HOW DOES A RAILROAD AIR HORN WORK?

By Eric Larson with Fred Berry

For some of you, particularly long term subscribers and horn collectors, this article may at first seem superfluous. You already know how these horns work. But since we have many new subscribers and since some of you have asked how these devices work, I have included this article which will show you a typical railroad air horn and explore the way it operates.

In this article, we will look at the well-known Nathan model K Airchime horn. The K is the most widely used horn for railroad service in both the USA and in Canada, and it has appeared on some railroads in other countries as well. It is also mechanically a very simple horn as well as being a very, very loud signal, so this makes it an ideal device to study if we want to learn how these signals work.

The K represents signals known as diaphragm air horns. You can find these in many applications; on ships, on trucks and on certain public or municipal buildings, particularly fire stations, even at some lighthouses or other Coast Guard installations; these applications in addition to their ubiquitous railroad use. In some marine applications, diaphragm horns are powered by steam instead of compressed air.

The operating principal of all diaphragm air horns is that of the modulated air stream. This fancy term simply means that since sound is vibratory motion of air, if we take a blast of compressed air and modulate or chop it up in a rapid and regularly repeating manner, we will produce a very effective sound wave. The diaphragm functions as a rapidly and regularly vibrating valve which modulates or chops up a stream of compressed air into a regularly recurring series of pulses, and it does this at the narrow end or throat of a resonator which is further designed to be very efficient at coupling these pulses to the surrounding air.

We will begin with a few elementary and very simplified diagrams of a generic diaphragm air horn, and then we'll look at real K horns to see what the actual units look like. Here in figure one, we see a cross-section diagram of a simple air horn. To make it easy to understand and as uncluttered as possible, we've left out fasteners, the back cover, the air diffuser ring and the unique double-disc "kettledrum" diaphragm of a real K horn.

"So," you ask, "how can the diaphragm of the horn in this drawing stay in place without a back cover or fasteners?" To which I will say that in a drawing anything is possible, as close scrutiny of an Escher print will prove.

Here we see a horn, essentially a one-piece casting

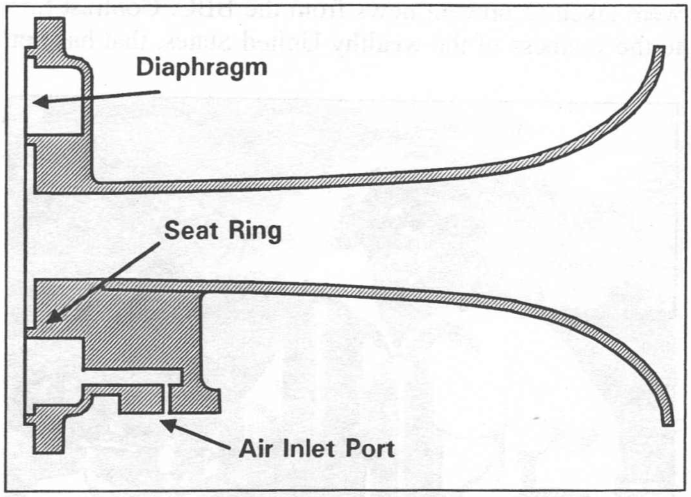

Figure 1. Elementary air horn and essential parts.

that includes an air inlet port in its base that leads to an annular space directly in front of the diaphragm, and we also see the diaphragm seat ring. Inside the seat ring a narrow space communicates directly to the throat of the horn. As it appears here, the annular space is effectively sealed off from the horn throat by the diaphragm, and air flow from the space to the horn is impossible.

When we introduce compressed air to the port, it quickly builds up pressure in the annular space. When the pressure is high enough to overcome the restorative spring force of the diaphragm, the pressure pushes the diaphragm off the seat ring (figure 2) and flows into the throat of the horn, increasing the instantaneous pressure at the horn throat.

