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WHISTLING PHENOMENA IN ISA 1932 NOZZLES

C. Millard*, M. Hirschberg**

* dBVib Consulting, 9, rue du 11 novembre, 38200, Vienne, France

** Eindhoven University of technology, Den Dolesh, 5612, Eindhoven, Netherlands

Tel.: 04.74.78.89.70 / Fax: 04.74.78.89.79 / Email: dbvib-cons@dtr.fr

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ABSTRACT

Large amplitude (110 dB) whistling tones of 1700 Hz have been observed near pipe systems carrying steam at 620K and 31 bar. Analysis of the phenomenon demonstrates that the tone is generated by a ISA 1932 metering nozzle. We suspect periodic vortex shedding at the trailing edge of the nozzle to couple with the first transversal resonance of the pipe. The conclusions are confirmed by observations on other systems and by replacing the nozzle by simple metering orifice plate. The particular trailing edge geometry of the nozzle is considered to be a possible cause of the problem.

1 - INTRODUCTION

The ISA 1932 metering nozzle [1] consists of a circularly curved inlet coupled to a cylindrical throat of diameter d_t for a pipe inner diameter d_p.
The nozzle is terminated by a small backstep of height h=0,03 d_t and equal length (w=h). The nozzle wall thickness is just upstream of this backstep t=0,07 d_t. Such a nozzle showed above a critical flow velocity a sharp whistle tone with a stable frequency. We will describe these observations more in detail and compare the phenomenon with the behaviour of related whistling systems. Based on this discussion a suggestion for further research will be provided.

2 - EXPERIMENTAL OBSERVATIONS

The phenomenon was first observed in a high pressure (p=31 bar) and high temperature (T = 620 K) steam flow through a duct with a diameter d_p=0.1907 m.
The speed of sound of the fluid (not pure steam) was estimated to be c=593 m/s. The whistling sound reached a level of more than 100 dBA outside the 14.2 mm thick pipe.
As the sound was mainly radiated at closed side branches which were not thermally isolated, we suspected closed side branch resonance as observed by Kriesels [2] and Ziada [3].
However the measured frequency f=1740 Hz did not match the Strouhal condition observed in such systems.
The frequency was quite close to the first acoustical transverse pipe resonance

$$fc = 0.586\frac{c}{d_p}$$

We therefore suspected vortex shedding at closed side branches to couple with this transverse pipe mode. The diameter of the pipe section was increased by 10% without any significant change in either amplitude nor frequency.
A significant result was obtained by removing the thermal isolation of the main pipe. The acoustical amplitude was clearly largest at the ISA 1932 flow meter placed upstream from the section considered first. In addition we now observed the subharmonic $f/2$ = 870 Hz which was radiated from the upstream pressure tap of the nozzle.
When closed this pressure tap forms a Helmholtz resonator with a volume V_h =2 * 10^{-5} m^3, a neck cross sectional S_h = 3.6*10 $^{-5}$ m^2 and a neck length L_h = 8 mm. Assuming in the pressure tap a temperature

of T = 503 K corresponding to the saturation temperature (dewpoint) of steam at 31 bar, we have a speed of sound in the resonator c = 530 m/s. Using for the end correction

$$\delta = 1.6\sqrt{\frac{S_h}{\pi}}$$

we found the resonance frequency

$$f_h = \frac{c}{2\pi}\sqrt{\frac{S_h}{V_h\left(L_h + \delta\right)}} = 1 \ \text{kHz}$$

which is close to the subharmonic $f/2 = 870$ Hz.
The amplitude of the subharmonic was weak and fluctuated in time with periods of 6 to 9 seconds. This phenomenon remains unexplained.
The whistling tone frequency f appears to scale with the square root of the temperature $\sqrt{T}$ which is expected for an acoustical resonance in an ideal gas with $c \sim \mathrm{T}^{1/2}$. As shown in the table 1 the relative change $\Delta f/f$ corresponds to $\Delta T/2T$.

frequency (Hz)	1713	1696	1690	1685	1683	1680	1688	1704
t (°C)	345	333	330	327	325	323	329	338
T (K)	618	606	603	600	598	596	602	611
$\Delta f/f$	0,0099	0,0035	0,0030	0,0012	0,0018	-0,0048	-0,0095	
$\Delta T/2T$	0,0097	0,0025	0,0025	0,0017	0,0017	-0,0050	-0,0075	

Table 1: Temperature dependence of whistling frequency.

