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# MANUAL OF
# WURLITZER ORGAN REED
# TUNING
# AND
# VOICING

Revised March 1947

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1945 - 46

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NORTH TONAWANDA, N. Y.

# PREFACE I

This manual covers most of the procedures and techniques required for the hand tuning of reeds and some of the techniques for the final voicing.

The manual is by no means a complete work on the subject, but represents what we believe is the first attempt to put into writing some of the various processes and techniques.

We know of no published book on the subject of tuning and voicing reeds.

The art is one which in the past was jealously guarded among skilled workers and a newcomer often had to spend years picking up and acquiring the necessary knowledge.

We believe, however, that a newcomer in the field, if possessing the proper hearing ability and dexterity of hands, and if properly instructed, can become proficient in the work in a few month's to a year's time.

This manual does not attempt to cover all of the phases of voicing as this is still a skill that is largely learned from someone else. However, all of the terminology, procedures and techniques contained herein are needed in qualifying a person to become a skilled Voicer.

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# PREFACE II

The following is a very brief description of sounds, notes, harmonics musical instruments, etc. which may be helpful to the layman as a foundation for the tuning and voicing skill.

Music is the relative association of various notes with more or less harmonic content. Generally speaking, there are four families of musical sounds in an organ. They are: Strings, Flutes, Reeds and Diapasons. The diapason tone is the sound of an organ pipe, of which most are familier. A large symphony orchestra, with its many instruments, still cannot produce the diapason tone unless accompanied by a pipe organ.

To have tonal variety there must be a certain amount of harmonic content to the note. By this we mean, vibrations which are superimposed on other vibrations. A pure vibration with no harmonic content may be heard, but may not be pleasant sounding. Symphony orchestras often employ percussion instruments to give certain expressions even though they are not strictly musical. However, such things as bells, chimes and cymbals, if properly made and constructed, do contain a certain amount of harmonics.

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There is a definite prescribed frecuency of vibration for the same note on all instruments. Middle C vibrates at 261.6 cycles per second whether sounded on a piano, by the human voice, or by an organ pipe. The frecuency of the note is called pitch and has nothing to do with harmonic content.

All instruments of sound have certain limitations of range. The violin ranges from 196 to slightly over 2000 cycles per second. The average bass voice ranges from 82 to 293 cycles per second. The standard piano keyboard (88 keys) ranges from A, below lower $C_3$, to high $C^4$, or from 27.5 to 4186 cycles per second.

The above can be clearly seen by studying a range chart of instruments, showing practical ranges commonly used for band and orchestra instruments.

Similar to the various instruments having definite ranges, most individual ears have definite ranges, that is, they do not pick up sounds outside of their range. Some ears cannot hear the lowest fundamental notes, while others have no difficulty. Likewise, some ears cannot hear high $C^4$ (4186 cy.) while others can go beyond. Some ears can hear both the low and high frequencies but will cut out in intermediate places. Still other ears will hear the entire range, but in different places their audibility is uneven. That is, two notes close together, played with the same intensity, will not sound the same loudness to the listener.

From the above, one can readily understand the variations between one person and another. This is the reason that Wurlitzer is prompted to spend large sums of money on research and development of electronic means of measuring pitch and harmonics.

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Because, the same note on various instruments sound at the same frequency is the reason for voicing Organ reeds. Two reeds identically made and pitched will naturally sound alike. In the Organ assembly, one can be made to simulate the sound of the flute and the other the sound of the diapason. This is done by twisting, bending and warping the tongues. It is this twisting, bending and warping that makes it possible to introduce other harmonics which add to the musical effects.

The sound produced by the vibrating string of a violin, certainly would not sound like a violin, if it were not for the body or shell. The combination of the two produce the proper sound.

Similarly, in the Wurlitzer Electronic Organ, the combination of the electrostatic pickup, the voiced reed, and the electronic amplifying system produces sounds containing the necessary harmonics to simulate string, flute and diapason instruments. Because the instrument is primarily an organ, the diapason sound is foremost and prominent.

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In the Wurlitzer Organ, one never hears the direct sound of the vibrating reeds, as they are almost completely muted. One only hears the resultant sound of the pickup and electronic system.

For the above reason, the final voicing of the reeds is done in the instrument proper so as to correlate all of the functions that produce the sound.

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# TEXT

## GENERAL

The following information is essential and must be learned immediately in order to proceed with work on the Wurlitzer Organ.

The white keys on the manual are called "Naturals". The black keys are called "Sharps". Twelve keys or notes are called an Octave (7 white keys and 5 black keys).

The notes in an octave are as follows:

C
$C^{\#}$ equivalent to $D^{b}$
D
$D^{\#}$ " " $E^{b}$
E
F
$F^{\#}$ " " $G^{b}$
G
$G^{\#}$ " " $A^{b}$
A
$A^{\#}$ " " $B^{b}$
B

The symbol ($^{\#}$) designates a sharp; ex. C - $C^{sharp}$. Instead of using the word "sharp", the symbol ($^{\#}$) is used. The "flat" ($^{b}$) symbol is seldom used.

One of the following pages, shows outline of the octaves and notes, used on the tuning jack, as well as a sketch of an individual reed test jack. The tuning jack (61 Notes) has an air or vacuum chamber and is used for pitching a complete stop of reeds. It has a cell for each reed in the stop and a master set of reeds which correspond. The master reed for any note will be sounded by pressing the corresponding key on the keyboard. At the same time the reed to be pitched, if in the cell, will also be sounded.

For the initial pitching, the reeds are not placed in the cells, but are tested on a single reed test jack. It is much easier and quicker to position a reed over the opening in the single test jack than to slide it in and out of the cell.

Both the tuning jack and the single reed test jack, operate from the same air supply or vacuum.

Another of the following pages gives a chart of symbols (Octave Numbers), equivalent pipe lengths, and vibrations in cycles per second, for the range of the Wurlitzer Organ.

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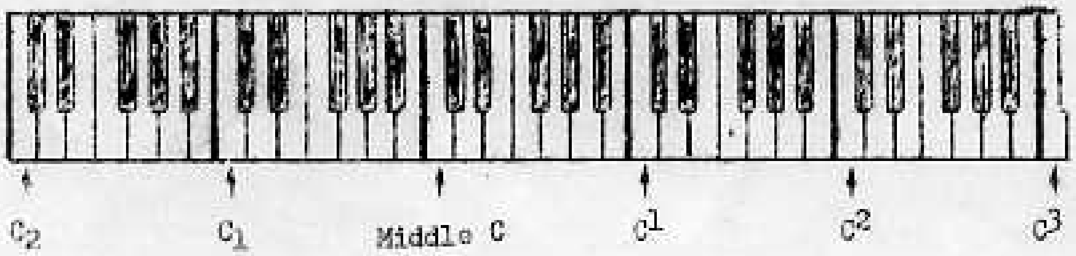
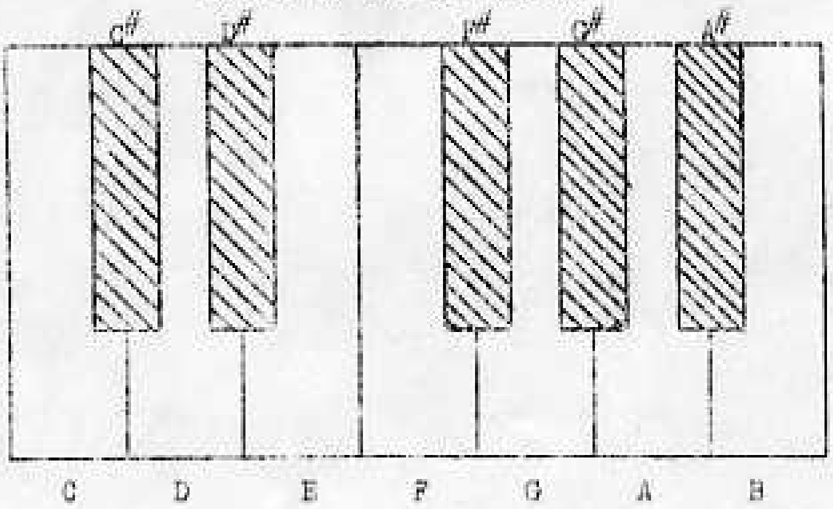
LAYOUT OF KEYS ON TUNING JACK,
FOR STOP OF 61 NOTES



LAYOUT OF TYPICAL OCTAVE



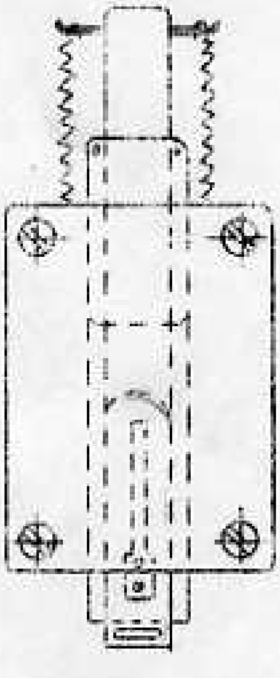


DIAGRAM OF
SINGLE REED
TEST JACK

## List of Symbols, Frequencies & Foot (Pipe) Sizes

| | Symbol | Series 20 C. Scale Diapason Foot Size | Series 10 F. Scale Diapason Foot Size | Vibrations per Second |
|---|---|---|---|---|
| (CCC) | $C_3$ | 16 | | 32.703 |
| | $F_3$ | | 8 | 43.654 |
| (CC) | $C_2$ | 8 | | 65.406 |
| | $F_2$ | | 4 | 87.307 |
| (C) | $C_1$ | 4 | | 130.813 |
| | $F_1$ | | 2 | 174.614 |
| | c (Middle) | 2 | | 261.626 |
| | F | | 1 | 349.228 |
| | $C^1$ | 1 | | 523.251 |
| | $F^1$ | | 1/2 | 696.456 |
| | $C^2$ | 1/2 | | 1046.502 |
| | $F^2$ | | 1/4 | 1396.913 |
| | $C^3$ | 1/4 | | 2093.005 |
| | $F^3$ | | - | 2793.826 |
| | $C^4$ (High) | 1/8 | | 4186.009 |

Note: Sometimes on Octaves below Middle C, the letter is repeated instead of using a sub. number. Ex: $C_3$ = CCC

Rule for Frequencies:- For each C in the octaves below middle C, the number of vibrations per second (frequency) is halved.

