Investigations on Mechanical Losses of Electrically Driven Air Screw Compressor

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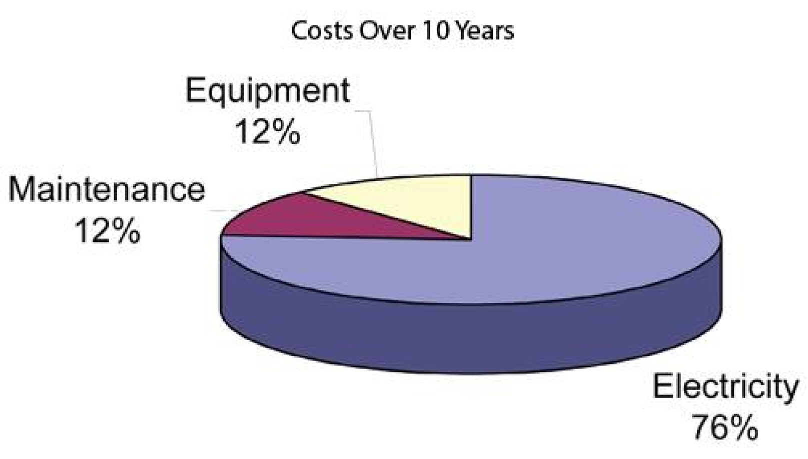
Abstract

High isentropic efficiencies for low to moderate pressure range, together with purely rotary motion are making screw compressors popular. However, with some sources of frictional loss and relatively higher loads acting on bearing compared to turbo-compressors, the adiabatic efficiencies of these are limited. In industrialised countries, compressors absorb 15-20% of the total electrical power generated. Hence there is a continuing demand to improve their energy efficiency. The mechanical losses inside a screw compressor arise due to relative motion between elements inside the screw compressor. Because of dynamic behaviour of elements like screw rotors, bearings, shaft seals and oil inside the screw compressor, it is difficult to calculate actual mechanical loss. The existing mathematical models only guesstimate mechanical losses as an additional increment to the power required to compress the gas. The aim of the study, was to estimate the effect of the individual parameters responsible for mechanical power loss in oil injected screw compressors and is focussed on the losses incurred in the rolling bearings, shaft seals and oil drag losses.



Compressor running cost over 10 years [1]

The problem

Following figure explains the elements of power loss of a screw compressor package. However, the study presented here is focussed on the mechanical losses arising inside the bare compressor.

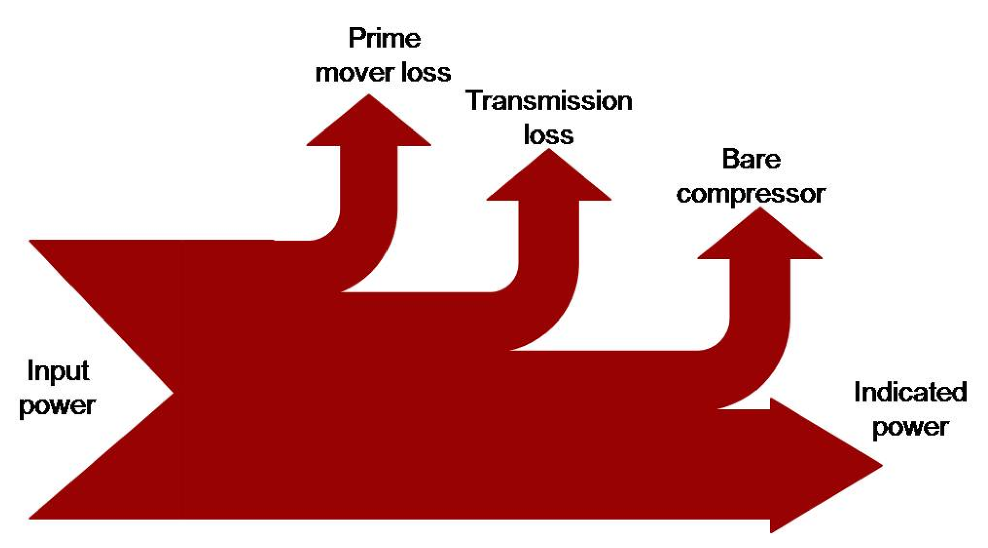


Figure 1: Elements of power loss inside bare screw compressor

The bare screw compressor consists of bearings, shaft seal, oil drag, transmission gears, if rotated at different speeds than driver speed, and windage loss arising from gas resistance inside the compressor.

