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X. Qian

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Qian Xinghua

Chemical Machinery Section, Xi'an Jiaotong University,
The People's Republic of China

ABSTRACT

This paper analyses the inlet noise of the piston compressor, and through experiments the main inlet noise source has been found, indicating that for the normal running compressor, the throttling jet noise cf the inlet system is much more greater than the noise from valve plate and the impact noise of the piston ring, the throttling jet noise is the main noisesource of the inlet system. Based on the above, the calculating formula of the inlet noise Sound Pressure Level (SPL) has been derived, and verified through 20 compressors of 11 types with capacities 0.6--100 M^3/min.

SYMBOLS

c sound wave velocity before jet

C_o sound wave velocity after jet

D first cylinder diameter

d jet diameter

d_s equivalent jet diameter

g acceler ation of gravety

K C_p/C_v

L inlet noise SPL

L_j inlet jet noise SPL

L_p impact noise SPL of the pistion ring

L_v impact nise SPL of the valve plate

M Mach number

M_s equivalent Mach number of the inlet system

n Lighthill number

p atmospheric pressure

p_j jet noist pressure

p_o fundamental sound pressure

R gas constant

r distance

T absolute temperature before jet

T_o absolute temperature after jet

u piston velocity

V jet velocity, impact velocity

ε_1 first stage pressure ratio

ρ air density

η damping cotfficient

δ_s relative suction pressure loss

INTRODUCTION

The air compressor is of astrong noise source. In order to provent the noise polution, limiting the noise has been ligislated. So the noise index is important to appraise the air compressor. The noise of the compressor is radiated through the following three:

a) The inlet system noise.

b) The second solid noise transmited by the machine body.

c) The solid noise produced by machanical vibration and trnsmited through the base.

Among the three the inlet noise is much more greater than the other two. Even if the best muffler is adopted, to the most, the inlet noise may be abated to the noise level transmited by the machine body. For desighning an advanced muffler, the inlet noise SPL must be known. Up to now, many people have done a lot based on the drawing of the compressor to calculate SPL and evindent progress have been made. However it is too complicated because of the complicated mathematic model and it is too expensive, sometimes the expenditure is much more than the expenditure spent by building a muffler itself.

The calculating formula for inlet noise SPL derived in this paper has advantages of simple operation and need of no profound mathematics, in addition, it is based on the noise testing.

THE DERIVATION OF THE CALCULATING FORMULA FOR INLET NOISE

The inlet systim consists of the all deveces from the inlet of the air compressor to the surface - piston top of the first stage. So the noise produced within the inlet system has three sources:

a) The impact noise of the piston ring: the piston ring has three motions (along axis, radius and rotation), in addition, the piston has a simple harmonic motion, so the impact btween piston ring and piston groove would occured.

b) The impact noise of the valve plate: When operation, the valve plate will dash against the spring, valve lift guard, valve seat.

c) Throttling jet noise: The inlet system consists of several series throttlings (air filter, unloader valve, suction valve and so on).

Piling the three components of the noise by decibel, the inlet noise SPL will be given. Let L_p, L_v, L_j represent the three components of the noise separately. L reoresents the noise SPL, then

$$L = 10 \log(10^{0.1Lp} + 10^{0.1Lv} + 10^{0.1Lj}) \qquad (1)$$

The Lj may be obtained by aeroacoustic. As for Lp and Lv, we attain the two parameters by practicaly testing, then compared with Lj separately in order to obtain the ratioes. The brief follows. After abolishing the impact noise of valve plate and piston ring in any way, then test the inlet noise SPL, that is the throttling jet noise SPL Lj. Thereafter manage to get the piston ring noise back then test the inlet noise SPL, i.e. the decibel sum of Lj and Lp. Resolving the sum by decibel, the Lp is obtained. In the same way the impact noise SPL Lv of the valve plate could be obtained also.

On the compressor L2-10/8-I, the above experiment is carried on. The impact noise depends on the damping coefficient η of the parts and the dashing load mv. To prevent the impact noise, the material with high damping coefficient η and less density is used in place of the cast iron piston ring and steel valve. In this case, Lp and Lv are nulled, so Lj is obtained. Thereafter, get the Lp and Lv back in turn to test the inlet noise, Lp and Lv are obtained separately. The result shows Lp and Lv are so much less than Lj that they could be negleted completely, i.e. the inlet noise of the compressor depends on the throttling jet noise, in that case

$$L = 10 \log 10^{0.1Lj} = Lj \qquad (2)$$

Let us calculete Lj by aeroacoustics. The formula for SPL is

$$L = 20 \log \frac{p}{p_o}$$

I.e.