For each C in the octaves above Middle C, the number of vibrations per second (frequency) is doubled.

This rule holds true for all of the remaining notes. By knowing and using the middle octave as a key the frequency of any note in any octave can be calculated.

## SEQUENCE OF OPERATIONS

The following procedure is used in preparing reeds for an organ:

1. Machine tuned by reed-making department. Reeds will be sharp, up to approximately one-half note.
2. Trim reeds. File edges and get clearances.
3. Pitching reeds - By filing toe or heel --
4. Thinning reeds.
5. Bending reeds to approximate standard patterns of curvature, warp and twist.
6. Bleed small reeds.
7. Install reeds in an organ.
8. First Voicing.
9. Second Voicing - Touch Up.
10. Third Voicing - Touch Up.

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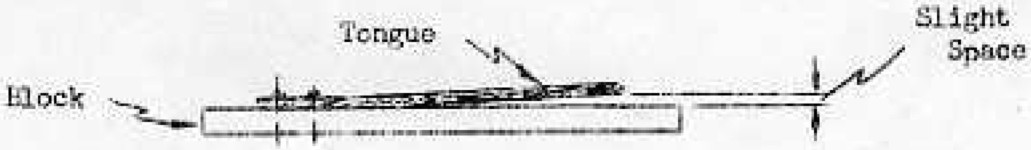
# TRIMMING OF REEDS

The trimming of reeds, follows after the reeds are received from the reed making department.

Procedure for proper trimming of reeds, before they are pitched, is outlined in the following:-

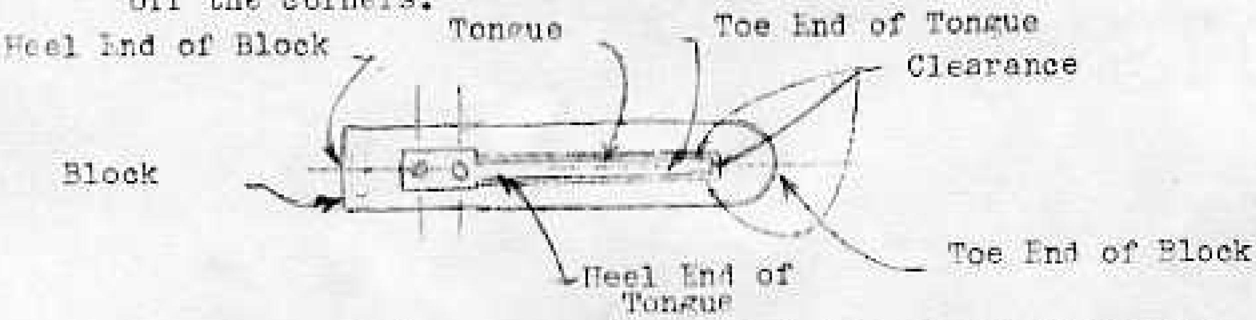
1. The tongue is raised slightly above the block, by the use of a thin brass wedge fixed to a bench. With tongue on top (tapered side) of wedge, the reed is pushed as far as necessary toward the rivets, in order that the tongue will be slightly bent up above the block, after it has been removed from wedge. The larger the reed, a proportionately larger space is required between block and tongues.



2. Raise the tongue by inserting the wedge between tongue and block, in order that one half the tongue length is, resting on wedge, holding the end of tongue 1/4" above the block. In this position, file down the free end of the tongue (crosswise), sufficiently to allow a clearance of .002" between the end of tongue and slot in block. The clearance may be observed or checked by removing reed from wedge and holding it up to a light, or inserting a feeler gauge. Although .002" is the nominal clearance, the larger reeds of the 1st and 2nd octave may go as high as .004".

3. The tongue should be positioned parallel, and depending on size, have a progressively increasing clearance of .002, .0025, .003, .0035 to .004 on each side of tongue. In some cases the sides of the tongue must be filed longitudinally to provide the clearance. Occasionally the tongue has to be pried over with a thin blade of brass, similar to the blade of a penknife, to the proper side to produce parallelism.

4. Another method of producing parrallelism is to place the reed blo in a slot in a stel straightening fixture with part of the reed block extending from the fixture and lightly tapping the reed block on the sides with a light (1 or 2 oz.) hammer. This fixture is illustrated later under procedures for the 7th. Octave. All fine burrs, caused from filing or previous machinin are carefully removed with a very fine file without rounding off the corners.



5. The above outline covers in general the procedure for the trimming of reeds. However, necessary caution must be emphasiz to reduce the difficulties when voicing the reeds; namely:-
    a. The sides of tongue must be straight and parallel with slot in block allowing the prescribed clearances.
    b. The end of tongue must be straight and at right angles to the sides, and with the prescribed clearance to the block.
    c. If the tongue is scored or kinked when being filed, the reed should be discarded, for eventually, the weakened tongue will break off.
    d. It may be observed, when glancing down a set of trimmed

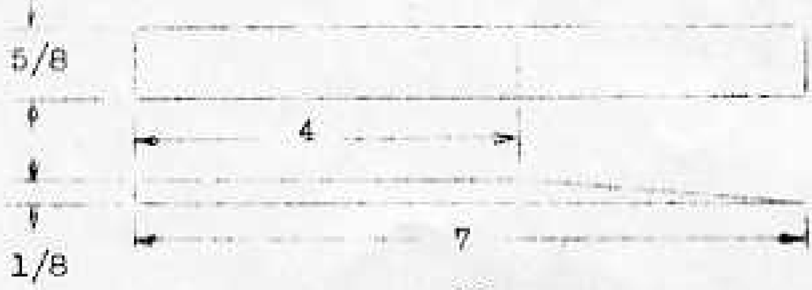
reeds, laid out in a line on a flat surface, that the height or clearance between the tip of tongue and block varies with the size of the reeds.

## TOOLS USED FOR TRIMMING REEDS

1. The following files are recommended for the trimming of Reeds. They are all of a very fine cut. The filed area on a reed must have more of a polished than a filed appearance.

| Make | Specification No. | Size |
|---|---|---|
| Nickelson | Mill Bastard | 6" |
| Nickelson | Mill Bastard | 4" |
| Piller | #2 | 4" |
| Warding | #4 | 4" |
| Nickelson | #4 Crossing | 4" |
| Nickelson | #6 Crossing | 6" |

If the edge on any of the files, as received, is serrated, the serrations should be removed by grinding them flat on an emery wheel and then the edges are rounded by use of a very fine Ind (oil) stone. This will leave only the flat sides of the file available for useful work, and will eliminate the possibility of gouging the reed. If a reed is gouged it has a tendency to weaken the brass material and the constant vibration will cause the reed to break at this point.

2. Wedge used for trimming.

WEDGE

BRASS

# PITCHING AND FILING OF REEDS

The pitching of reeds, follows, after they have been trimmed. The first step in this operation is to produce a reed of approximate pitch.

Note: About 99% of the reeds from the reed making department are "sharp". "Sharp" means they are higher in pitch than the required tone.

Example. - A sharp C sounds like $C^{\#}$ or D.

A "Flat" Note sounds lower in pitch than the required tone.

Example - A flat C would sound like B or $B^{b}$.

The procedure used for pitching reeds is as follows:-

A. To sharp a note, file the toe of tongue on the reed; to flat the note, file the heel of the tongue. The reeds should be held, on and parallel to the wedge when filing. File across the top of tongue at about a 45° angle.

B. Large reeds that are flat in tone can be corrected by filing a taper straight across the toe end of tongue. This generally applies to reeds of 110 cycles and lower.

C. It is advisable to start pitching reeds of the lowest octave of the stop(set) being worked on. These reeds are of the larger sizes and have thicker tongues and are less subject to damage.

Note: Waver, is the beat which is heard, due to interference of two sound waves, of different frequencies.