The phenomenon was also observed in three different systems with different pipe diameters d_p and with different nozzle geometries. There is an excellent agreement between the observed whistling frequency f and the cut-off frequency f_c of those pipes

	n° 1	**n° 2**	**n° 3**
d_p	194.9 mm	237 mm	249.2 mm
d_t	123.3 mm	154.5 mm	139.7 mm
length L	71 mm	83 mm	95 mm
length l	58.8 mm	75.5 mm	63.4 mm
speed of sound c	589 m/s	607 m/s	607 m/s
whistling frequency	1750 Hz	1420 Hz	1390 Hz
f_c	1770 Hz	1500 Hz	1430 Hz

Table 2: Comparison of whistling frequency with cut-off frequency for transversal mode in three different pipes.

As the nozzle length L and the cavity depth l (fig. 1) doe not scale with the pipe diameter d_p it becomes clear that the observed resonance is not a quarter-wave-length resonance of the ring cavity formed between the nozzle and the pipe wall at the downstream side of the meter. When the ISA 1932 nozzles were replaced by metering orifice plates the whistling disappeared. This confirm that the whistling is induced by the ISA 1932 nozzle. The fact that the phenomenon appears above a critical flow velocity (U_0 = 85 m/s in the nozzle throat) indicates a vortex sound phenomenon (40 T/h mass flow). Measurements where carried out up to U_0 = 102 m/s (50 T/h mass flow).

3 - DISCUSSION AND CONCLUSIONS

The back step at the trailing edge of the ISA 1932 nozzle (fig. 1) is similar to the whistler nozzle configuration studied by Hill and Greene [4], Hussain and Hasan [5] and Hirchberg [6]. At moderately high ratios $U'/U_0<0.1$ of the acoustical particle velocity U' and the main flow velocity U_0, Hirchberg [6] reports an optimal whistler nozzle configuration with $w/h = 6$ and a Strouhal number $fw/U_0 = 0.2$. At high amplitude $U'/U_0 = 0.3$ the optimal nozzle geometry is $w/h = 3$ and $fw/U_0 = 0.14$. For the ISA nozzle $w/h = 1$ and $fw/U_0 < 0.07$ which is rather far from the whistler nozzle operation. Also the vortex shedding couples with a transverse pipe resonance while in the whistler nozzle a longitudinal mode was excited.

In this sense the observed whistling is similar to the sound production of a cylinder bundel [7] or a thick plate [8]. For a cylinder of a diameter d_c, Blevins [7] reports of $fd_c/U_0 = 0.33$ while for the plate of thickness t welsh reports $ft/U_0 = 0.23$ In our case $Sr_t = ft/U_0$=0.14 based on the thickness t of the nozzle trailing edge.

A difference between the nozzle and the cylinder or the plate is however that we have flow only at one side. Hence it could be argued that we should compare $2tf/U_0$ =0.28 for our case with the Strouhal number data of Blevins [7] or Welsh [8].

This calls for a further study of the influence of the trailing edge geometry. In particular we suspect the backward facing step of the ISA 1932 nozzle to be a source of trouble. The ASME metering nozzle has a quite different trailing edge geometry. It would therefore be interesting to study the whistling behaviour of the ASME nozzle at high flow rates.

