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ON TWIN-SCREW COMPRESSOR GAS PULSATION NOISE

J. Tanttari

VTT AUTOMATION, P.O.Box 1307, FIN-33101, Tampere, Finland

Tel.: +358 3 3163235 / Fax: +358 3 3163782 / Email: jukka.tanttari@vtt.fi

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ABSTRACT
Screw compressors are rotary positive displacement compressors with two rotating rotors. The gas is compressed in the decreasing interlobe spaces between the rotors. Oil is injected to the process for sealing and cooling. At the point determined by the built-in compression ratio, the compressed gas is discharged to a discharge tube. The discharge flow is periodic thus giving rise to gas pulsations. The source of sound may be described as a combination of fluctuating volume velocity source and a discontinuous pressure (force) source. The resulting sound pressures at the discharge tube are high, of the order up to 3 % of the ambient pressures. The results to be presented consist of experiments on the effect of operating parameters (discharge pressure, rotational speed, temperature, oil content) on the sound pressure and of experiments on the source properties of the discharge opening. The findings are discussed in the light of theoretical background. The discharge tube sound pressure is a smoothly increasing function of static discharge pressure. A traditional assumption has been that there is a clear minimum at the pressure point where the built-in pressure at the moment of discharge equals the static pressure in the discharge tube. However, the experiments do not support such an assumption. The effect of oil mist or "foaming" also seems to have a strong influence on the sound propagation, thus making difference to the "dry gas" assumption. The measurement of source properties and the non-linear effects are discussed.

1 - INTRODUCTION

Screw compressors are rotary positive displacement compressors with two rotating rotors, Fig. 1. Gas is compressed in the decreasing interlobe spaces between the rotors. Oil is mixed to the gas during the compression for sealing and cooling.
Compressor noise has been a subject to many studies [1]. However, there have been few studies of screw compressor noise. Sångfors [2] reported of high sound pressure levels at screw compressor discharge and noted attenuating effect of oil. Koai and Soedel [3] studied theoretically the effect of discharge pressure on port flow and the interaction of the flow with discharge system gas dynamics. This paper discusses basic characteristics of gas pulsation noise in screw compressors. Selected results of sound pressure measurements in the discharge tube are presented.

2 - GAS DISCHARGE AS A SOUND SOURCE

At the instant determined by the geometric form of the discharge port, the compressed gas is discharged to a discharge tube. The flow is periodic in nature thus generating certain type of noise called gas pulsation. The Fourier series describes the periodic discharge flow $Q(t)$ as sum of DC-component and time harmonic components. The harmonic components of the flow may be seen as volume velocity sources acting at the associated frequency. The time variant part $q(t)$ is the difference between the total flow volume velocity $Q(t)$ and the flow DC-component Q. The first estimate for the resulting sound pressure $p(t)$ is obtained from the multiplication of $q(t)$ and a suitable impedance (for plane waves in an "infinite" discharge tube), scaled for the tube area:

$$p\left(t\right)=\frac{\rho c}{S}\left(Q\left(t\right)-Q\right)=\frac{\rho c}{S}q\left(t\right) \tag{1}$$