D. To start with, first place the unfiled reed in the individual test jack and then press the proper key on the large tuning jack to play the master reed, to ascertain approximately the amount of filing required to bring the unfinished reed to pitch with the master reed. After filing to obtain a note almost in tune with the master reed, let finger up slowly from the key of tuning jack.

Carefully listen to the waver between the notes of the two reeds. If the waver gets faster as the key comes up, the note is sharp, indicating that more filing is necessary off of the heel. If the waver decreases as the key comes up, the note is flat and the toe of the reed must be filed to get the note on the sharp side again. Occasionally, however, the waver may not be noticeable. This indicates that the notes are in pitch and it will be necessary to further file or scrape stock from the tongue. (Scraping of reeds is an operation subsequent to filing, which is generally necessary for the final pitching.

E. Reeds of 110 Cycles and higher, are smaller and the tongues are much thinner. The filing required on these thin tongues must be done carefully. These reed tongues are filed in much the same manner as outlined above. When filing as outlined above, be sure that all milling machine marks are removed from the toe end of tongue. This filing should work back toward the heel. Sometimes, a reed does not speak fast enough and will require more thinning. This is due to, small reeds having smaller air cells and less vacuum. A reed properly thinned will have a distinct twang when lifted with a pick as well as the ability to speak quickly when placed in the air cell of the tuning jack. A slightly tapered tongue, thicker at the heel than at the toe, gives the best tone. After filing tongue, observe in the light whether or not the tongue is bent and binding on the block. Make sure that the tongue is properly raised with respect to the top side of the block.

F. Regardless of the number of octaves to be thinned, begin with #33G# (415.3 cy.) of the 3rd. Octave working on up to the last reed. All reeds, whose tongues have been filed sufficiently thin, will be finally pitched by carefully scraping, because the file will occasionally catch and bend the thin tongues. Reeds with bent (sharp bend) tongues are discarded. As mentioned before, it is advisable, when filing reeds, to keep them on the "sharp" side, as it is then easier and more economical to scrape them down to the proper pitch.

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## BENDING REED TONGUES

Reed tongues are bent in such manner as to give improved quality to their tone, as well as reducing the amount of voicing work done in the Organ assembly. All reeds, both common and narrow tongues, between 43.6 and 587.3 cycles (refer to Drawing No. 12,000) are bent. Reeds below and above these frequencies, are not bent. The bend should be slight on the first reed and increase in magnitude on each successive one, up to about "D" (293.6 cy.) of the 3rd Octave. At this point the bend decreases gradually until about "D" (587.3 cy.) of the 4th Octave. After the "D" of the 4th Octave, it should not be necessary to further bend reed tongues.

A. The only tool that is required for bending reed tongues is a pair of needle nose pliers. These pliers are similar to those used by jewelers or opticians and are about 3½" long. The inside of the nose tines are smooth, so they will not score the reed tongues.

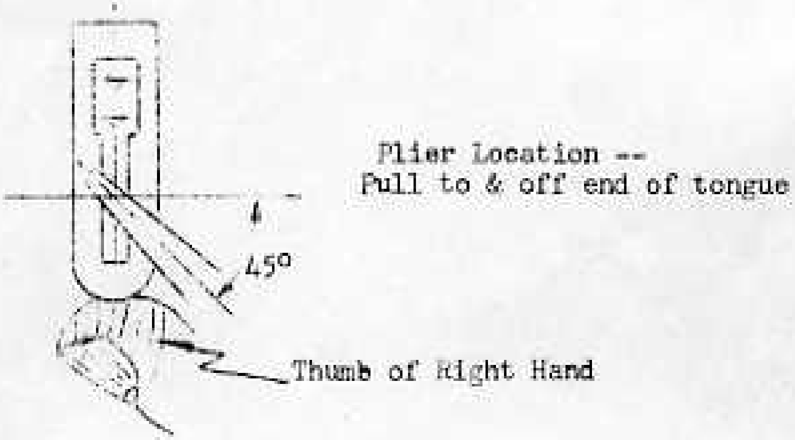
B. The bending of reed tongues is prior to the scraping operation. Procedure for bending is covered in the following: -

1. Hold the reed at the heel, with the first finger of the left hand on one side of the reed and the thumb on the opposite side. Support the reed with the second finger and point the toe away from you. Place the pliers in the palm of the right hand and grasp the tongue lightly at the toe, then slide the pliers snugly back, towards the heel. Doing this, increases the space between the tongue and block, so that the tongue is accessible in the later bending steps.

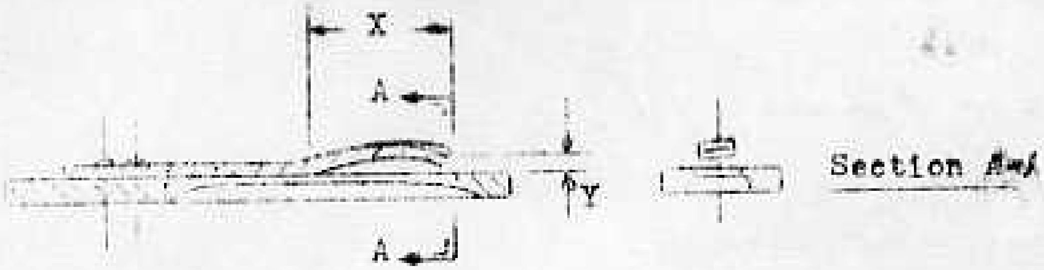
   Now turn the hand so that the toe of reed faces you. Place your second and third fingers on the edge of the reed, and support it by placing the little finger under the toe of block.

With the pliers still in the palm of the right hand, grasp the tongue firmly at about a 45° angle, and at the proper distance from the toe (see list following, showing where to start reed bends; also 1st sketch below showing the proper position of pliers, when bend is started) and twist the toe end of reed, higher than the heel end. After the tongue is raised to the desired height and with the pliers in the same position, place the thumb against the toe of the block, and draw the pliers toward and off of the toe end of tongue.

After doing this, take both tips of pliers and using them as a prod, push the heel of the reed down so that it is parallel with top side of Block. The second sketch following shows a finished reed and a list of the approximate lengths of bends and heights of the arcs that should result.



This operation, not only bends the free end of tongue into a slight arc but also twists it slightly. See end and side view of sketch following.



| FREQUENCY & REED NO. | START BEND X | HEIGHT OF ARC Y |
|---|---|---|
| 6F 12B<br>43.6 - 123.4 | 1" | 3/64 |
| 13C 24 B<br>130.8 - 246.9 | 5/8 | 3/64 |
| 25C 36B<br>261.6 - 493.8 | 7/16 | 1/16 |
| 37C 39D<br>523.2 - 587.3 | 7/32 | 1/32 |

The end of twisted tongue should not be below the level of top of block. A soft note, will result if tongue extends into the slot. The low corner at the end of twisted tongue should be level with or slightly above top surface of block, depending on size of reed.

2. Carefully check with a lighted background, and correct by trimming with a file, or prying with a pick, any edges of tongue that may not be equally spaced over slot in block. Also remove any burr raised by the pliers.
3. In general, Arc-bends should not be necessary above 587.3 cycles. However, this condition depends a great deal on the construction of the Organ being tuned and the judgment of the final voicer. If voicer decides a note is too loud, the bend and arc should be increased. If a note is too soft the bend and arc should be decreased.

# HIGH FREQUENCY REEDS

(7 Octaves above Lowest Pedal Reed)

A. The octave of reeds, starting with 2093 cycles, are the smallest and most difficult to tune. They must speak promptly, and be heard, before the sound of air is heard, rushing thru the tuning jack. Their tones should be loud and clear.

B. Reed tongues of 2093 cycles and higher must necessarily be thin. It is possible, but not advisable, to machine-mill tongues down to a thinness where no filing is needed before scraping to pitch. But, there is an approximate 50% loss in spoiled reeds which makes such procedure too expensive.

NOTE: Reed tongues of extreme thinness are necessary in the higher octaves because: - The diminishing sizes of the air cells, reduce the vacuum, necessary for vibration of tongues.

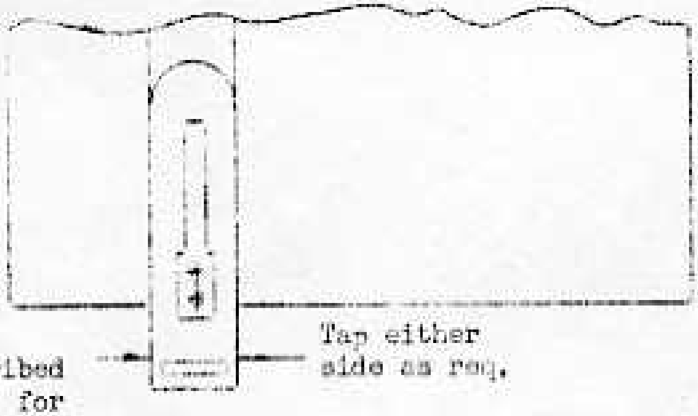
C. Occasionally one of these reeds will not respond quickly when pressing key. This may be attributed to one or more of the following reasons and corrected as outlined: -

1. Tongue too thick: - Tongues which are too thick will not speak promptly, because they are too strong to be vibrated with the vacuum available. They should be thinned down to a point where they will speak, but still can be lifted up in a smooth arc (  ). A pick is used to lift the tip of tongue. However, if the bend is sharp, (  ) the tongue is too thin -- too thin at heel and too thick at toe, or vice-versa. Also, if tongue does not spring back in place, or the tip of tongue curls-up, the tongue has been thinned too much and should be discarded.