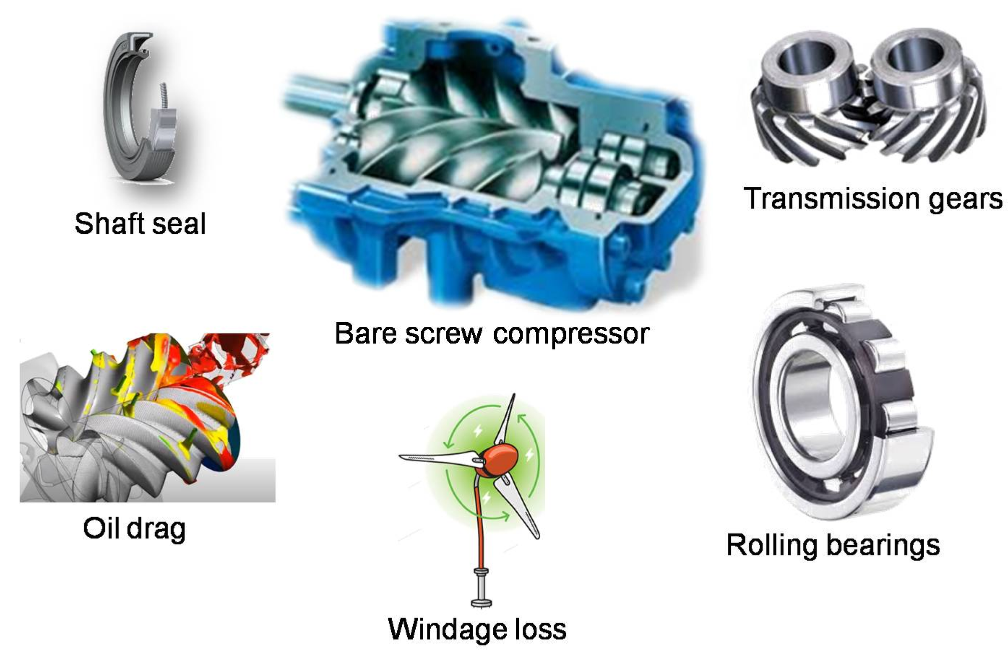


Figure 2: Elements of power loss in bare screw compressor

The methods available in literature for prediction of mechanical loss for a screw compressor approximations overall loss as some percentage of total shaft power which are fine tuned for a specific operating point. Uncertainty over quantification of mechanical losses arising in individual elements leads to not so optimised selection of the elements. This leads to less efficient operation of the screw compressor.
In this study individual elements are studied for power loss predictions and a general method will be proposed for calculation of overall power loss.

Predictions for mechanical power loss

Rolling bearings

The bearing frictional power loss consists of loss due to rolling, sliding movement between the rolling and the stationary races of the bearings and due to oil churning between the races of the bearing. Also, the frictional moment can be divided into two groups as load dependent and load independent case. The load dependent case represents loss due to loads acting on the bearing while the load independent case represents loss due to lubricating oil/grease. For rolling bearings power loss prediction; SKF, Harris and Palmgren models are analysed and compared for the operating range of the compressors from 6.5 to 12.5 pressure ratio with operating speed reaching up to 40 m/s.