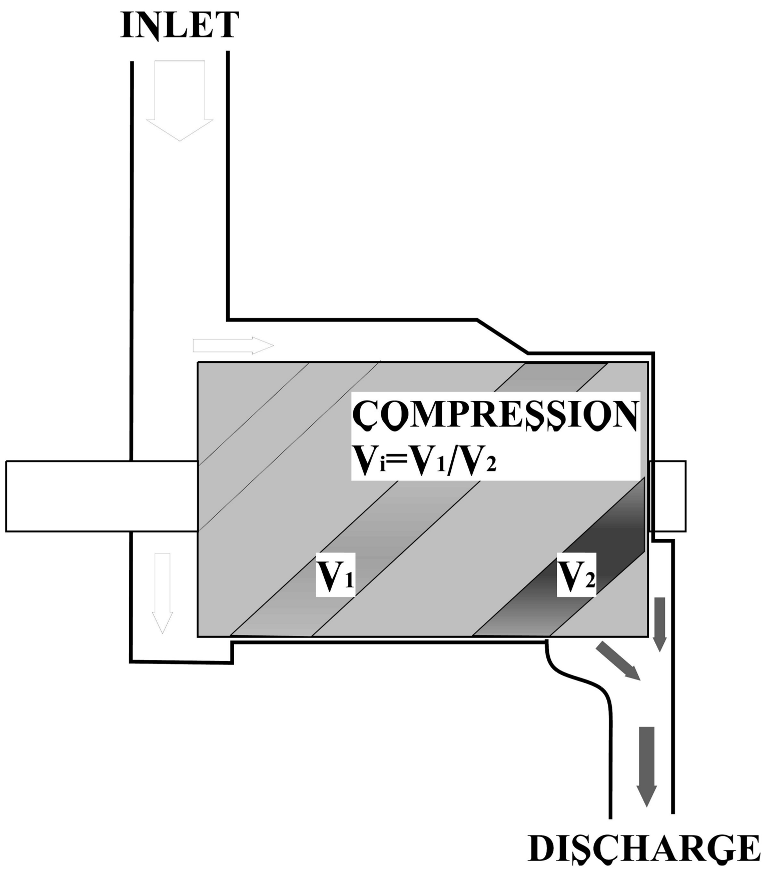

Figure 1: Screw unit, side view.

where ρ is the gas density, c is the speed of sound and S is the cross-sectional area of the tube. The estimated sound pressure amplitude for the concerned screw unit is about 15 kPa (177 dB), when a half-sine pulse lasting 50% of the discharge period is used.
There is another source mechanism associated with the pressure difference (net force) between the compressed pressure and the discharge (ambient) pressure at the discharge. It may be assumed that the sound generation is at minimum when the compressed pressure equals the discharge pressure [2,3].

3 - MEASUREMENTS

Measurements were carried out to get knowledge of sound pressures in the discharge tube, especially the dependence of sound pressure on discharge pressure, rotational speed, oil flow and temperature. The displacement volume of the screw unit was 0,6013 l/rev and lobe combination "4/5". The volume ratio was 4.6. A special measurement tube installed between the screw unit and compressor housing was used (Fig. 2).
Pressure signals were detected using four piezoelectric pressure sensors (PCB type M102A07). The signals were analysed by a four-channel signal analyser LD 3200. The drive axis was used as a trigger source and for tacho measurements.

4 - SELECTED RESULTS

The total sound pressure levels in the tube were calculated from levels at individual measurement points. The male rotor rotational speed was 3500 rpm and the fundamental pulsation frequency (1. order) was 233 Hz. The "discharge pressure" means overpressure. A typical sound pressure spectrum is shown in Fig. 3. Usually the first eight harmonic components contain most of the energy.

4.1 - Effect of discharge pressure

The effect of discharge pressure on sound pressure is shown in Fig. 4. The levels at the first three orders show a clearly rising trend, roughly 5 to 7 dB per doubling of the absolute pressure. The higher orders show no clear trend.

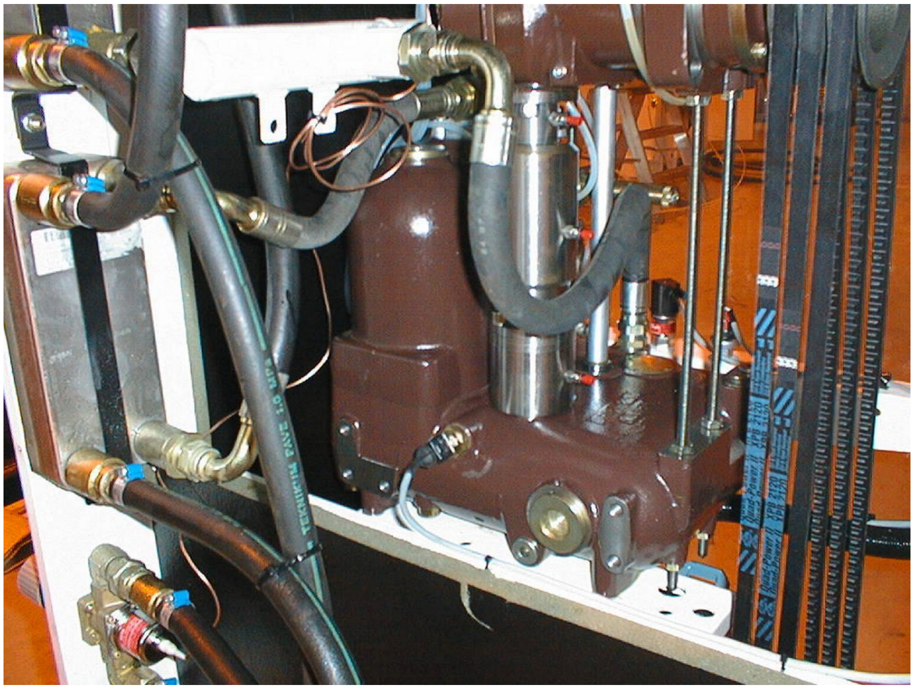

Figure 2: Measurement set-up (meas. tube is the clear thick upright part).

