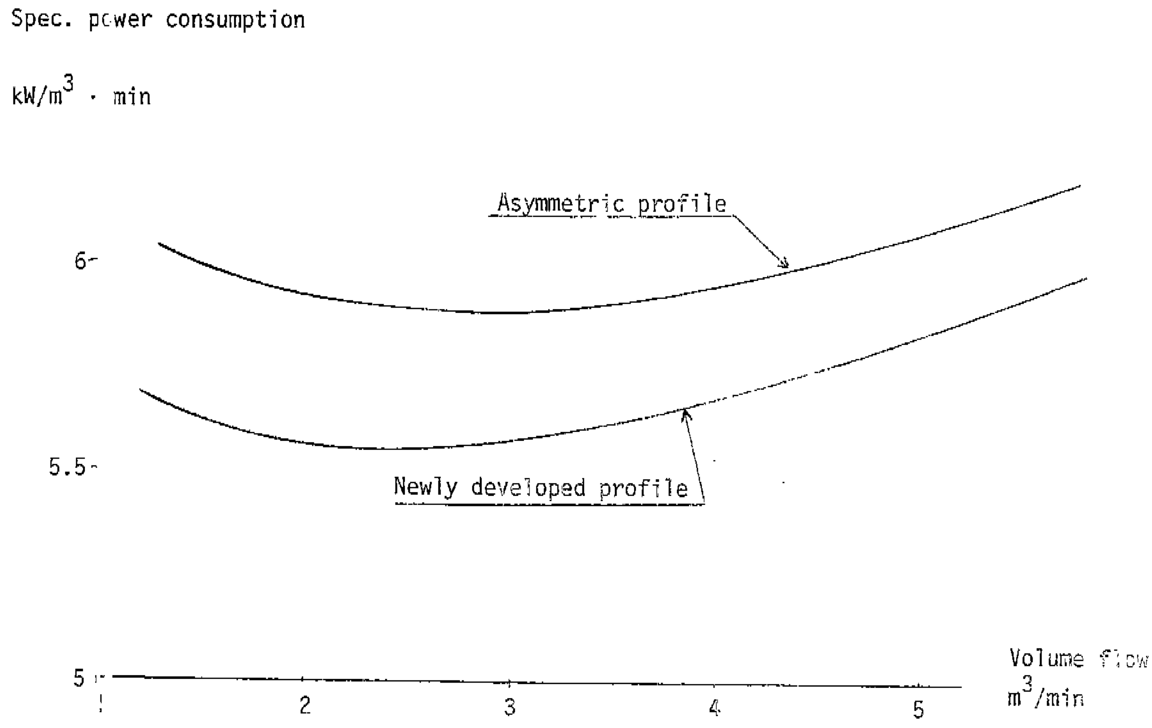

Fig. 4. Computer simulated screw compressor performance for two different rotor profiles.

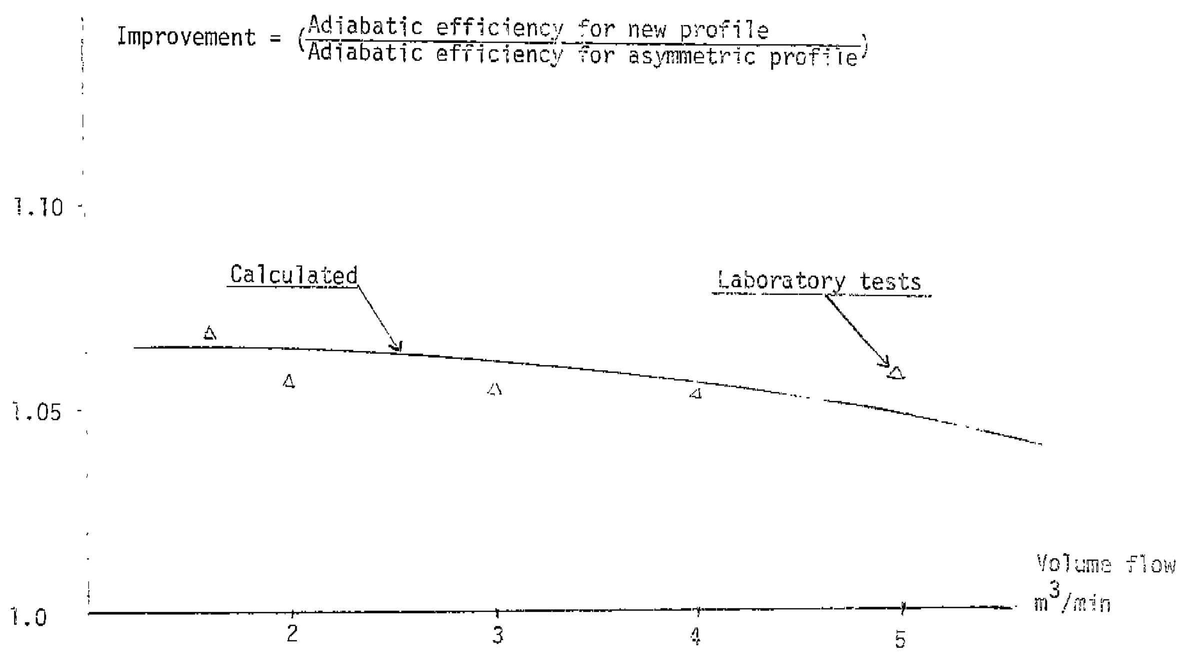

Fig. 5. Comparison between computer simulated and measured performance improvement.