$$L = 20 \log \frac{p_j}{p_o} \qquad (3)$$

Where p_p is the excess pressure of the throttling jet noise. The formula is

$$pj = \frac{1}{r}\sqrt{\frac{wc\rho}{\pi\beta}} \qquad (4)$$

For the air flow speed of the inlet system, the Mach Number $M<1$, so the throttling jet noise power W may calculated using Lighthill speed to the eighth power formula

$$W = \frac{n\rho^2 d^2 v^8}{\rho_o\ C_o^5} \qquad (5)$$

Where rerreset represents the air dencity, C represents the sound speed. From a single stage cylinder and the inlet sustem continuous equation we can get

$$V = \left(\frac{D}{d}\right)^2 u \qquad (6)$$

And

$$\rho = \frac{p}{RT} \qquad (7)$$

$$C = \sqrt{KgRT} \qquad (8)$$

The throttling jet is of a isentropic process, so

$$\frac{p}{\rho^k} = \text{const}$$

Deffrentiate it and the formula (7), we can get

$$\frac{dp}{p} = K\frac{d\rho}{\rho}$$

$$\frac{d\rho}{\rho} = \frac{dp}{p} - \frac{dT}{T}$$

Based on the above two equations, we get

$$\frac{dT}{T} = \frac{K-1}{K} \cdot \frac{dp}{p}$$

$$\frac{\Delta T}{T} = \frac{K-1}{K} \cdot \frac{\Delta p}{p} \qquad (9)$$

Because of the relative pressure loss $\Delta p/p$ is very small. We can see from (9), that the relative tempreture variation is very small, too. In this case, we consider that the pressure, temperature are not changed before and after the throttling, i. e. $p_o = p$, $T_o = T$. So from (7), (8) we get $\rho_o = \rho$, $C_o = C$. Considering

$$V = MC \qquad (10)$$

The formula of inlet system jet noise power of the air compressor is represented

$$W = nkg\rho uD^2M^7 \qquad (11)$$

the inlet system consists of several throttlings in series, showing as Fig. 1.

Based on the formula (11), the following throttling jet noise powers are given:

$$W_1 = nkg\rho uD^2M_1^7$$

$$W_2 = nkg\rho uD^2M_2^7$$

$$\vdots$$

$$W_i = nkg\rho uD^2M_i^7$$

Summing them, the total throttling jet noise power of the inlet system

$$W = W_1 + W_2 + W_3 \dots + W_i$$

$$= nkgpuD^2 \sum_{i=1}^{N} M_i^7 \qquad (12)$$

Let $$M_s^7 = \sum_{i=1}^{N} M_i^7 \qquad (13)$$

The M_s represents the equivalent Mach Number. Let the equivalent throttling corresponding to the M_s is d_s , then Fig. 2 is equivalent to Fig. 1. Substituting (13) into (12) and considering M_s may be expressed as pressure loss δ_s

$$M_s = \sqrt{\frac{2\,\delta_s}{K}}$$

the formula (11) may be expressed as

$$W = nkgpuD^2 \left(\frac{2\delta_s}{K} \right)^{7/2} \qquad (14)$$

According to (4), (2), (14), the formula is reformed as

$$L = 20 \log\left[\frac{D}{rp_o} \left(\frac{nkgpuc}{\pi \beta} \right)^{1/2} \left(\frac{2\ \ s}{k} \right)^{7/4} \right]$$

Consideri g the air compressor, $K = 1.4$, $\rho C = 400$, $p = 1 kgf/cm^2$, $\beta = 2$, $p_o = 2\times10^{-5} N/m^2$. Substituteing them into the above formula

$$L = 188.64 + 35 \log\delta_s + 20\log\frac{D}{r} + 10\log u + 10\log n \qquad (15)$$

That is the final formula for inlet noise SPL of the air compressor. That is the fonal formula for inlet noise SPL of the air compressor. Where the limits of constant n, according to Lighthill, are taken from 3×10^{-5} to 1.8×10^{-4}. Based on the vast amount of data tested on the compressor L2-10/8-I, the constant n shouls be taken as 1.8×10^{-4}. So

$$L = 151.19 + 35\log\ _s + 20\log\frac{D}{r} + 10\log u \qquad (16)$$

Where the air compressor parameters δ_s, D, u, are all known, r represents the distance to test the noise. So it is conveniet to calculate the air compressor inlet noise SPL through the formula (16). If the pressure loss δ_s of the inlet system is unknown, it may be looked up through Fig. 3 and corrected using $(u/3.5)^2$.