Another interesting observation was that the speed of sound decreased when the pressure increased. At the usual discharge pressure range 6…7 bar, the speed of sound assessed from phase differences was 280…320 m/s, far less than about 380 m/s, which might be expected from ”dry gas” theory at temperatures around 370 K.

4.2 - Effect of oil on sound pressure

The results are presented in Fig 5. A clear finding is that decreasing the oil flow increased the sound pressures at the higher 5…8 orders by up to 15 dB: The levels at lower orders were relatively insensitive to the oil flow.

5 - DISCUSSION

The resulting sound pressures are quite well (within a few dB) approximated by the equation. However, this applies only to total levels, not frequency distributions.

No clear minimum was found in sound pressures measured as function of discharge pressure. However, the minimum reported in [2] was anyway local and weak. The higher orders showed a maximum at intermediate pressures. The increase of sound pressure indicates that the screw unit is a high-impedance (constant volume velocity) source at low orders. The constant volume velocity source would theoretically increase the sound pressure 5.6 dB when discharge pressure increases from 4.1 to 8.7 bar. The measured increase was 6.4 dB.

The ”oil attenuating effect” noted in [2] is confirmed. However the ”attenuation” was measured at higher orders (from order 5) than in Sångfors' measurements (from order 3). An explanation to the ”attenuation” might be simply a more linear (shock-free) acoustic behaviour at high oil flows. Altogether, the influence of oil on the acoustic behaviour of the gas in discharge tube seems to be one of the key challenges in the future work.

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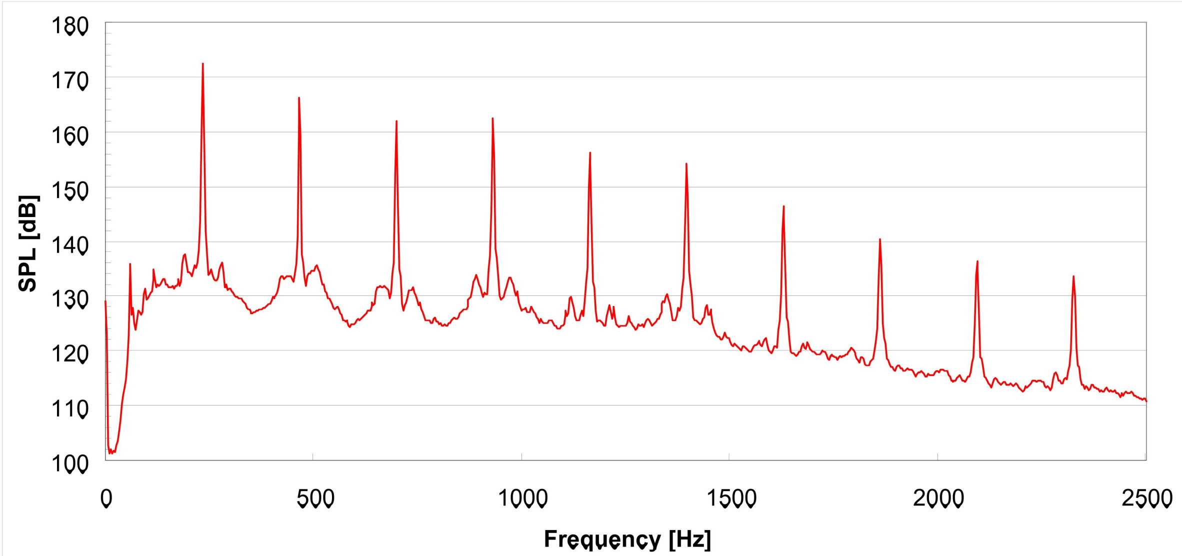

Figure 3: A sound pressure spectrum in discharge tube (6.6 bar).