REFERENCES

1. **R.D. Blevins**, *Applied fluid dynamics handbook*, Van Nostrand Reinhold company, 1984
2. **P.C. Kriesels, M.C.A.M. Peters, A. Hirschberg, A.P.J. Wynands, A. Iafrati, G. Riccardi, R. Piva**, High amplitude vortex induced pulsations in a gas transport system, *Journal of Sound and Vibration* , Vol. 184, pp. 343-368, 1995
3. **S. Ziada and E.T. Bühlmann**, Self-excited resonances of two side branches in close proximity, *Journal of Fluids and Structures*, Vol. 6, pp. 583-601, 1992
4. **W.G.Jr Hill and F. R. Greene**, Increased turbulent jet mixing rates obtained by self-sustained acoustic oscillations Trans ASME, *Journal Fluid engineering*, pp. 520, 1977
5. **A.K.M.F. Hussain and M.A.Z. Hasan**, The "whistler-nozzle" phenomenon, *Journal of Fluid Mechanics*, Vol. 134, pp. 431-438, 1983
6. **A. Hirschberg, J.C. Bruggeman, A.P.J. Wynands, N. Smith**, The whistler nozzle and horn as aeroacoustic sound sources in pipe system, *Acustica*, Vol. 68, pp. 157-160, 1989
7. **R.D. Blevins**, *Flow induced vibration* , Van Nostrand Reinhold, 1990
8. **M.C. Welch, A.N. Strokes and R. Parker**, Flow resonant sound interaction in a duct containing a plate, *Journal of Sound and Vibration*, Vol. 95, pp. 305-323, 1984

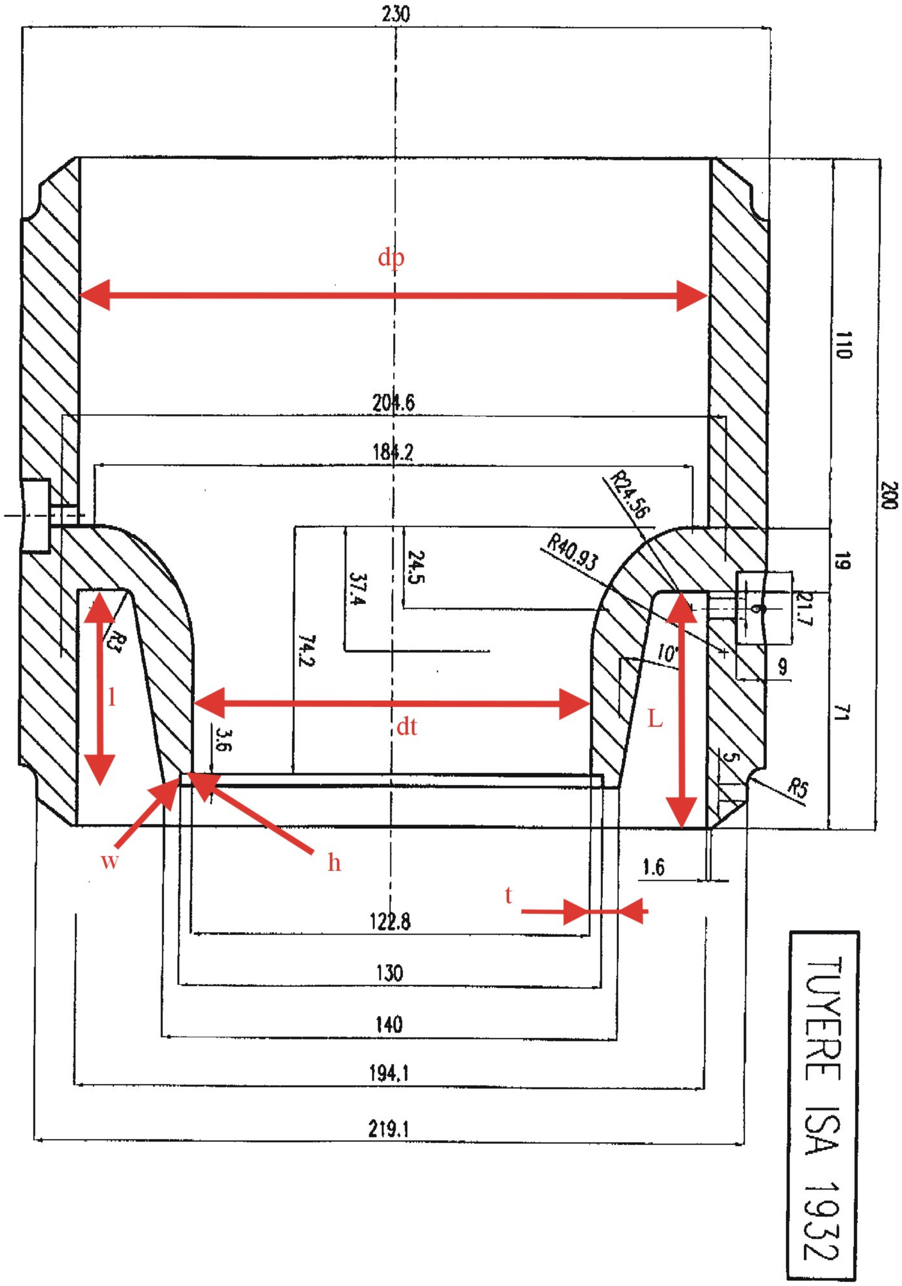

Figure 1: ISA 1932 nozzle.