VERIFICATION OF THE FORMULA CORECTNESS

To verify the correctness ot this formula (16), this paper gives 20 compressors under 10 types and 6 capacities (0.6, 3, 10, 20, 40, 100 M^3/min). The datd practically testes and calculated through the formula (16) are all shown in the table 1, from which we can see that they are nealy equal. The 19 errors are all small (0.2% - 3.8%) except one error is greater (6.8 %).

To a certain extent, the result is satisfacted, because there a lot of factors to affect the noise test, such as the atmospher ambient, the circumstances of testing the noise ,the instrument correctness, the skill of the operators and machine running state, and so on, even for the same one machine, the difference is unavoidable.

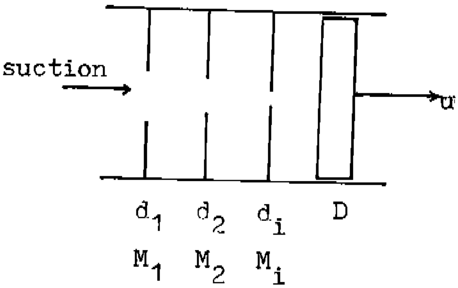

Fig. 1

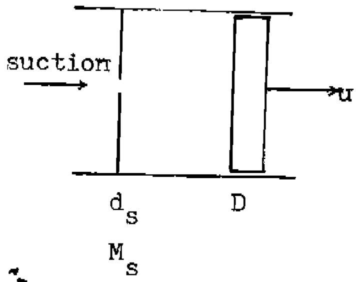

Fig. 2

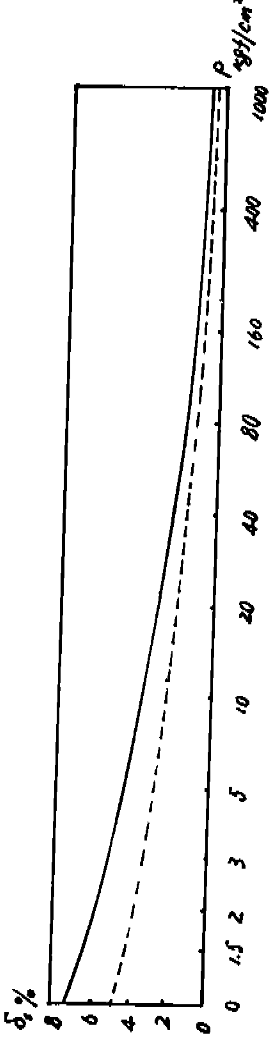

Fig. 3

Table 1.

	Type	Q M^3/min	D m	u m/s	δ_s %	r m	$L=151.19+35\lg\delta_s+20\lg\frac{D}{r}+10\lg u$	measuring SPL(dB)	error %
1	2V-0.6/7-B	0.6	0.09x2	2.66	6	1	L=151.19-42.76-17.91+4.25=94.77	92	3.0
2	2V-0.6/7-B	0.6	0.09x2	2.66	6	1	L=151.19-42.76-17.91+4.25=94.77	94	0.8
3	V-3/8-1	3	0.21	3.59	6	1	L=151.19-42.76-13.55+5.55=100.43	99.5	0.9
4	2Z-3/8-1	3	0.25	2.92	6	1	L=151.19-42.76-12.04+4.65=101.04	102	0.9
5	2V-6/8-1	6	0.21x2	3.59	6	1	L=151.19-42.76-10.55+5.55=103.43	104	0.5
6	L2-10/8-I	10	0.275	3.92	8	1	L=151.19-38.39-11.21+5.93=107.52	106.4	1
7	"	"	"	"	"	"	"	106.9	0.6
8	"	"	"	"	"	"	"	109.5	1.8
9	"	"	"	"	"	"	"	107.3	0.2
10	3L-10/8	10	0.300	3.2	6	1	L=151.19-42.76-10.46+5.05=103.92	106.5	3.3
11	"	"	"	"	"	"	"	110.5	6.8
12	"	"	"	"	"	"	"	105.6	2.4
13	"	"	"	"	"	"	"	104	0.9
14	L3.5-20/7	20	0.38	3.92	8	0.5	L=151.19-38.39-2.38+5.93=116.35	118.5	1.8
15	L3.5I-20/8	"	"	"	"	"	"	121	3.8
16	4L-20/8	20	0.400	3.2	6	1	L=151.19-42.76-7.96+5.05=105.52	106	0.5
17	"	"	"	"	"	"	"	109	3.2
18	"	"	"	"	"	0.5	L=151.19-42.76-1.94+5.05=111.54	113.6	1.8
19	L5.5-40/8	40	0.560	3.2	8	0.5	L=151.19-38.39+0.98+5.56=119.34	118	1.1
20	7L-100/8	100	0.840	3.7	8	0.2	L=151.19-38.39+12.46+5.68=130.94	128	2.3