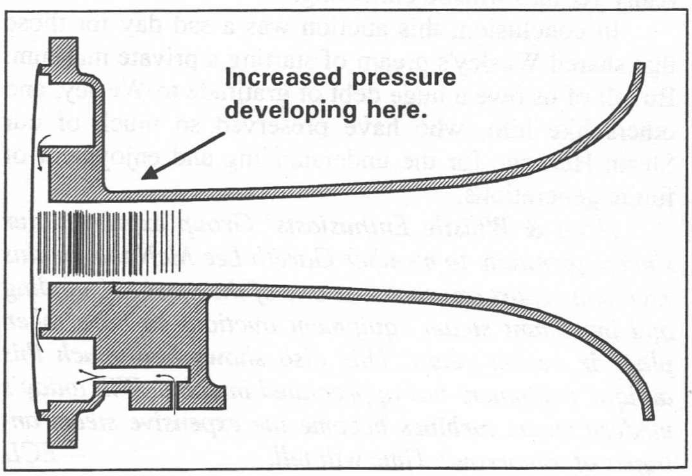

Figure 2. Air pressure in annular space deflects diaphragm backward, allowing air to flow past the seat ring and increase the pressure in the throat of the horn as shown by the vertical lines.

Soon the diaphragm deflects enough that its spring tension exceeds the force created by the air pressure in the annular space, which pressure, by the way, drops, because very quickly the newly formed opening between the diaphragm and the seat ring allows more air to enter the horn throat than can enter through the supply or inlet port. At this point the diaphragm begins to move back to its normal position. This of course cuts off the airflow into the horn throat. At the same time, the pressure wave which formed at the horn throat moves forward, creating an area of lower pressure behind it. See figure three.

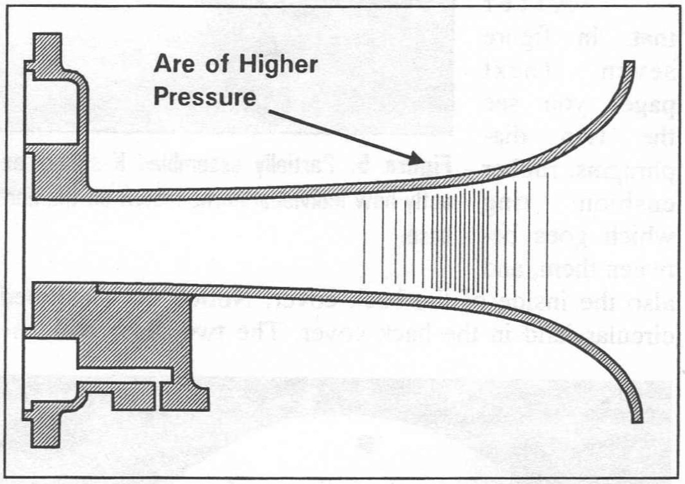

Figure 3. Pressure wave moves forward. Resulting lower pressure behind helps diaphragm to return to its starting position.

This area of lower pressure assists the diaphragm in returning to its starting position, after which, since air is still entering the supply port, the cycle can continue. As the diaphragm settles into oscillation, the air mass in the horn likewise gets set into oscillation. With each cycle, some air escapes through the bell of the horn, and more replaces it by flowing past the seat ring, however in effect, the air mass in the horn "sloshes" back and forth at the natural resonant frequency of the horn. This "sloshing" action exerts a very strong influence on the horn diaphragm and is what determines the frequency at which the diaphragm will vibrate.

If as a child, you have ever sloshed the water in a bathtub back and forth, you will have noticed that if you do it at the correct rate, the water will very quickly increase its sloshing from side to side until it spills over the top of the tub. At the same time, you will feel the water's action on you, so that you will be moving your body back and forth at the same rate. All of a sudden, one of your parents probably appeared and told you to stop, since those water stains on the ceiling below are particularly annoying to some folks. However, this illustrates the point that once the air column in the horn has been set into vibration, it does not require too much energy to keep it going, an it also exerts a strong influence on the one moveable part (the diaphragm) which is in close proximity to this vibrating air column.

This action determines diaphragm frequency, tuning it to the correct pitch. The air column in the horn has a high Q of resonance, meaning that it is easily set into vibration and at mainly only one frequency. If you snap your fingers in front of the bell of a horn, you will hear a brief echo with the actual pitch of the horn.

When the Canadian inventor Robert Swanson first developed the multi-tone or chime railroad horns, he scaled each horn's diaphragm and seat to what he determined to be the optimum diameter. Each horn also had a back cover that could be screwed in or out like the cover of a jar to put exactly the right tension on the diaphragm. All of this he did to make each horn as effective as possible at its design frequency. Subsequent experiments by Swanson and others soon proved, however, that this was not necessary. That is, one size diaphragm and seat, and a non-adjustable adequate tensioning could provide a wide range of frequencies, determined only by the resonant frequency of the horn bell. This fact became very important to both the horn makers and the railroads, because the chime horns were much better sounding and also more effective than the earlier single note "honkers" that were the first signals on diesel locomotives.