2. Binding of tongue in slot of block: - Burrs on side of tongue or block will prevent free movement of tongue. It is advisable to check for burrs by holding reed up to a light. Remove any burr or fuzzy edges appearing in the space between tongue and block, with a fine file.

3. Excessive clearance of tongue, in slot of block: - The edge of tongue should just clear (about .002 clearance) the side of slot in block. If clearance is excessive, place edge of reed block on steel fixture and tap the edge to close up the excessive side clearance, first on one edge and if necessary on the opposite edge. Tapping should be done with a small one or two-ounce hammer.

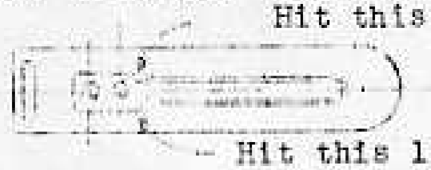
After tapping, should the clearance be too small or the tongue rub against block, file edge of tongue to give the proper clearance. Check clearance and remove all burrs.



Shows reed being paralleled as described in Par. 4, Page 12, for larger reeds.

Shows excessive side clearance being closed.

The position of the riveted tongue, which may have been riveted off of center, in relation to slot, can be straightened by hitting the tongue slightly ahead of rivets with a cross peining hammer.



Hit this location to shift tongue to other side.

Hit this location to shift tongue to opposite side.

4. Tongue too low in slot or too high above block:- The bottom edge of tongue must be parallel with surface of block. An end of plier jaws is used to raise or lower, as may be recuired.

5. A delicate balance exists between the thickness of the tongue an the vacuum available. A properly thinned tongue may speak, but not promptly, when tested in the cell of the tuning jack. In such cases, the reed will require bleeding to lessen the pull of the vacuum, so that the tongue will instantly start to vibrate.

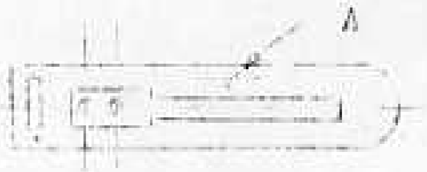
6. Bleeding of reeds will be explained in the next chapter.

D. The final tuning of the reeds is done by scraping and is described in a later chapter.

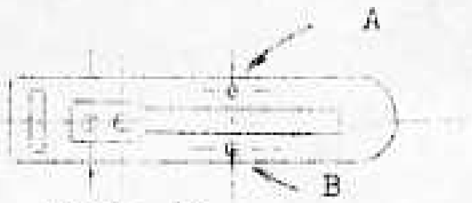
E. Occasionally, in tuning, a reed may sound as though the burrs had not been removed from the tongue. Remove reed from tuning jack and examine it for burrs. If no burrs are found it indicates that end of tongue is too thin and the reed must be discarded.

F. Quality of tone does not enter into consideration in tuning reed above 2093 cycles. Quality of tone disappears around 523.2 cycles. However, it is imperative, that these reeds speak quickly.

# BLEEDING REEDS



Style I



Style II

1. One or two bleeder holes will be drilled, through the block, as shown in above sketches.
2. Style I Reeds are 50C#, 51 D and 52D#. These reeds are drilled with a #38 (.1015) drill (hole A), the exact location of which is fixed by a drill jig which is provided for this purpose. Remove drill burr with file and place in tray.
3. Style II Reeds are 53E to 73C inclusive. These reeds require two (2) bleed holes (A & B). These holes are also drilled in a jig, using a #38 (.1015) drill. Remove drill burrs and place in tray.

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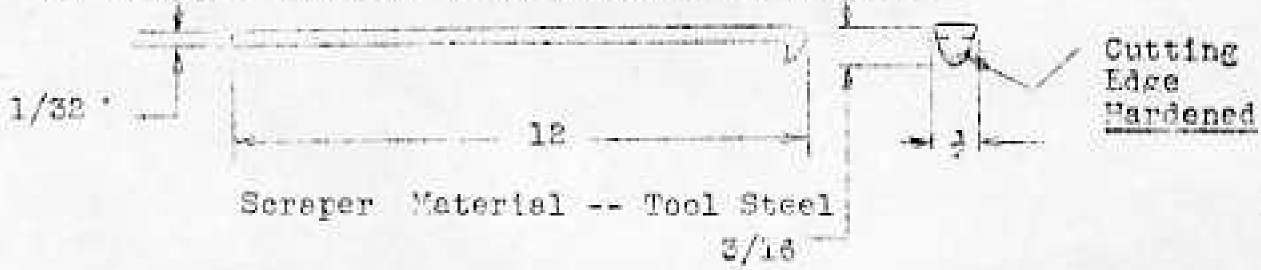
# TUNING AND SCRAPING OF REEDS

Scraping of reed tongues to a satisfactory pitch is the final operati of tuning and voicing.

A. Scraping, as compared to filing, can be considered a precise operation, in obtaining the proper pitch. Most reeds of the 1st and 2nd Octave, do not require scraping. On these reeds, the scraper removes such a small amount of stock, as compared to the total mass of stock, as to barely affect the pitch.

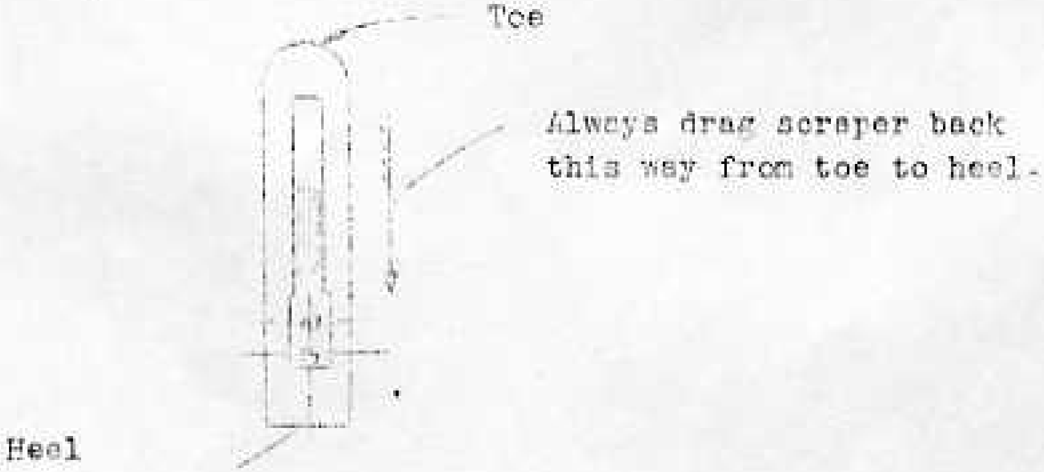
B. The term "Waver" is explained in the following: By playing one of the master reeds and the corresponding note, in an unscraped stop, simultaneously, in the tuning jack, a distinct waver in tone between the two notes will be heard. This indicates that the unscraped reed is either sharp or flat of the master reed. Reference is made to waver chart, in the next chapter, under - Setting a Temperament. Another way of expressing this statement is by saying that, the notes are not in unison. This wavering sound resembles the sound of a person saying WOW. The more a sharp reed is scraped the more the waver will be drawn out. It is necessary to continue scraping until the waver disappears completely. If however, the reed has been scraped too much, and the notes are past the point of unison, the waver between the notes will gradually increase. To correct this condition the reed must be removed from the air cell and the toe of the tongue filed, to bring the note back to the sharp side again.

C. Scraper used for final pitching of reeds:-



The scraper as sketched above, is held between the index finger and thumb of right hand. Insert the scraper in the air cell of the reed to be scraped, and starting half-way down the length, and in the center of the width, of the tongue, drag the scraper back toward the heel.

This operation is done on all reeds that need scraping in all stops.



Always drag scraper back this way from toe to heel.