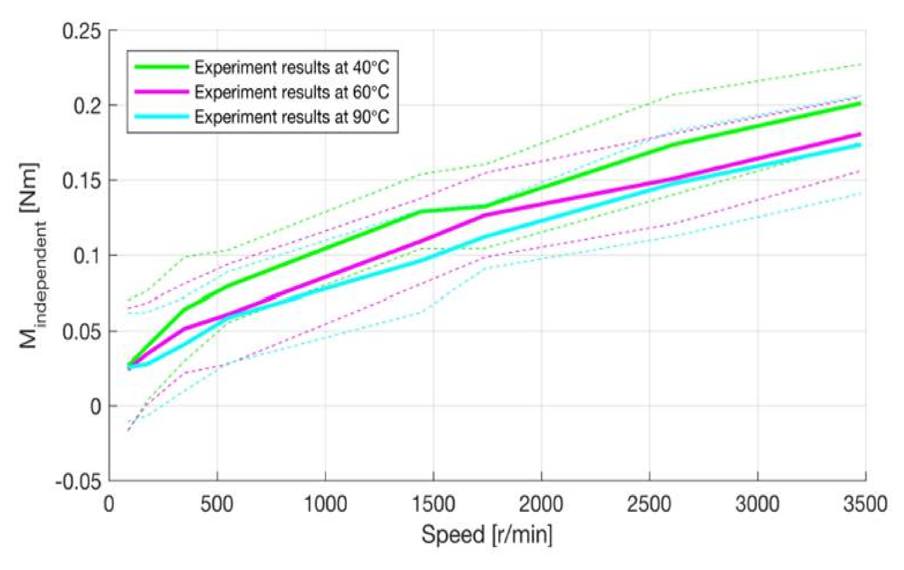


Figure 3: Experimental resutls of load independent power loss

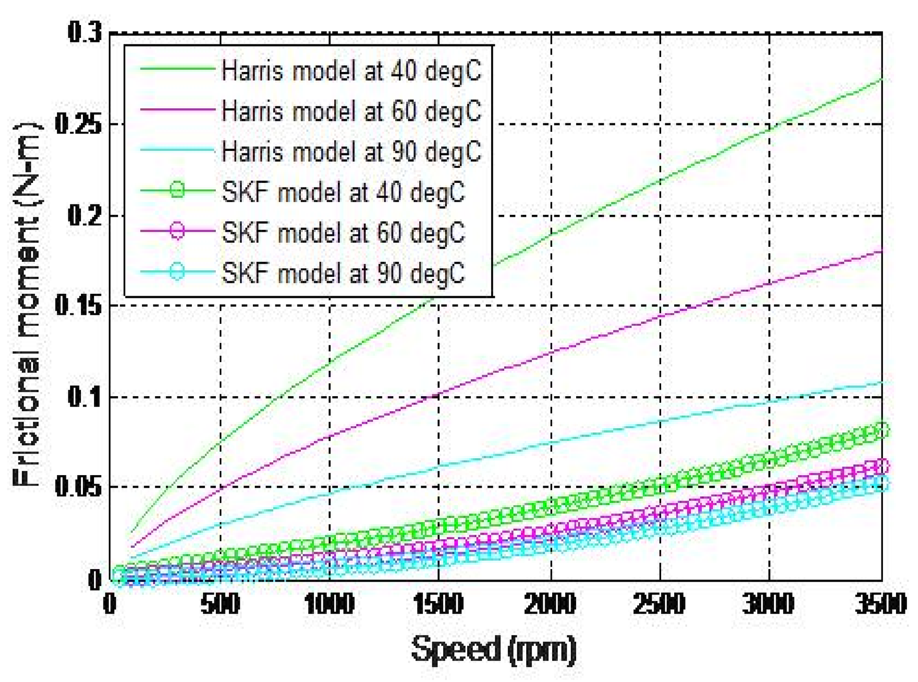


Figure 4: Predictions of Harris and KSF model for load independent power loss

From the analysis and comparison from experimentally results available in literature, it is clear that Harris model predictions are better.

Oil drag

Oil is mainly used for three different purposes inside the oil injected screw compressor. It is used for cooling of the gas during compression, sealing of the clearances gaps and forming lubricating layer between two relatively moving elements. A rotating Couette flow model is considered for the calculation of oil drag loss between the clearance gaps.

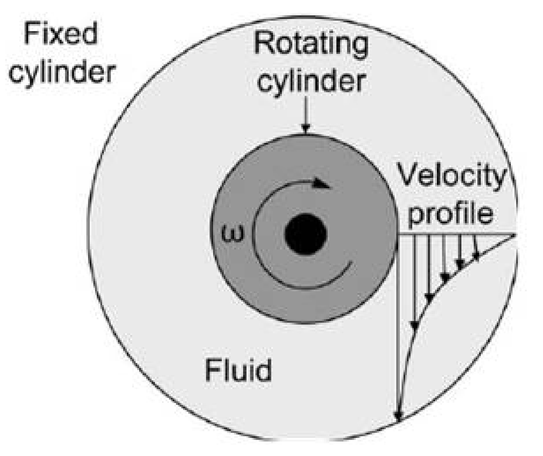


Figure 5: Rotating Couette flow

Oil fills the clearance gaps between the rotors and between the rotors and the housing. The reduced form of 2D rotating Couette flow for velocity profile between the clearance gap is as shown below.

$$u_\theta = \frac{V_t r_i}{r_o^2 - r_i^2}\left(\frac{r_o^2}{r} - r\right) \tag{1}$$

Improvements in the predictions of oil drag loss are brought by the use mixture, air-oil, properties and use of Cicchitti correlation. Cicchitti et al. (1960) proposed a model to predict two-phase viscosity as below

$$\overline{\mu} = x \times \mu_g + (1 - x) \times \mu_f \tag{2}$$

The Cicchitti correlation shows better predictions as compared to McAdams and Dukler correlations when compared with the overall power loss measurements.

Shaft seal

Frictional torque arising out of radial shaft seal is proposed by Frolich et al. (2014) and Engelke (2011) have found to be the most suitable. The methods predict the frictional loss using an iterative method with initial assumptions of seal surface and oil temperature.