But, having a chime horn with five notes or pitches meant initially having five different groups of spare parts for repairs. It also made manufacturing much more complicated, requiring five different sets of foundry patterns and much more machining work. Once the horn makers realized that diaphragm (and thus horn) frequency was essentially just a function of the horn bell size, they developed chime horns with diaphragms and other parts all identical. The same diaphragm would vibrate at the correct frequency in any horn that they put it in, since the pitch was controlled by the air in the horn "sloshing" back and forth.

Modern five chime railroad horns typically have pitches which span a complete octave, or a 2:1 frequency ratio. Yet, despite such a wide frequency range, each horn of the chime uses exactly the same size diaphragm and other related parts. Railroads love this, because their maintenance facilities need only carry a relatively small number of spare horn parts, and it is very easy to get any horn working again, generally by simply replacing a part without having to look up a specific catalog number and then the subsequent adjusting of the tension for the best signal.

We have mentioned the horn bell as controlling frequency. But it also serves an even more important function which is the efficient coupling of the vibration of the air column to the surrounding air. This coupling is one of the reasons why the horn bell should flare out. A straight conical resonator, like a megaphone or that of a diaphone foghorn is almost as good, but much early empirical work by pipe organ builders as well as makers of other musical instruments, and of course the horn developers' own experimentation has proven that the most effective shape of all is a horn whose walls flare out in what is called a *catenary* curve.

The word *catenary* comes from the Latin word, *catena*, which means a chain. A catenary curve is the curve that an ideal chain makes when hanging freely from two points and allowed to droop down forming a roughly parabolic loop. An ideal chain is one in which all of the links weigh exactly the same and there is no friction between them. But any well-made chain will closely approximate this curve, and that is why the best air horns have horn bells that are referred to as catenary. The catenary-curved horn bell is both a very good resonator and its flaring open end is a very effective coupler of the internal vibrating air column to the outside air.

The preceding information applies to all diaphragm air horns. We will now look at a specific horn, the Nathan Airchime model K. This next picture shows a single K horn assembly not mounted to a manifold. It is a complete, single tone signal. All K horns look like this one except that others have larger or smaller bells.

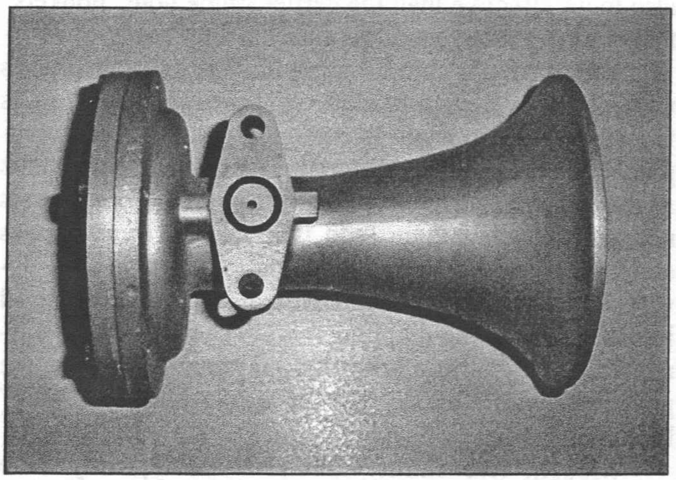

Figure 4. Single K horn. This upside-down view shows a #4 K horn and also shows its integral base with inlet port surrounded by an O ring in a groove and the two mounting bolt holes.

In the following picture, we see two horns mounted to the common base which also serves as the air manifold. This will, with the third horn added, become a three chime loco horn.

In the subsequent picture, figure six, we look at the inside of a single K horn's diaphragm housing. Notice the diffuser ring, held in place by three socket-head cap screws. The air enters through the port at the bottom (not visible, behind diffuser) and the diffuser forms a narrow circular slot which keeps the air from impinging on just one part of the diaphragm and distributes it evenly throughout the annular space. Also visible is the circular seat ring, as well as the outer diaphragm support ring. (Both are integral parts of the casting).

