Schilke

Schilke Music Products, Inc.

529 S. Wabash Avenue, Chicago, Illinois 60605

Telephone: 312/922-0570

SCHILKE BRASS CLINIC

THE PHYSICS OF INNER BRASS ACOUSTICAL EFFECTS OF VARIOUS MATERIALS AND THEIR TREATMENT

by

Renold O. Schilke

The physical shape of the inside of a brass instrument and its mouthpiece has always been of great interest, not only to manufacturers of brass instruments, but to those who perform upon them. The harmonics of an open pipe, if the inside diameter is straight, cannot be used on a brass instrument unless the active use of a slide controlling each one of the notes in the harmonic series is applied. Many manufacturers have found that when added tapers are put to the instrument, in other words tubing of a conical shape, that it made it more possible to give a harmonic series that are closer to useable on a brass instrument. By trial and error, they evolved a method of tapering the tubing whereby very good harmonics were created and made useable. However, many years ago Victor Mahillon established a theory in which the pressure points of the nodal pattern of the inner brass could be controlled so as to change the pitch of the individual notes in such a way that a very useable harmonic series could be created. His theory calls for a change of taper at the pressure point of the node that had to be altered in order to make it a useable musical sound.

Let me first explain exactly what happens when an energy impulse is created by expelling air under pressure through the lips during the period of opening and closing, generally referred to as a vibration. This energy impulse is further compressed in the cup of the mouthpiece. This is the reason why the shape of a mouthpiece cup is so important to obtain certain effects that the performer desires. It reaches its maximum pressure point in the throat of the mouthpiece where it sets up the nodal pattern in the air that is already in the instrument, just as the first contact of a violin bow (to the string of the instrument) sets up the vibration or nodal pattern in the string. At the last point of rarefaction, which occurs in front of the bell of the instrument, a standing node is formed which gives a rescinding node going back through the instrument and culminates itself in the larynx of the performer. This is the reason why performers with different sized oral cavities will play the over-all pitch of the same instrument differently. A good example of this occurred when Mr. Arnold Jacobs and Mr. A. Hirada of Japan were in my studio trying tubas. To obtain the same pitch, Mr. Jacobs had to have his slide all the way in, making the instrument on the extremely sharp side as his oral cavity was of such a tremendous size it lowered the pitch to the given pitch. However, Mr. Hirada, whose oral cavity is very small, had to pull his tuning slide to give approximately eight additional inches of tubing to the instrument in order to play in the same pitch.

In working out a formula to shape the inside of the instrument properly, I first tried to work it out mathematically. In fact, I worked several years in making drawings of the nodal patterns of the trumpet, superimposing them on onion skin paper above one another to find out exactly where the multiples were in both the pressure points and the points of rarefaction. As you understand, it would be only at the singular points that a variation in the taper could affect a note favorably. If it was at a multiple point, we could correct one note, but all of the other notes having their pressure point at the same place would be adversely affected. After having worked out a particular formula in this manner, I tried to apply it and found I was mistaken in my calculations. If I had nothing but straight tubing to work with, the formula could be applied as I had applied it. In other words, my original formula consisted of taking the speed of sound, dividing it by the number of vibrations per second, then dividing the nodal pattern from point of rarefaction to point of rarefaction giving me the maximum pressure point of the nodal pattern. As I asserted, if it were straight tubing I was working with, this formula would have worked out very well, but since the mouthpipe and the bell consisted of French curves, I would have had to develop a new formula for every location of pressure points on the instrument.