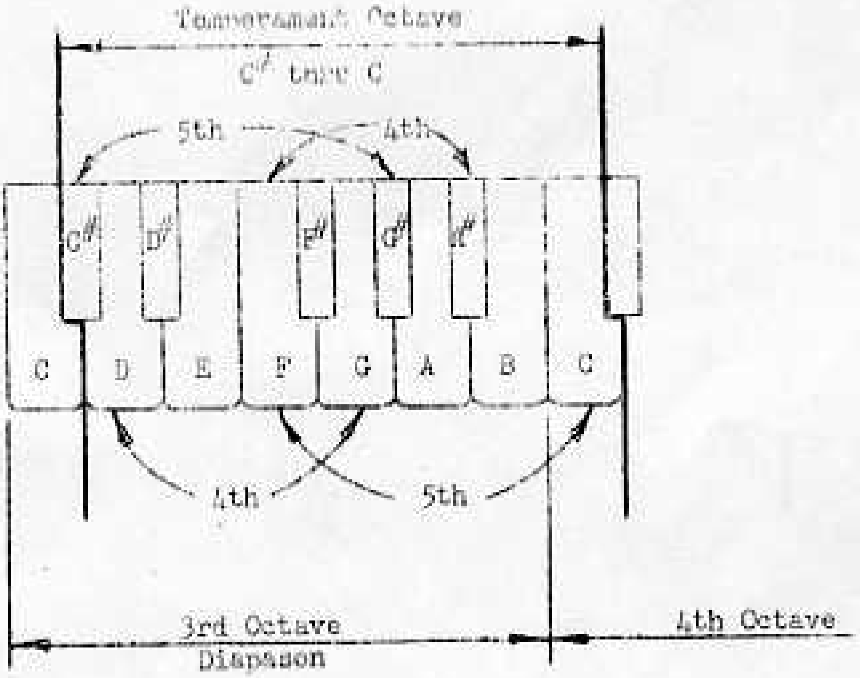
WARNING: NEVER USE A SCRAPER ON THE "TOE" OF A "FLAT" REED TO MAKE IT SHARP. THE REED SHOULD BE REMOVED FROM THE CELL AND FILED TO THE DESIRED PITCH.

# SETTING A TEMPERAMENT IN WURLITZER ORGAN PROPER

Temperament is the tuning of a musical instrument so that the intervals of the scale shall follow a suitable law of succession.

Before proceeding with the actual work of setting a temperament, the following should be understood; -

A "Fourth" and a "Fifth" is the relationship of certain notes from other notes in an equally tempered scale. A Fourth is equal to 5/12 and a Fifth is equal to 7/12 of the scale



## EQUALLY TEMPERED SCALE

| Name & number of tone from C in ascending order | Name of Interval from C as starting point | Frequency (cycles per second) | Fraction of scale | Frequency ratio from starting point |
|---|---|---|---|---|
| C | Unison | 261.626 | 0 | 1:1 |
| C# - Db | Half-tone | 277.183 | 1/12 | 1.059463:1 |
| D | Whole tone | 293.665 | 2/12 | 1.122462:1 |
| D# - Eb | Minor third | 311.127 | 3/12 | 1.189207:1 |
| E | Major third | 329.628 | 4/12 | 1.259921:1 |
| F | Fourth | 349.228 | 5/12 | 1.334840:1 |
| F# - Gb | (Augmented fourth<br>(Diminished fifth | 369.994 | 6/12 | 1.414214:1 |
| G | Fifth | 391.995 | 7/12 | 1.498307:1 |
| G# - Ab | Minor sixth | 415.305 | 8/12 | 1.587401:1 |
| A | Major sixth | 440.000 | 9/12 | 1.681793:1 |
| A# - Bb | Minor seventh | 466.164 | 10/12 | 1.781797:1 |
| B | Seventh | 493.883 | 11/12 | 1.887749:1 |
| C | Octave | 523.251 | 12/12 | 2:1 |

The tone that is heard, when setting a temperament is a "compound tone" and has little bearing on the partial tone eminating from a single pitched reed. When reference is made to sharpening or flattening, it means sharpening or flattening the compound tone.

Each individual note has its approximate pitch and its proper place in the sequence of notes in the octave. This was originally accomplished by the pitching of the reeds in a prior operation. When sharpening or flattening a compound tone, one of the notes is merely shaded, but is not changed far enough, as to make it lose its orderly position in the Octave.

Setting a temperament is all done within one octave except for the C note, one octave above, which is set with the tuning bar or fork. After the temperament is set in this octave, other octaves, are tuned to it.

Procedure is as follows: -

A. The reed C, above Middle C (523.25 cy.), of the Diapason stop, should be tuned to a master tuning bar or tuning fork.

B. Play the C key and strike the tuning bar or fork. The resulting tones should be identical -- no waver. However, if there is a waver, use the scraper on the reed-tongue and scrape until all the waver disappears. It is of major importance that <u>this note C be in perfect unison with master tuning bar.</u> This is done only on the Diapason reed. Also, it is the only time the tuning bar is used.

C. After tuning this C in absolute unison with the tuning bar or fork, play F of the octave below (5th down). These two notes should produce a compound tone with a waver of 90 per minute. This compound note is left on the sharp side. At first, the waver between the above two notes, compounded, is fast (above 90) but is decreased by scraping of F until the waver comes down to 90. However, with excessive scraping, the waver may drop below 90 and the F will then require sharpening, by filing the toe of tongue.

D. C and F having been tuned on the sharp side, drop the C and play A# with F (4th down). Scrape the tongue of A# until the compound tone is on the sharp side having a waver of 100 times per minute.

E. The following is a list of compound notes to be tuned: -

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Scrape | F | of | F & | *C (5th) - | Leave on sharp side - | 90 | wavers per min. |
| " | A# | " | A# " | F (4th) - | " | 100 | " |
| " | D# | " | D# " | A#(5th) - | " | 90 | " |
| " | G# | " | G# " | D#(4th) - | " | 100 | " |
| " | C# | " | C# " | G#(5th) - | " | 90 | " |
| " | F# | " | F# " | C#(4th) - | " | 100 | " |
| " | B | " | B " | F#(4th) - | " | 100 | " |
| " | E | " | E " | B (5th) - | " | 90 | " |
| " | A | " | A " | E (4th) - | " | 100 | " |
| " | D | " | D " | A (5th) - | " | 90 | " |
| " | G | " | G " | D (4th) - | " | 100 | " |

Then test G & *C (4th) - Should sound flat if OK

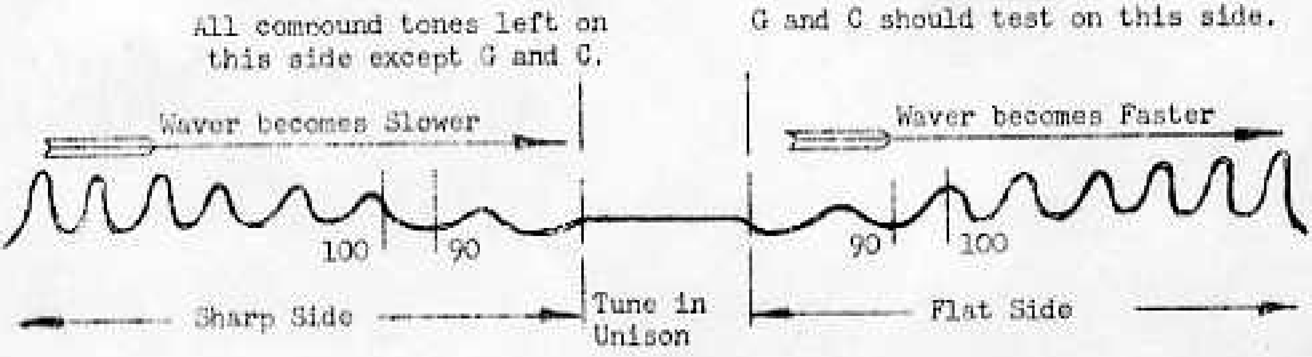
* IndicatesC tested with tuning bar or fork.

N. B. It is important that all Fourths have 100 wavers per minute and all Fifths have 90; otherwise the whole temperament is thrown off.

After tuning the above combinations, test them by playing G and C. There should be 100 wavers per minute and the tone should sound flat. This is the only compound tone in the above sequence which should sound flat.

If the test does not come out right, start from the beginning, repeat the procedure as outlined above, and pay particular attention to the wavers per minute. Somewhere in the operation, a pair of notes has been shaded (scraped) too much or too little.

No mechanical devices are used to check the number of wavers per minute. The ear must be trained to distinguish the tones and tell whether they are sharp or flat, as well as being able to hear the wavers, so they can be counted.



WAVER CHART

F. If several attempts have been made to set the temperament, and the results are not satisfactory, reverse the process and proceed as follows:
   1. Check C of the 4th Octave with the tuning Bar or Fork and make sure it is in perfect unison.
   2. Check C of the 4th Octave, against G of the 3rd Octave. This tone should sound flat with 100 wavers per minute. If not, scrape G to make it so.
   3. Play G and D of the 3rd Octave. The tone should be flat and have 100 wavers per minute. If this waver is slow or fast, correct it by altering the D note.

