Steam Whistles

By Chris Rizzoli

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TECHNICAL TALK SUMMARY FOR SEPTEMBER 2003

This month's topic was *Whistles* presented by Chris Rizzoli. His talk covered: (1) History of the whistle, (2) Types of whistles, (3) Prototype whistle construction, and (4) Whistle engineering.

History of Steam Whistles

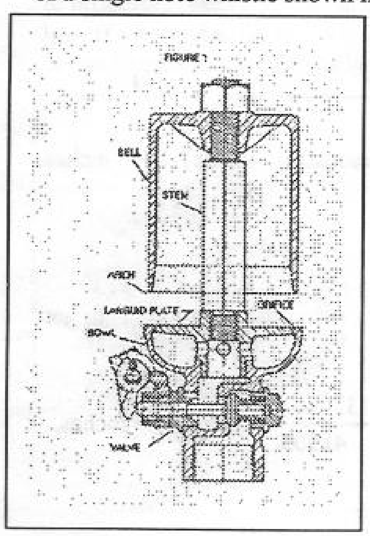
By 1835 Adrian Stevens in South Wales documented the use of a steam whistle as a warning device. The wail of a steam whistle signaling a coal mine disaster immediately comes to mind. By 1860 American companies like Hayden-Gere, Crosby, Stare, Lunkenheimer, American Steam Gauge, and many others were offering steam whistles in their catalogs. Between 1829 and 1949 over 40,000 locomotives were built which sounds like a lot of whistle should be available. However, Chris cautioned those inclined to shop for whistles to be aware that for every locomotive whistle built, 200 were built for stationary service. Hence, most of the whistles offered for sale today are of the stationary type. Locomotive whistles were over four inches in diameter whereas stationary types were three or less inches in diameter.

Types of Steam Whistles

The simplest one tone whistle is the <u>Plain Bell Single Note.</u> Later whistles were arranged to produce a chord; that is, blending several notes together to produce a harmonious sound. These included the <u>Multiple Chime Flat Top</u> and the <u>Multiple Chime Step Top</u>.

Whistle Construction

Early on brass and bronze were used in full size whistle construction; however, as steam pressures were increased these materials were not strong enough to withstand the force of the steam blast. Cast iron and nickel then became the metals of choice. The cross-section of a single note whistle shown in Fig. 1 identifies the major components. Steam from the boiler is controlled by a small poppet valve which upon opening admits steam to the bowl. The steam escapes through an orifice formed by the gap between the ID of the bowl and the OD of the languid plate. The resultant jet strikes the edge of the bell called the arch. The term is a misnomer because the edge of the bell may not be arched at all. The positioning and angling of the orifice is such that the steam jet impinges centrally on the sharp lip of the arch.

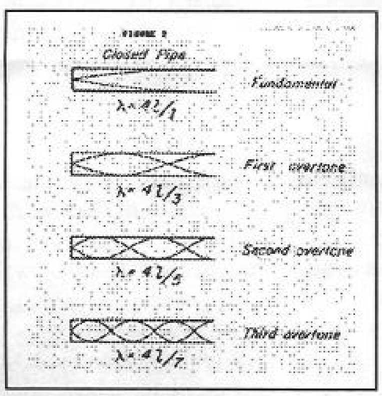


How a Whistle Works

Steam issuing from a simple orifice produces sounds of almost every frequency. We call it noise. An example is the release of steam by a safety valve. The function of a whistle is to concentrate the energy spread all over the spectrum into one frequency. At the first release of steam, a pressure wave travels to the top of the bell where it is reflected and travels back toward the languid plate. When the pressure wave reaches the arch it deflects the steam jet towards the outside. This action momentarily reduces the pressure within the bell and the steam jet once more fills the bell causing a reflection from the top and the cycle repeats. The steam jet deflecting inward and outward behaves like a vibrating reed in a musical instrument. The period of the oscillation is determined by the resonant cavity formed by the languid plate and the top of the bell. Numerically, the period of oscillation is a function of the speed of a pressure wave in steam, about 1330 feet/second, and the length of the resonant cavity.