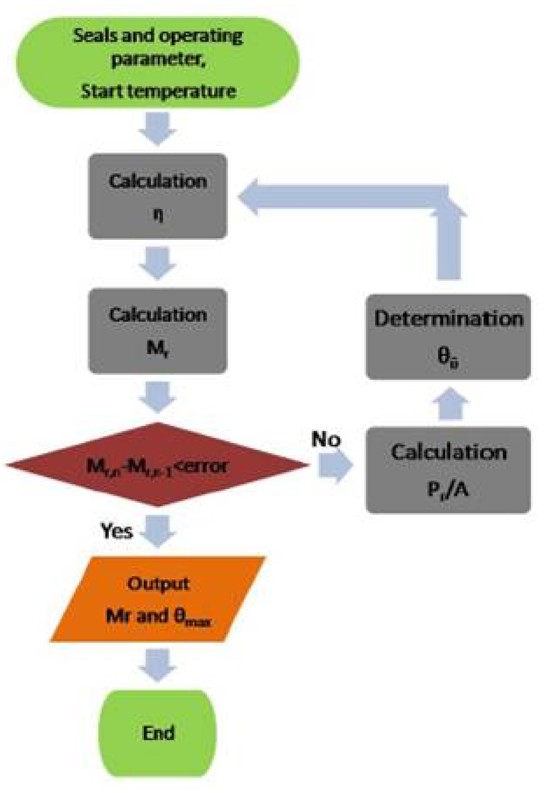


Figure 6: Flow chart for calculation of shaft seal frictioanl torque

Results

It is experimentally measured that around 14-20% of the shaft power is lost in the range of 10-35 m/s of operating speed and pressure ratio between 6.5 to 12. With the use of proposed model which includes different power loss prediction models, it is observed that the bearing power loss constitutes around 70% of overall power loss for low speeds of 10 m/s which increases up to 81% for relatively high speeds of 35 m/s. The contribution from oil drag loss using rotating Couette flow model and with the use of Cicchitti correlations for mixture properties, is found to be 29 to 18% of the total shaft power respectively for 10 to 35 m/s of operation.
This concludes that the bearings and oil flow properties are the major contributors of mechanical power loss within the oil injected screw compressor. The contribution by these two elements is around 99% of overall power loss as predicted by the model proposed.
Following figure shows the overall loss prediction for one of the oil injected, twin-screw compressor size with 4/5 male/female rotor lobe combination used for 22 kW motor rating. The model predictions are compared for different pressure ratios from 6.5 to 12 and tip speed of the male rotor from 10 to 31 m/s.

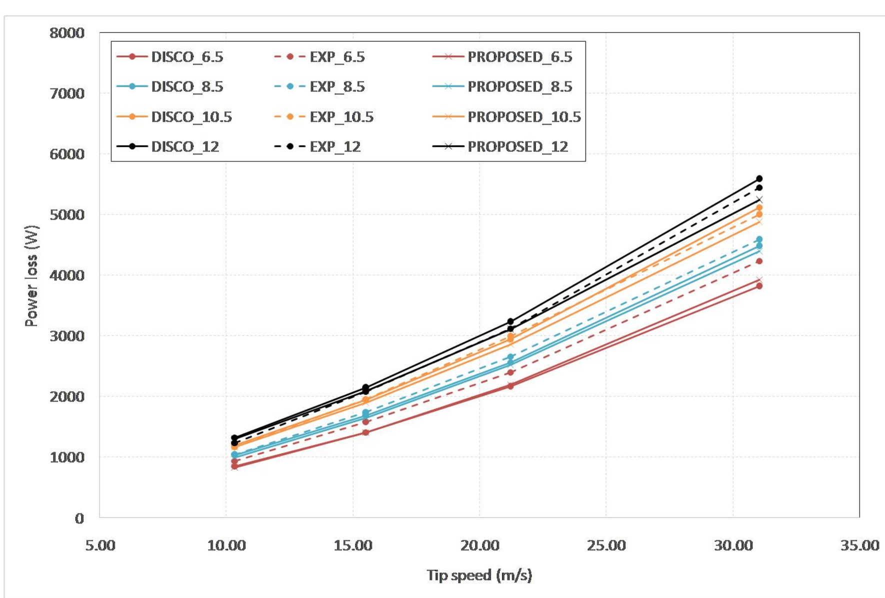


Figure 7: Total mechanical power loss 98mm compressor DISCO, Proposed model, Experiment

As can be seen from the figure, with the use of proposed method, the prediction of overall mechanical loss matches well with the experimental observation as well as with DISCO model. The DISCO is a tool for screw rotor profile generator and performance calculator suite developed by continuous research at Centre for Compressor Technology. Upon completion of the model and validation over a wide range of operation, the method can be used for parametric analysis at design stage. The analysis will help designers to optimally select the elements like bearings, shaft seals, gears and oil flow properties etc. and to build better energy efficient compressor.

Acknowledgements

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