It was at this time that I met Dr. Aebi and we discussed notes on this particular control of the inner brass. Those of you who have read the articles of Dr. Aebi know that he is an amateur horn player and possibly one of the world's greatest physicists. He had approached the horn in the process of locating the nodal pattern by having the horn completely extended and inserting a small microphone on the end of a rod and taking it through the instrument while a note was being played and the results registered on an oscilloscope. However, during my stay there, we started utilizing a contact mike so we could work with the instrument in its natural shape while a performer was playing a particular note. In following along the instrument with the contact mike right into the oral cavity of the performer and registering the results on an oscilloscope with the aid of a movie camera, we were able to discover exactly the points of pressure as well as the points of rarefaction. At the point of rarefaction on an instrument, if we only had one note to play, it would be possible to play that particular note without any disturbance even if the tubing at that particular point was completely removed from the instrument. I have often given demonstrations of this with a C trumpet. When the 2nd line G is played on a C trumpet, a pressure point is directly at the water key and when the water key is opened, it completely stops the tone. If a C is played on the instrument, it is on the taper-off of the pressure point and when you open the water key, it sharpens the note a full tone so you could use it as a trill key. If you played the E on the fourth space, the note sound would be true whether the water key was opened or not. In other words, there would be absolutely no disturbance from the fact that the water key was open. In fact, at that area, five-eighths of an inch of tubing could be cut out of the instrument and if you only had to play that one note, you could play all day and never have a disturbance in it with that piece of tubing missing.

I know it is hard for people to conceive the idea of changing the pitch of an instrument by only changing the rate of taper one to two thousandths of an inch at exactly the pressure point of the note that you want to affect. On the mouthpipe of my instrument, if you will look carefully through the inside of it, you will see that I have corrected faulty notes in fourteen different places. In some places, the pitch of the note receives almost an eighth of a tone by utilizing less than one thousandth variance in taper over a quarter of an inch length. As I stated previously, we can only correct intonation on one note at a particular point. We must find a single pressure point for that note in order to accomplish this. If it goes to a multiple pressure point, too many notes would be affected adversely. Some of the corrections on intonation are clear into the bell area. It is only at the places where we can change it on tapered surfaces that we can make the corrections. On the slides of the instrument, it is impossible to make the necessary corrections. In the bow of the tuning slide it is possible and it is also the reason why, on all my instruments, you will find such a long mouthpipe...longer than anyone else uses.

I hope I have made myself clear in my approach to the physics of inner brass. I know sometimes, at the first hearing, it is difficult to assimilate everything. In fact, in Hamamatsu, in order to demonstrate what I was doing very clearly, I had the men build me a pipe organ of one octave with all the pipes of exactly the same length. Then, by changing the inside proportions of the pipes and the rate of taper at the pressure points of the nodal patterns, I was able to produce a true scale over one octave. Again, it is important in the manufacture of a brass instrument not to have braces, particularly at multiple pressure points. Even with the few braces that I have on my sliding bell instruments, two notes are affected. They, of course, change according to the pitch of the instrument that we are working with. On certain trumpets, such as the Eb tuning bell and the G and F, these instruments may be played in tune by the majority of performers without any slide manipulation. The answer to how this is accomplished has already been given to you so if you are in doubt, refer back to my earlier statements.

Let me spend a few minutes referring to the materials and their effect on the acoustics of brass instruments. The majority of bells on brass instruments are made of various forms of brass such as a combination of copper and other metals, depending upon the ultimate properties required. The common formulas contain copper and tin with a certain amount of antimony for hardness. Some use copper, zinc and tin. In my experiments on my instruments, my favorite brass formula until recently was a 60/40 combination of copper and silver which was especially made for me for just the bells of my instruments. However, approximately a year ago, I worked out a new formula for what I term beryllium bronze. This particular material has a wonderful acoustical effect in that it has remarkable carrying power. Its projection of sound is quite phenomenal. However, let us go into the various metals that we have experimented with. At one time we ran an experiment in which we used steel, aluminum, various plastics, glass, silver, various combinations of brass and the last one we used was lead. To demonstrate the results as quickly as possible, I will choose the two extremes. The steel bell, which we tempered so it was extremely hard, gave possibly one of the most interesting results. Many people test a bell by tapping it with their finger or knuckle and in tapping the steel bell, it would emit a very ringing sound, truly like a bell. However, when we played this instrument, the quality of sound was extremely dead. On searching for the reason for this, we looked at the oscilloscope while the performer played on the instrument and found the sine pattern very faint but the distortion pattern, coming from the vibration of the bell itself, going through at a very jagged and rapid rate, killing the brilliance of sound of the true tone. At the other extreme is the lead bell. This bell, if tapped with your knuckle, emitted an extremely dead sound like rapping on a piece of wood. However, the sound that emanated when it was blown was extremely brilliant, brilliant to the point of being mechanical. This showed up on the oscilloscope as a perfectly true sine pattern, there being no distortions in the harmonics either above or below, and, as a result, the sound was absolutely pure but not usable musically, except for a general effect such as a percussion instrument would give. The voice, you know, registering on an oscilloscope, gives harmonics both above and below the note. These distortions, if we may call them such, give warmth to the tone. We have to have that "distortion" in order to have the sound acceptable to our ears as a musical sound.