4. Alter any of the compound tones in the following list, that are outside of limits.

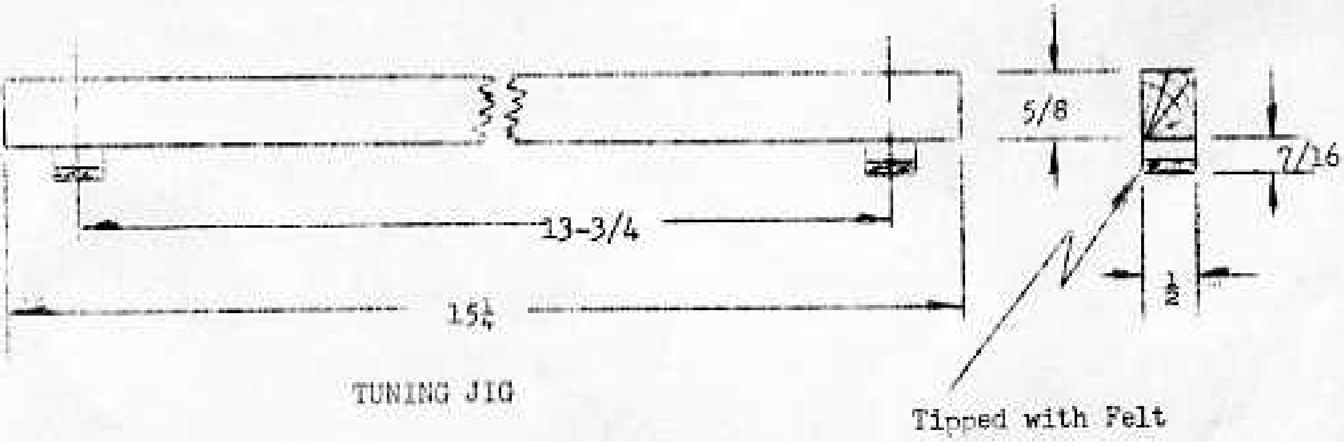
Scrape G of *C & G (4th) - Leave on flat side - 100/min.
" D " G " D (4th) - " 100/min.
" A " D " A (5th) - " 90/min.
" E " A " E (4th) - " 100/min.
" B " E " B (5th) - " 90/min.
" F# " B " F# (4th) - " 100/min.
" C# " F# " C# (4th) - " 100/min.
" G# " C# " G# (5th) - " 90/min.
" D# " G# " D# (4th) - " 100/min.
" A# " D# " A# (5th) - " 90/min.
" F " A# " F (4th) -- " 100/min.
Test F & *C (5th) - Should sound sharp if OK.

*Indicates C tested with tuning bar or fork.

It should not be necessary to check all combinations of notes in reverse; because sooner or later, the error made in the first process will show up. After the mistake has been found and corrected, the balance of the pairs of notes should be correct. When reversing the procedure, it is well to bear in mind that the compound tone is left on the flat side.

G. The balance of reeds in the Diapason are set by using the temperament Octave (3rd), as the Standard. They should be pitched in unison, C of 4th Octave and C of 3rd Octave - C# of 3rd Octave and C# of 2nd Octave - D of 3rd Octave and D of 4th Octave, etc., with no waver between them. The reeds of the Flute, Pedal, and Viole stops are tuned using the Diapason reeds as Standard. The Celeste stop is set, by using the Viole reeds as standard, and is explained in the chapter "Setting the Waver in Celeste Reeds".

H. When tuning reeds of the 1st or 5th Octave with the 3rd Octave, the keys are too far apart for the fingers of one hand to reach; some tuners find the following jig useful.



TUNING JIG

I. It is necessary to apply uniform pressure on organ keys when tuning. This pressure should be the natural weight of the hand -- do not force keys down. To bear down on some keys and lightly touch others, tends to change the pitch.

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## SETTING THE WAVER IN CELESTE STOP OF REEDS

Because Viole and Celeste reeds are both narrow tongued, it is necessary to tune the Celeste reeds sharp, as compared to the Viole; using a greater number of wavers per minute, than previously described for other stops. This will give a pleasing celestial tone when played in the Organ along with Viole stop.

1. After setting the temperament and tuning all remaining octaves of Diapason reeds, in unison with the temperament octave, close the Diapason mutes so these reeds will not be heard.
2. Install a set of Viole reeds. With the mutes open, play and check each Viole reed for soft or loud notes, rattles, and for those that do not play. Repair these irregularities and then open the mutes on the Diapason reeds. Play a Diapason and Viole reed together. Using Diapason reeds as standard, tune Viole reeds in unison with them.
3. With the Viole reeds correctly tuned, close the Diapason and Viole mutes and install the set of Celeste reeds in their proper cells. With the mutes open on the Celeste reeds, play and check each reed for soft or loud notes, rattles, and for those that do not play. Repair these irregularities and then open the mutes on the Viole reeds.

Celeste reeds are tuned sharp in relation to Viole reeds, with a waver of approximately 120 per minute at Middle C. Going up the scale from Middle C the wavers increase, down the scale the wavers decrease. Using Viole reeds as standard start at Middle C and scrape the Celeste reeds sharp and with wavers as follows:

## 1ST. TUNING

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1st. | Octave: | Approx. | 90 | Wavers/min. | to | 180 | Wavers/min. |
| 2nd. | " | " | 180 | " | | 360 | " |
| 3rd. | " | " | 360 | " | | 480 | " |
| 4th. | " | " | 480 | " | | 720 | " |

Each note in each octave has a gradual increase in number of wavers per minute. Likewise, the entire stop is graduated.

## 2ND. AND FINAL TUNING

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1st. | Octave: | Approx. | 60 | Wavers/min. | to | 120 | Wavers/min. |
| 2nd. | " | " | 120 | " | | 240 | " |
| 3rd. | " | " | 240 | " | | 300 | " |
| 4th. | " | " | 300 | " | | 360 | " |

# COMMENTS

This manual was written prior to any production of electronic organs of the Wurlitzer design -- Series 20 and 10, and is based on information available at time of writing.

Some of the information was gained during time spent at Estey Organ Company, as well as, by producing a limited number of organs of the Everett design.

As production gets under way on the new series of Wurlitzer Organs, some of the techniques described in this manual will necessarily change, to fit conditions required by Wurlitzer Engineering.

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ASA
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Z24.1-1942

American Standard

# Acoustical Terminology

American Standards Association
Approved March 20, 1942

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# Foreword

THIS American Standard Acoustical Terminology—Z24.1–1942 comprises a part of a group of definitions, standards, and specifications for use in acoustical work.

In May, 1932, following a proposal of the Acoustical Society of America, the American Standards Association initiated a standardization project on Acoustical Measurement and Terminology under the sponsorship of the Acoustical Society of America, and with the following scope:

> Preparation of standards of terminology, units, scales, and methods of measurement in the field of acoustics.

A committee in charge of the work was organized, and its first meeting was held in May, 1932. Numerous changes in both the personnel and the organizations represented on this committee have been made since 1932. Also, in May, 1942, the scope of the work was extended to include vibration.

Various subcommittees have been organized to take care of the committee's program. They are:

Acoustical Terminology
Audiometry and Hearing Aids
Fundamental Acoustical Measurements
Noise Measurement
Sound Absorption and Sound Insulation Measurements
Sound Levels and Sound Level Meters

The organizations represented on the sectional committee responsible for these standards, together with their representatives, are as follows:

V. O. Knudsen, Acoustical Society of America, *Chairman*
J. W. McNair, ASA, *Secretary*

| | |
|---|---|
| Acoustical Society of America (Sponsor) | Harvey Fletcher<br>V. O. Knudsen<br>W. F. Snyder<br>C. F. Wiebusch |
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| | Wallace Waterfall |
| | F. R. Watson |

The standard contained in this publication comprises revisions of a standard which was approved by the ASA as American Tentative Standard in February, 1936.

The subcommittees responsible for this standard have the following personnel:

| *Terminology Subcommittee* | *Music Subcommittee* |
|---|---|
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| Paul H. Bilhuber | A. T. Jones |
| L. G. Bostwick | Otto Ortmann |
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| R. V. Parsons | |
| L. J. Sivian | |
| Julius Weinberger | |

# American Standard Acoustical Terminology

## 1. GENERAL DEFINITIONS

### 1.1 Sound

(*a*) Sound is an alteration in pressure, particle displacement, or particle velocity propagated in an elastic material or the superposition of such propagated alterations.

(*b*) Sound is also the sensation produced through the ear by the alterations described above.

Note: In case of possible confusion the term "Sound wave" may be used for concept (*a*), and the term "Sound sensation" for concept (*b*).

### 1.2 Pure Tone (Simple Tone)

A pure tone is a sound produced by an instantaneous sound pressure which is a simple sinusoidal function of the time.

### 1.3 Periodic Quantity (Harmonic Quantity*)

(American Standard Definitions of Electrical Terms—C42-1941:05.05.170).

A periodic quantity is an oscillating quantity the values of which recur for equal increments of the independent variable. If a periodic quantity, $y$, is a function of $x$, then $y$ has the property that $y=f(x)=f(x+k)$, where $k$, a constant, is a period of $y$. The smallest positive value of $k$ is the primitive period of $y$, generally called simply the period of $y$.

In general a periodic function can be expanded into a series of that form.

$$y=f(x)=A_0+A_1\sin(\omega x+\alpha_1)+A_2\sin(2\omega x+\alpha_2)+\cdots,$$

where $\omega$, a positive constant, equals $2\pi$ divided by the period $k$, and the $A$'s and $\alpha$'s are constants which may be positive, negative, or zero. This is called a Fourier series.

### 1.4 Cycle (~)

One complete set of the recurrent values of a periodic quantity comprises a cycle.

### 1.5 Period ($k$)

The time required for one cycle of a periodic quantity is the period. The unit is the second.

### 1.6 Frequency ($f$)

The number of cycles occurring per unit of time, or which would occur per unit of time if all subsequent cycles were identical with the cycle under consideration, is the frequency. The frequency is the reciprocal of the period. The unit is the cycle per second.