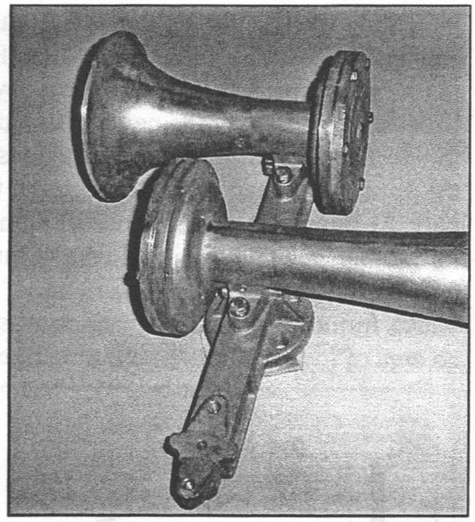

Figure 5. Partially assembled K shows exactly how individual horns mount on the horn base.

After that, in figure seven (next page) you see the two diaphragms, rubber cushion ring which goes between them, and also the inside of the back cover. Notice the machined circular land in the back cover. The two discs with the cushion ring between them form a small drum, which is why Swanson referred to the K horn as the "kettledrum principle" horn, from which it got the model designation "K" horn.

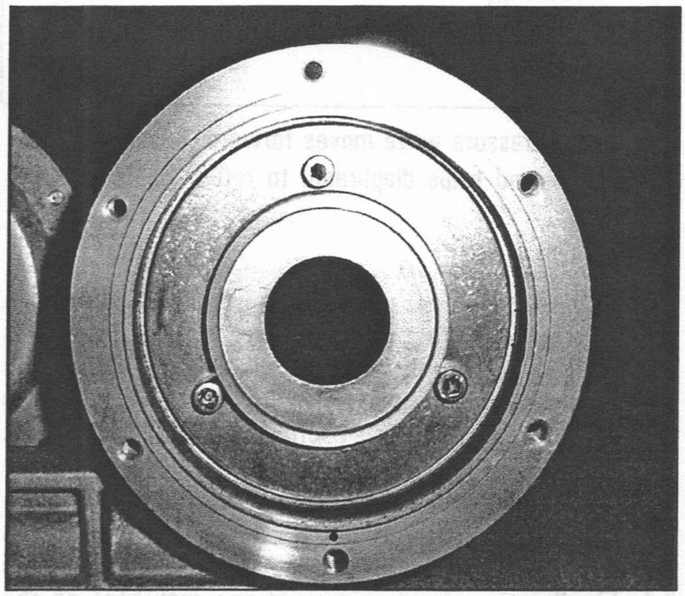

Figure 6. Interior of K horn power chamber shows diffuser ring, diaphragm seat ring and horn throat entrance. Notice the small hole at the bottom, just above the lowest bolt hole. This is for the insertion of a pin to aid in disassembly if the diaphragms and back cap should become stuck to the rest of the horn.

If you examine the forces acting on the forward diaphragm in a K horn, which is the one doing the actual air modulation, you will notice that the forward diaphragm is much freer to flex than the rear diaphragm

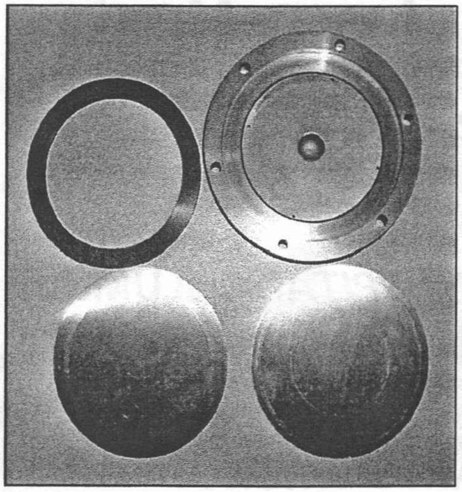

Figure 7. Upper right, horn back cover, inside view. Upper left, neoprene cushion ring, and below, the two stainless steel diaphragm discs.

which is limited by the circular land in the back cap. Therefore, when the forward diaphragm flexes backward, it compresses the air between the two. The rear diaphragm deflects slightly. This imparts a fairly complex variable tensioning which limits forward diaphragm travel, helps stabilize the pitch, and actually increases the sound output. (Nathan now uses the double-disc diaphragm system in their smaller P horns also). The forward diaphragm is tensioned by the neoprene cushion ring, which of course has considerable 'give' as compared with the unyielding land on the back cap. The back cap also has 5 vent holes which insure that when the rear diaphragm deflects, it will not compress the air in the space between the diaphragm and the back cover.