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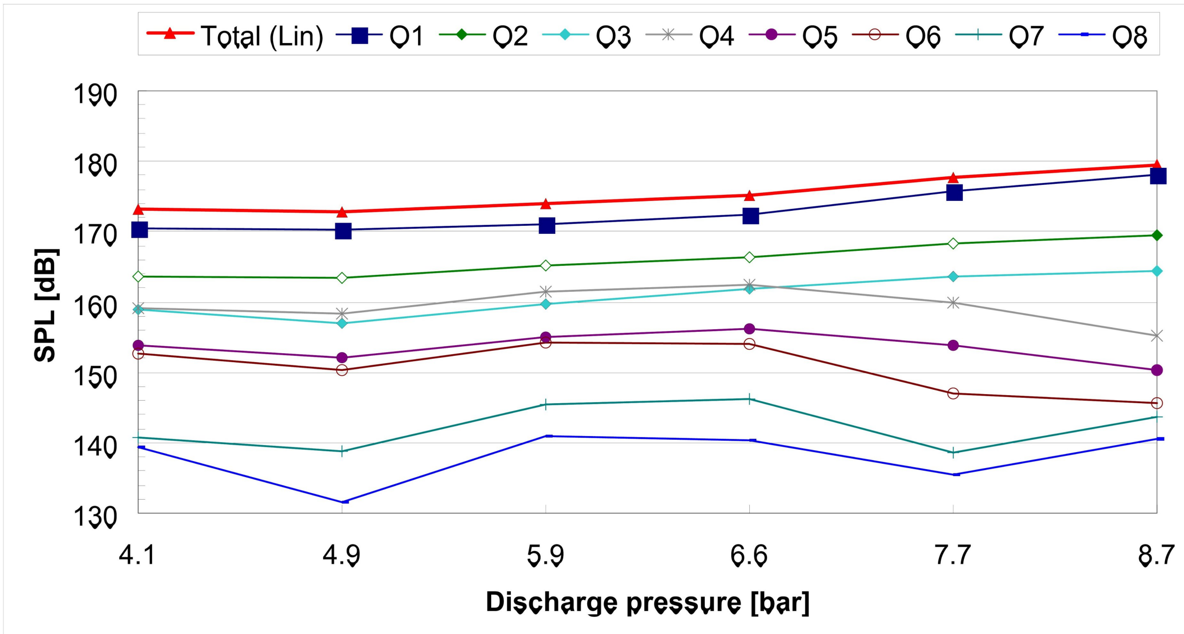

Figure 4: Effect of discharge pressure on sound pressure (O1 is 1. harmonic etc.).

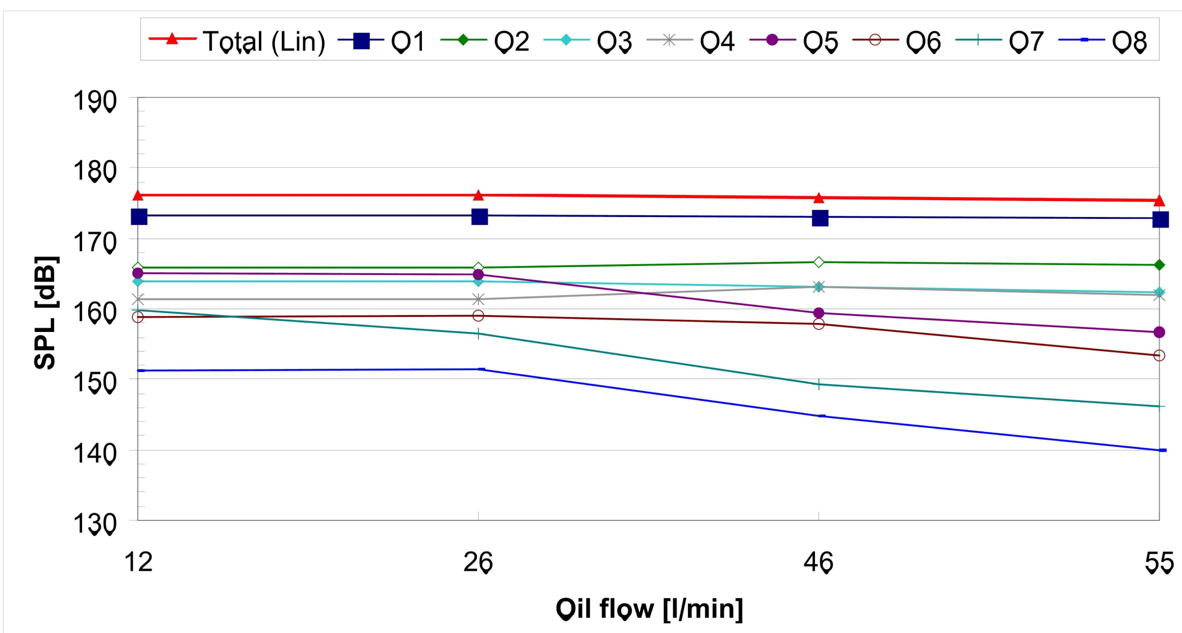

Figure 5: Effect of oil flow on sound pressure (7 bar).