To continue about materials that go into a brass instrument, it is also necessary to add something concerning the treatment of the metal after it is formed into the bell of an instrument. As far as the over-all instrument is concerned, the more inert it is to vibration, the better it is. However, the thickness of the metal and the temper of the metal in the mouthpipe, tuning slide and bell greatly affect the quality of sound produced by the instrument. For instance, with a yellow brass, either 70/30 or 80/20 formula, it is necessary after the bell is formed to anneal it at two different points. This is to take the excess temper out of the bell caused by work hardening. If this temper were left in the bell, we would find the quality of sound had become very dark (remember here the results when we attempted to use a tempered steel bell). Metal with excess temper gives too many vibrations of its own. Regarding the thickness of an ordinary brass bell, I like the vulnerable areas to be under fourteen thousandths of an inch, that is, between twelve and fourteen thousandths. However, with the beryllium bronze, I am able to make bells with the vulnerable areas down to six and seven thousandths of an inch and one bell in particular which I finished for Mr. Faddis in New York was down to three thousandths of an inch. This particular bell works exceedingly well for him inasmuch as he plays most of the time in the extreme top register. The response was most excellent for his particular type of work. In other words, it all depends upon where the bell is going to be used and the quality of tone the performer wants from his instrument. All of this determines exactly whether a bell should be built in one way or another. As you can see, many things enter into the acoustical properties producing sound on a brass instrument.

One large point of controversy has always existed between those who prefer a lacquered horn and those who prefer plated horns, either silver or gold, or a third group who prefer their instruments in plain brass without any protective coating whatsoever. Let me give you my findings on the three different finishes of instruments. First, I tried to find myself three instruments that played absolutely identically. One, I silverplated, one I had a very good lacquer job put on and a third I left in brass. Now, recall that all three instruments played identically the same in brass, or as close as it is possible to get. I had various players from the Symphony working with me as well as other professional trumpet players in Chicago and they agreed unanimously on the results. The findings were that plating does not affect the playing qualities of brass instruments. That is, the plated instrument and the plain brass instrument played identically. The lacquered instrument, however, seemed to be changed considerably. This instrument, which originally had played the same as the other two, now had a very much impaired tonal quality and the over-all pitch was changed.

To explain these findings as to why the silver and brass instruments played alike and the lacquered instrument did not, let me give you some figures. The silver plating on a brass instrument is only one-half of a thousandth inch thick. In other words .0005". The lacquer that goes on, if it is a good lacquer job, is approximately seven thousandths of an inch thick, or .007". Now to get an idea in your minds as to what these thickness figures represent, an ordinary piece of writing paper is approximately four thousandths of an inch thick so the silver that goes on an instrument is only 1/8 as thick as a piece of writing paper, while lacquer is almost double the thickness of a piece of writing paper. The silver in itself is very compatible to the brass. The lacquer, if it is a good lacquer and baked on, will be almost as hard as glass and not at all compatible to brass. The lacquer on the bell of an instrument is seven thousandths of an inch thick on the outside and another seven thousandths on the inside which gives you a total thickness of fourteen thousandths or .014". This is already the thickness of the metal of my instruments so the lacquer process would double the bell thickness. As you can see, it is bound to affect the playing quality of the instrument.