Note: It is recommended that the following terms be discontinued: double vibrations (*dv*), periods per second (*pps*), and Hertz, all these being equivalent to cycles per second; and vibrations per second (*vs*) which has usually been used as the equivalent of half-cycles per second.

### 1.7 Octave

An octave is the interval between two frequencies having a ratio of two to one. One octave is equal to 1200 cents. (See 6.10 and 6.12.)

### 1.8 Fundamental Frequency

(American Standard Definitions of Electrical Terms—C42-1941:65.10.025)

A fundamental frequency is the lowest component frequency of a periodic quantity.

### 1.9 Harmonic

(American Standard Definitions of Electrical Terms—C42-1941:65.10.030)

A harmonic is a component of a periodic quantity which is an integral multiple of the fundamental frequency. For example, a component the frequency of which is twice the fundamental frequency is called the second harmonic.

### 1.10 Basic Frequency

The basic frequency of any wave is that frequency which is considered to be the most important. In a driven system it would in general be the driving frequency while in most

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* Deprecated.

periodic waves it would correspond to the fundamental frequency.

### 1.11 Partial

A partial is a component of a complex tone. Its frequency may be either higher or lower than that of the basic frequency and may or may not bear an integral relation to the basic frequency.

### 1.12 Overtone

An overtone is a partial having a frequency higher than that of the basic frequency.

### 1.13 Subharmonic

A subharmonic is a component of a complex wave having a frequency which is an integral submultiple of the basic frequency.

Note: The term subharmonic is generally applied in the case of a driven system whose vibration has frequency components of lower frequency than the driving frequency.

### 1.14 Wavelength (λ)

The wavelength of a periodic wave in an isotropic medium is the perpendicular distance between two wave fronts in which the displacements have a phase difference of one complete cycle.

### 1.15 Diffuse Sound

Sound is said to be in a perfectly diffuse state when in the region considered, the energy density, averaged over portions of the region large compared to the wavelength, is uniform and when all directions of energy flux at all parts of the region are equally probable.

### 1.16 Particle Velocity

The particle velocity in a sound wave is the instantaneous velocity of a given infinitesimal part of the medium, with reference to the medium as a whole, due to the passage of the sound wave.

### 1.17 Bel (*b*)

(American Standard Definitions of Electrical Terms—C42-1941:65.11.005)

The bel is the fundamental division of a logarithmic scale for expressing the ratio of two amounts of power, the number of bels denoting such a ratio being the logarithm to the base ten of this ratio.

Note: With $P_1$ and $P_2$ designating two amounts of power and $N$ the number of bels denoting the ratio $P_1/P_2$:

$$N = \log_{10} (P_1/P_2) \text{ bels.}$$

### 1.18 Decibel (*db*)

(American Standard Definitions of Electrical Terms—C42-1941:65.11.010)

The decibel is one-tenth of a bel, the number of decibels denoting the ratio of two amounts of power being 10 times the logarithm to the base 10 of this ratio. The abbreviation *db* is commonly used for the term decibel.

Note: With $P_1$ and $P_2$ designating two amounts of power and $n$ the number of decibels denoting their ratio:

$$n = 10 \log_{10} (P_1/P_2)\ db.$$

When the conditions are such that ratios of currents or ratios of voltages (or analogous quantities in other fields such as pressures, amplitudes, particle velocities in sound) are the square roots of the corresponding power ratios, the number of decibels by which the corresponding powers differ is expressed by the following formulae

$$n = 20 \log_{10} (I_1/I_2)\ db$$
$$n = 20 \log_{10} (V_1/V_2)\ db$$

where $I_1/I_2$ and $V_1/V_2$ are the given current and voltage ratios, respectively.

By extension, these relations between numbers of decibels and ratios of currents or voltages are sometimes applied where these ratios are not the square roots of the corresponding power ratios; to avoid confusion, such usage should be accompanied by a specific statement of this application.

### 1.19 Dyne Per Square Centimeter (Bar*) (Microbar) (Barye)

A dyne per square centimeter is the unit of sound pressure.

Note: The term "bar" was originally applied to a pressure of $10^6$ dynes per square centimeter, and in all other fields except acoustics it is used with this meaning. Unfortunately in acoustics it was used to mean one dyne per square centimeter. It is suggested that in speaking

---

* Deprecated.

of sound pressures the more fundamental term "dyne per square centimeter" be used.

### 1.20 Static Pressure ($P_0$)

The static pressure is the pressure that would exist in the medium with no sound waves present. The unit is the dyne per square centimeter.

### 1.21 Instantaneous Sound Pressure ($p$)

The instantaneous sound pressure at a point is the total instantaneous pressure at that point minus the static pressure. The unit is the dyne per square centimeter.

NOTE: This is often called excess pressure.

### 1.22 Effective Sound Pressure ($P$)

The effective sound pressure at a point is the root mean square value of the instantaneous sound pressure over a complete cycle, at that point. The unit is the dyne per square centimeter.

NOTE: The term "effective sound pressure" is frequently shortened to "sound pressure."

### 1.23 Maximum Sound Pressure ($P_m$)

The maximum sound pressure for any given cycle is the maximum absolute value of the instantaneous sound pressure during that cycle. The unit is the dyne per square centimeter.

NOTE: In the case of a sinusoidal sound wave this maximum sound pressure is also called the pressure amplitude.

### 1.24 Peak Sound Pressure

The peak sound pressure for any specified time interval is the maximum absolute value of the instantaneous sound pressure in that interval. The unit is the dyne per square centimeter.

### 1.25 Sound Energy Flux ($J$)

The sound energy flux is the average over one period of the rate of flow of sound energy through any specified area. The unit is the erg per second.

NOTE: In a gas of density $\rho$, for a plane or spherical free wave having a velocity of propagation $c$, the sound energy flux through the area $a$ (square centimeters) corresponding to an effective sound pressure $P$ is

$$J = \frac{P^2 a}{\rho c} \cos\theta \text{ ergs per second}$$

where $\theta$ is the angle between the direction of propagation of the sound and the normal to the area $a$.

### 1.26 Pressure Level[*]

The pressure level, in decibels, of a sound is twenty times the logarithm to the base ten of the ratio of the pressure $P$ of this sound to the reference pressure $P_0$. Unless otherwise specified, the reference pressure is understood to be 0.0002 dyne per square centimeter. Pressure level may also be expressed in bels.

NOTE: It is to be noted that in many sound fields the sound pressure ratios are not proportional to the square root of corresponding power ratios and hence cannot be expressed in decibels in the strict sense; however, it is common practice to extend the use of the decibel to these cases. See 1.17 and 1.18.

### 1.27 Velocity Level[*]

The velocity level, in decibels, of a sound is twenty times the logarithm to the base ten of the ratio of the particle velocity of the sound to the reference particle velocity. Unless otherwise specified the reference particle velocity is understood to be 5 times $10^{-6}$ centimeter per second effective value. Velocity level may also be expressed in bels.

NOTE: It is to be noted that in many sound fields the particle velocity ratios are not proportional to the square root of corresponding power ratios and hence cannot be expressed in decibels in the strict sense; however, it is common practice to extend the use of the decibel to these cases. See 1.17 and 1.18.

### 1.28 Sound Energy Density ($E$)

Sound energy density is the sound energy per unit volume. The unit is the erg per cubic centimeter.

### 1.29 Sound Intensity[*] ($I$) (Sound Energy Flux Density) (Flux Density)

The sound intensity of a sound field in a specified direction at a point is the sound energy transmitted per unit of time in the specified direction through a unit area normal to this direction at the point. The unit is the erg per

---

[*] In discussing sound measurements made with pressure or velocity microphones, especially in enclosures involving normal modes of vibration or in sound fields containing standing waves, caution must be observed in using the terms "Intensity" and "Intensity Level." Under such conditions it is more desirable to use the terms "Pressure Level" or "Velocity Level" since the relationship between the intensity and the pressure or velocity is generally unknown.

second per square centimeter but sound intensity may also be expressed in watts per square centimeter.

NOTE (a): The sound intensity in any specified direction "$a$" is given by

$$I_a = \frac{1}{k}\int_0^k p v_a dt$$

where $k$ is the period, $p$ the instantaneous sound pressure and $v_a$ is the component of the instantaneous particle velocity in the direction "$a$."

NOTE ($b$): In the case of a plane or spherical free wave having the effective sound pressure $P$ dynes per square centimeter, the velocity of propagation $c$ (centimeters per second) in a medium of density $\rho$ (grams per cubic centimeter), the intensity in the direction of propagation is given by

$$I = \frac{P^2}{\rho c} \text{ (ergs per second per square centimeter).}$$

This same relation can often be used in practice with sufficient accuracy to calculate the intensity at a point near the source with only a pressure measurement. In more complicated sound fields the results given by this relation may differ greatly from the actual intensity.