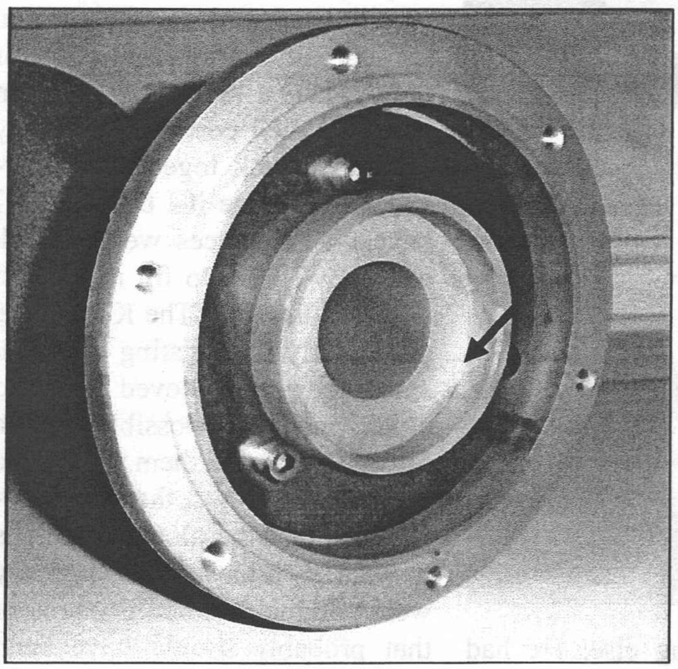

Figure 8. American tuning detail. Notice metal machined for about 0.5" away inside of diaphragm seat ring. (Black arrow) This lowers air column resonant frequency and makes the horn sound a lower pitch than it would otherwise.

The horn in figure six has the unaltered horn throat and gives the standard pitch for that particular horn. In figure eight, we see a horn where some metal has been machined away to lower its pitch for American tuning for use on a USA locomotive. The current B major 6th chord of the five chime K for American railroad usage was developed by HWEG member Deane Ellsworth when he was asked to advise on the use of the K horns for American railroad service. By retuning the horns internally, it meant that it was not necessary to have different foundry patterns and molds for individual horns that would be reasonably close in pitch but yet audibly different.

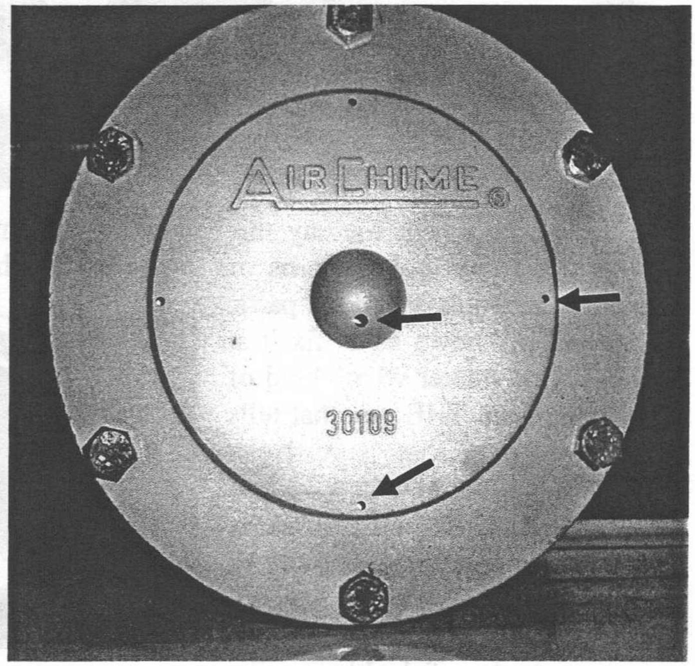

Figure 9. back of K horn shows the vent ports in the back cover (arrows) and the hex-head cap screws that hold the horn together. This same back cap is used for all sizes of current production K horns regardless of pitch or horn bell size.

Check out the article by Mike Muha in *H&W* #102 for an excellent CAD diagram of the unique Leslie power chamber which uses compressed air on both sides of the diaphragm and uses correctly timed pulses to help push the diaphragm back on the seat ring during the appropriate part of each cycle. Interestingly, each horn builder has specific unique design features which depart from the elementary basic design and in each case enhance performance. Regardless of individual design differences, all of these horns use the same operating principle. Railroad air horns are considerably louder than regular truck or fire engine horns, comparing favorably with the horns used on public buildings as fire alarm signals, the latter however being slightly larger and sounding lower pitches. —ECL