So much for the materials going into the instrument. Now let us get to the next point which is possibly the most important and that is the tightness of an instrument. You are all acquainted with woodwind instruments and know the effect in intonation of a slight leak of a pad. The same is true in a brass instrument. If there is at any time any leak in the valves, in the water key or in any of the solder joints, there will be a definite effect on the intonation. This is caused by the disturbance of the nodal pattern. At a leak, a turbulence occurs which creates a standing node and establishes a rescinding node from that point affecting the intonation. (Refer to Page 1)

I feel the tolerance on the pistons of a brass instrument should be kept under one thousandth. In other words, a half a thousandth on each side of the piston. This permits free movement and still gives good acoustical qualities to the instrument. Without having the instrument completely air proof, all of these things we have been talking about amount to nothing. Any corrections we make in the instrument with a variance of tapers and what not would be ineffective unless the instrument was first absolutely tight. Now that does not mean I feel it is essential for the air to go through the instrument. It is not! If, after our lips were vibrated, the air could be disposed of in another way other than going through the instrument, the tone would be at its best. People who have used and understand physics know that this is true. However, there are people who do not understand this point. I put this as a question one time when I was giving a clinic to some bandmasters after listening to various remarks made by them about air having to go through the horn. I asked, "Is it necessary in the production of sound for the air to carry the sound through the horn?" I had hands by people in the affirmative that it was. To prove my point, I had a tuba player come up on the stage and had him blow some smoke in his tuba and then begin to play. He played over a minute before some smoke finally began to trickle out of the bell of the instrument. So, it is necessary to have air in the instrument so the player can establish the nodal pattern. It is not necessary for that air to move through the instrument any more than an energy impulse created by dropping a stone in water causes the water to actually move. What happens is, the energy impulse travels along lifting and depressing the water in its particular area ad infinitum. This is true of musical sound in relation to the air. The sound leaves the instrument and keeps on travelling in the same manner.

I know we have talked of many ideas that are somewhat controversial. However, I always hate to make a statement unless I have studied it and proven it, not only to myself but to many outstanding performers. I hope these facts prove to be of great interest to you.

Now let us spend a little time discussing brass mouthpieces. Invariably, a discussion among brass experts starts with an expression that such and such a mouthpiece is the best, the poorest, or the producer of best results for one particular player. The argument that follows is mainly based on conjecture. Very seldom are the opinions or "conclusion" backed by sound reality or scientific evidence.

In order to clarify the situation, let us first identify the parts of a mouthpiece so that we may have a ready vocabulary. Figure A shows a trumpet mouthpiece that has been cut in half. No. 1 is the RIM, the convex* portion of the upper part of the mouthpiece. No. 2 is the CUP, the concave** portion as viewed from above, which is located just below the rim. No. 3 is the SHOULDER of the throat, a convex surface as viewed from above, blending the cup into the throat.

No. 4 is the THROAT, generally cylindrical in shape and having straight or almost straight sides. The throat extends in length from perhaps 1/8 inch or less to as much as 3/4 inch. No. 5 is the BACKBORE, that part of the mouthpiece which extends from the throat to the lower end of the mouthpiece.

No. 6 is the WIDTH of the cup, its diameter on the inside of the rim. No. 7 is the outside DIAMETER of the SHANK at the very bottom or end where the shank makes contact with the mouthpipe. The MOUTHPIPE, shown in part in illustration B is the tubing inside the mouthpiece receiver pipe which abuts, or should abut, the shank end of the mouthpiece. In illustration B is shown a common deficiency in which there is an appreciable gap between the end of the shank of the mouthpiece and the beginning of the mouthpipe. The two should meet. To correct the deficiency, the shank is turned down somewhat on a lathe so that it will be small enough to meet the end of the mouthpipe. A marked improvement in the playing of the instrument is thereby affected.

Figure L shows a cut-away section of a mouthpiece and receiver pipe. Notice the substantial overlap from the end of the shank to the mouthpipe. This is a serious defect. Though it does not show a gap between the end of the shank and the beginning of the mouthpipe as in B, it is possible that if the shortcoming of B is remedied, the present overlap as shown in L remains.

The diameter of the inside of the mouthpipe at the point where it meets the mouthpiece shank is from .325 to .345 inches on most trumpets; however, since some shanks measure only .275 to .300, there is bound to be an overlap from the shank to the mouthpipe of .030 inches. This is the shortcoming shown at L.

In the correction of this shortcoming, it is not desirable to ream out the shank with a reamer as this would change the contour too far up into the backbore. It is preferable to taper the shank opening with a cutting tool only about 3/8 inch. Thus, the tapering remedies the shortcoming of L without appreciably altering the backbore of the mouthpiece.