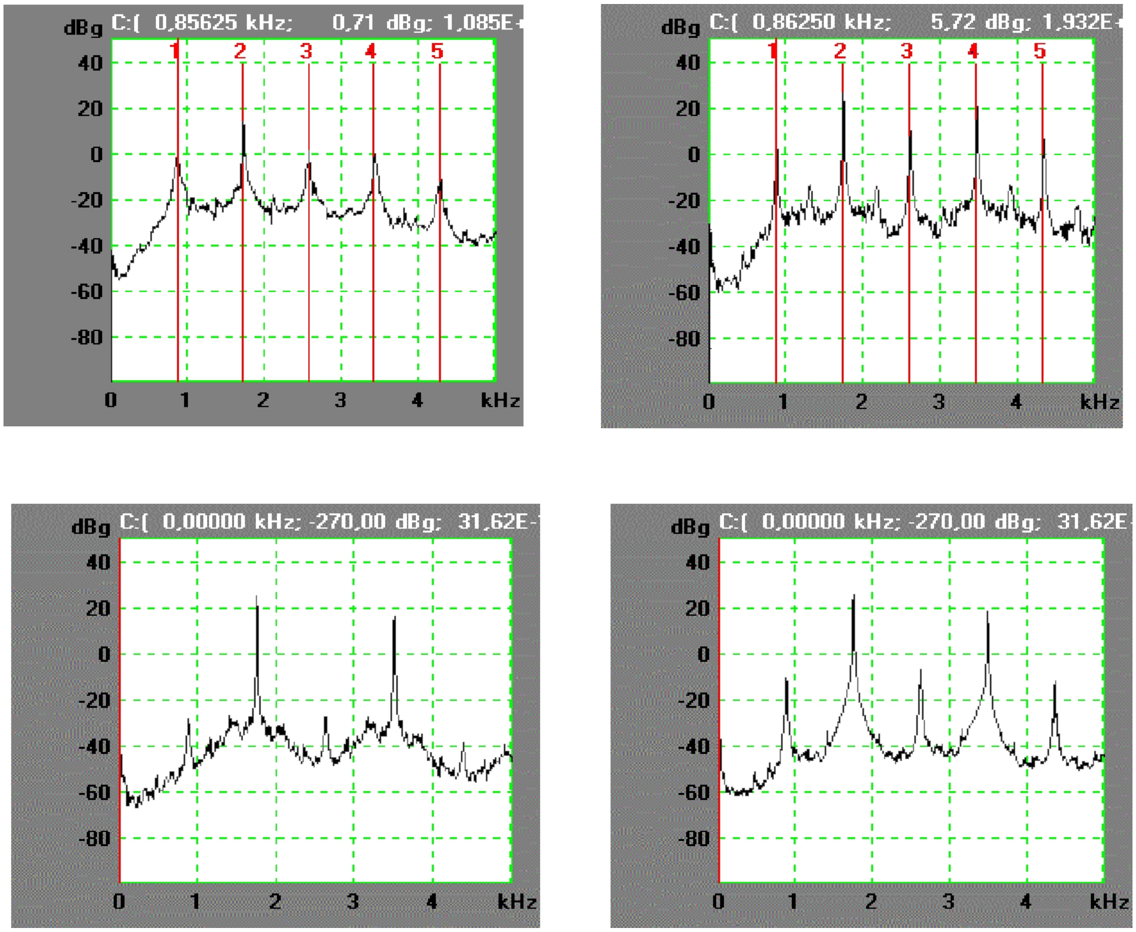

Figure 2: Typical spectrum of the sound measured at 10 cm outside the pipe near the nozzle with OROS system.