Formula for Determining the Whistle Length for a Desired Frequency

Chris showed how to determine the length of the bell to achieve a particular note or frequency. But before going on, it should be pointed out with the help of Fig. 2 that a resonant cavity can produce not only the desired fundamental frequency, but harmonics (overtones) of the fundamental also. For the case of a steam whistle, which is closed at one end (the top) and open at the other (at the arch), only the odd harmonics will be present. The curves represent displacement of the steam particles from equilibrium. At the closed end the displacement is zero and at the open end the displacement is at a maximum. The pressure curves would be exactly the opposite. Pressure at the closed end would be at a maximum and zero at the open end. The figures show the wavelength and for the fundamental, the length of the resonant cavity is $\frac{1}{4}$ of the wavelength. The



frequency and wavelength are related by this expression: **f** = v/λ where v is the speed of sound in steam and λ is the wavelength in feet. This expression is ideal and Chris pointed out it needs to modified slightly to account of the effect of the arch opening. For cases where the orifice is open for 360 degrees, the modifier, K, is 0.95. Here is the complete expression to find the frequency if the length of the whistle is known. Chris used a length of 9.625 inches.

$$f = 12\frac{vK}{4L} \qquad (1)$$

where v = 1330 feet per second, K =0.95, L = length of resonator (whistle) 9.625 inches. Hence,

$$f = 12\frac{1330x0.95}{4x9.625} = 393.8 Hertz$$

If the frequency is known and it's required to determine L, rearrange equation (1) to get

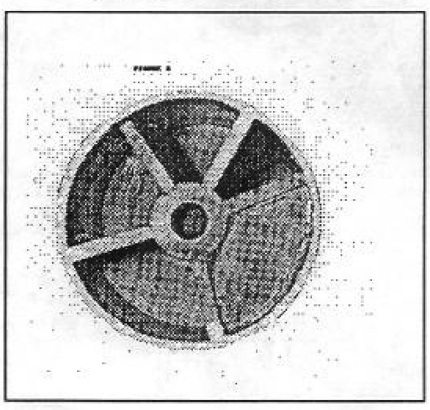
$L = 12\frac{vK}{4f}$ If the frequency is 505 Hertz find L. $L = 12\frac{1330x0.95}{4x505}$ or L = 7.5 inches.

Thus a resonant chamber $\frac{1}{4}$ wavelength long determines fundamental frequency. What about the overtones? Referring to Fig.2 notice that at $\frac{4}{3}$, $\frac{4}{5}$, and $\frac{4}{7}$ wavelength the displacement of the steam particles is the same as for the fundamental; that is, the displacement is zero at the closed end and maximum at the open end. Therefore odd harmonics will be supported. As the order of the harmonic increases, its amplitude usually decreases. The relative amplitude of the overtones depends on how the steam jet impinges on the arch lip. If the whistle is overblown, then the harmonics will predominate and the whistle will screech. The trick is to get the right balance so the composite tone is musically pleasing. It's at this point that science blends with art.

Whistle Construction

Building a small single tone whistle is mostly a lathe job using brass components and tubing silver brazed together. One way to make a chime whistle is to make single tone whistles for each tone desired and nest them into a large covering tube. Alternatively, the separate chambers can be formed inside the main tube by silver brazing separators into a central rod that has been grooved to facilitate the assembly. The individual chamber lengths are formed by fitting stops in each sector at the appropriate length. Chris recommended that the bell end with a square cut at the opening. The cutting of actual arches, while visibly appealing, invalidates the equation (1) and trial and error methods need to be used to get the right tone. That requires making the stops that close a chamber adjustable. The selection of the frequencies to make a chime whistle are based on musical chords and the advice of a musician could be helpful in making the right choice.

The amount of opening between the languid plate and lip of the bell should be made adjustable so that a compromise between efficiency and musicality of the tone(s) are balanced. The orifice gap should be about 0.06 (maximum) for high-pressure steam and about 0.02 for the lower pressures. At first, the separators in a chime whistle appear they should be distributed equally around the circle. If done that way, the fundamental will not develop its voice until the rest of the whistle is overblown. Chris explained the remedy is to proportion each chamber angle so that the highest tone has the smallest angle and the lowest the largest. Figure 3 is a view looking up into a chime whistle with chambers correctly proportioned. The basis for the angular proportions is equality of the chamber



Chris pointed out that he made many whistles before all the little nuances became clear. Once again, there no better teacher than the experience gained by actually doing something.

Many thanks to Chris for putting on a very professional and informative talk.

Technical Summary by Stephen Vitkovits