Let us consider next the rim of the mouthpiece. Illustration A shows a mouthpiece with a desirable amount of roundness of the rim; it is especially well suited to beginners but is also used by many professional symphony players.

The narrower rim shown at C would give one more flexibility, such as demanded in playing arpeggios and intervals, than the rim shown in A. Yet flexibility is also dependent on another factor...the shape or outline of the rim curvature. Thus, two mouthpieces may have an equally wide rim, but one will have a higher surface at the edge of the cup as shown in D, which produces the feeling of a narrow rim and yet has almost its flexibility, but when pressure is applied, the lips contact a relatively larger surface.

Thus, this rim is a working compromise between the cushion feeling of the wide rim and the flexibility of the narrow rim. Obviously, such a mouthpiece is best suited to a player who tends to use more than ordinary pressure or who plays for long stretches of time as is the case with dance band players.

Experimental evidence and experience suggest that the higher the inner portion of the rim, as shown in D, the more accurate the attack is in both pianissimo and fortissimo playing. However, flexibility is sacrificed somewhat thereby. As the inner edge or "bite" becomes rounded, as in F, the more difficult become the attacks but the greater is the flexibility.

Let us consider the cup next. A desirable cup for all-around performance is shown in A. If precision of attack is the major requisite, the cup shown in M is preferable. This cup produces a stridency of tone that is piercing. It is important that a cup of this shape have a high shoulder at the throat (No. 3 in A) so that the shoulder becomes more convex and less like a second cup ro duo-cup.

Mouthpiece H is an old French Besson (there's also an English Besson); I is the famous Arbans cornet mouthpiece; J is a modern mouthpiece of the former first trumpet of the Chicago Symphony, Mr. Ed Llewellyn; K is the cornet mouthpiece of the renowned Jules Levy. It is interesting to compare these. Note especially the varying shapes of the backbores of G and H and the varying cups of I and K as compared to the others.

The wider or more open we make the shoulder of the throat, the mellower becomes the tone. In I the throat and cup shape combine into one long cup similar to that in a French horn mouthpiece, which, if used on the trumpet, is colorless. It is possible to achieve a judicious combination with the shallow cup which aids the lip and still avoid the stridency of tone usually produced by such a mouthpiece as F. This is done by opening the shoulder somewhat as shown in E, resulting in the double cup originally designed by L.A. Schmidt of Cologne about seventy years ago for use in the low F, E, Eb, and D trumpets used by R. Strauss. These latter instruments incidentally, but significantly, were played in the upper harmonics like a French horn. The double cup mouthpiece makes for easier control in the difficult high passages.

As shown in the dimensions of mouthpieces by Rohner, the average throat diameter uses a 27 drill size. Small throats of 30 or even smaller and extremely large throats of 18 or 19 are used by some players, but these extremes should be avoided by the average player.

A throat made with a drill No. 27 having straight sides for as much as 3/4 inch will tend to cause the player to play sharp in the higher register. On the other hand, if the straight sides of the throat are too short, the player will tend to play flat in the high register. Thus intonational tendencies, either sharp or flat, can usually be corrected in the mouthpiece. A lot of instruments are blamed for poor intonation when the fault actually lies in the mouthpiece.

If the backbore flares out rather rapidly, the tone will be full but slightly more difficult to control. If the backbore becomes straighter with less flaring out, the tone becomes thinner but more easily controlled. At the same time the blowing resistance is increased.

Needless to say, the shape of the outside of the mouthpiece, provided there is adequate thickness of metal in the wall, has nothing to do with its playing qualities.

Finally, it is a physical impossibility to provide all of the ideal features in any one mouthpiece; at best, a superior mouthpiece is an intelligent compromise of the major factors. The performer should strive for the optimum combination of factors. These will vary with the individual and the demands of the job. As a whole, one should favor tone quality and accurate intonation to ease of playing high notes unless the latter is a "must." No mouthpiece is perfect and no mouthpiece will sound better than the player behind it. The player is still the major variable.

Extremes should be avoided whenever possible. This does not mean that everyone should use an average size mouthpiece, but an average size should be the most common one for beginners.

Excessive experimentation on the part of the player should be avoided; yet all players will benefit from careful thinking and trials of different mouthpieces.