### 1.30 Intensity Level* ($I_L$) (Sound Energy Flux Density Level)

The intensity level, in decibels, of a sound is ten times the logarithm to the base ten of the ratio of the intensity $I$ of this sound, to the reference intensity $I_0$. Unless otherwise specified the reference intensity $I_0$ shall be $10^{-16}$ watt per square centimeter. Intensity level may also be expressed in bels.

### 1.31 Beats

Beats are the periodic variations of the amplitude of the sound pressure or the particle velocity at a point due to the interference of two sound waves of different frequencies.

### 1.32 Free Wave (Free Progressive Wave)

A free wave is a sound wave free from interference effects.

### 1.33 Interference Pattern

An interference pattern is the resulting space distribution of pressure, particle velocity, energy density, or energy flux when sound waves of the same frequency are superposed.

### 1.34 Stationary or Standing Waves

Stationary waves are the wave system resulting from the interference of waves of the same frequencies and are characterized by the existence of nodes or partial nodes.

NOTE: This definition broadens the ideal classical concept which is limited to a wave system characterized by a zero sound energy flux at all points.

### 1.35 Nodes

Nodes are the points, lines, or surfaces of a stationary wave system which have a zero amplitude.

NOTE: There are different types of nodes such as pressure nodes or velocity nodes and hence the type must be specified.

### 1.36 Partial Nodes

Partial nodes are the points, lines, or surfaces of a stationary wave system which have a minimum amplitude.

### 1.37 Antinodes

Antinodes are the points, lines, or surfaces of a stationary wave system which have a maximum amplitude.

### 1.38 Echo

An echo is a wave which has been reflected or otherwise returned with sufficient magnitude and delay to be perceived in some manner as a wave distinct from that directly transmitted.

### 1.39 Multiple Echo

A multiple echo is a succession of separately distinguishable echoes from a single source.

### 1.40 Flutter Echo

A flutter echo is a rapid succession of reflected pulses resulting from a single initial pulse. If the flutter echo is periodic and if the frequency is in the audible range it is called a musical echo.

### 1.41 Unpitched Sound

An unpitched sound is any sound to which no definite pitch can be assigned.

### 1.42 Noise

Noise is any undesired sound.

### 1.43 Infra-Audible Sound ($IA$ Sound)

Infra-audible sound is sound whose frequency is below the lower pitch limit. See 3.2.

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* See footnote on p. 7.

### 1.44 Ultra-Audible Sound (Supersonic Sound) (*UA* Sound)

Ultra-audible sound is sound whose frequency is above the upper pitch limit. See *3.3*.

## 2. ARCHITECTURAL ACOUSTICS

### 2.1 Acoustic Reflectivity

The acoustic reflectivity of a surface not a generator is the ratio of the rate of flow of sound energy reflected from the surface, on the side of incidence, to the incident rate of flow. Unless otherwise specified all possible directions of incident flow are assumed to be equally probable. Also, unless otherwise stated the values given apply to a portion of an infinite surface thus eliminating edge effects.

### 2.2 Acoustic Absorptivity

The acoustic absorptivity of a surface is equal to one minus the reflectivity of that surface.

### 2.3 Sabin (Plural-Sabins)

The sabin is a unit of equivalent absorption and is equal to the equivalent absorption of one square foot of a surface of unit absorptivity, i.e., of one square foot of surface which absorbs all incident sound energy.

### 2.4 Acoustic Transmittivity

The acoustic transmittivity of an interface or septum is the ratio of the rate of flow of transmitted sound energy to the rate of incident flow. Unless otherwise specified all directions of incident flow are assumed to be equally probable.

### 2.5 Reverberation

Reverberation is the persistence of sound, due to repeated reflections.

### 2.6 Rate of Decay (of Sound Energy Density) (*S*)

The rate of decay of sound energy density is the time rate at which the sound energy density is decreasing at a given point and at a given time. The practical unit is the decibel per second.

### 2.7 Reverberation Time (*T*)

The reverberation time for a given frequency is the time required for the average sound energy density, initially in a steady state, to decrease, after the source is stopped, to one-millionth of its initial value. The unit is the second.

### 2.8 Mean Free Path

The mean free path for sound waves in an inclosure is the average distance sound travels in the inclosure between successive reflections.

## 3. HEARING

### 3.1 Pitch

Pitch is that subjective quality of a sound which determines its position in a musical scale. Pitch may be measured as the frequency of that pure tone having a specified sound pressure, or specified loudness level, which seems to the average normal ear to occupy the same position in a musical scale. The unit is the cycle per second.

### 3.2 Lower Pitch Limit

The lower pitch limit is the minimum frequency, for a sinusoidal sound wave, that will produce a pitch sensation.

### 3.3 Upper Pitch Limit

The upper pitch limit is the maximum frequency, for a sinusoidal sound wave, that will produce a pitch sensation.

### 3.4 Threshold of Audibility

The threshold of audibility at any specified frequency is the minimum value of the sound pressure of a sinusoidal wave of that frequency which produces a pitch sensation. This term is often used to denote the minimum value of the sound pressure of any specified complex wave (such as speech or music) which gives the ear a sensation of sound. The point at which the pressure is measured must be specified in every case. It is expressed in dynes per square centimeter.

NOTE: Unless otherwise specified the ear is assumed to be in a silent place.

NOTE: The threshold of audibility is also expressed in terms of the sound intensity in ergs per second per square centimeter, or in terms of the intensity level above a specified reference intensity.

### 3.5 Normal Threshold of Audibility

The normal threshold of audibility is the modal value of the threshold of audibility of a large number of normal ears. The unit is the dyne per square centimeter.

Note: The term may be shortened to "normal threshold" when no danger of confusing it with the normal threshold of feeling exists.

### 3.6 Threshold of Feeling

The threshold of feeling at any specified frequency is the minimum value of the sound pressure of a sinusoidal wave of that frequency which will stimulate the ear to a point at which there is the sensation of feeling. The point at which the pressure is measured must be specified in every case. It is expressed in dynes per square centimeter.

### 3.7 Normal Threshold of Feeling

The normal threshold of feeling is the modal value of the threshold of feeling of a large number of normal ears. It is expressed in dynes per square centimeter.

### 3.8 Level Above Threshold (Sensation Level)

The level above threshold of a sound is the difference between the intensity level of the sound and the intensity level of the threshold of audibility for that sound. It is expressed in decibels.

Note: The term "Level Above Threshold" as here defined has a unique meaning only in the case of a free wave. If, however, the intensities specified are those along the ear canal of the listener then the meaning is definite in any kind of sound field and the intensity level values may be replaced by either the pressure level or the velocity level in the ear canal, assuming that the ear impedance is linear.

### 3.9 Hearing Loss (Deafness)

The hearing loss of an ear at a given frequency is the ratio of the threshold of audibility for that ear to the normal threshold of audibility, at the same frequency. It is expressed in decibels.

### 3.10 Percent Hearing Loss (Percent Deafness)

The percent hearing loss at any given frequency is one hundred times the ratio of the hearing loss in decibels to the number of decibels between the normal threshold levels of audibility and of feeling at that frequency.

### 3.11 Percent Hearing

The percent hearing at any given frequency is one hundred minus the percent hearing loss at that frequency.

### 3.12 Air-Conduction Perception

Air-conduction perception is perception in which the sound is conducted to the inner ear through the air in the meatus.

### 3.13 Bone-Conduction Perception

Bone-conduction perception is perception in which the sound is conducted to the inner ear by the cranial bones.

### 3.14 Loudness

The loudness is that subjective quality of a sound which determines the magnitude of the auditory sensation produced by that sound.

### 3.15 Loudness Level

The loudness level, in phons, of a sound is numerically equal to the intensity level in decibels of the 1000 cycles per second pure tone which is judged by the listeners to be equivalent in loudness.

Note 1: The 1000-cycle comparison tone shall be considered as a plane sinusoidal sound wave coming from a position directly in front of the observer. The listening is to be done with both ears and the intensity level of the 1000-cycle comparison tone is to be measured in the free progressive wave. The reference intensity shall be $10^{-16}$ watt per square centimeter in air at normal condition. This is near the value of the threshold of audibility for a 1000-cycle pure tone measured in a plane free wave coming directly to the front of the observer.

Note 2: This is the same concept defined in the *British Standard Glossary of Acoustical Terms and Definitions No. 661–1936* as equivalent loudness.

### 3.16 Masking of a Sound

The masking of a sound is the shift of the threshold of audibility of the masked sound due to the presence of the masking sound. The unit is the decibel.

### 3.17 Auditory Sensation Area

The auditory sensation area is the area enclosed by the curves defining the threshold of feeling and the threshold of audibility.

### 3.18 Audiogram

An audiogram is a hearing loss—frequency graph or a percent hearing—frequency graph.

### 3.19 Noise Audiogram

A noise audiogram is a graphical record of the masking due to a given noise, as a function of the frequency of the masked tone.

### 3.20 Loudness Contours

Loudness contours are curves of equal loudness for sinusoidal sound waves.

### 3.21 Instantaneous Speech Power

The instantaneous speech power is the rate at which sound energy is being radiated by the speaker at any given instant.

### 3.22 Average Speech Power

The average speech power for any given time interval is the average value of the instantaneous speech power, over that interval.

### 3.23 Phonetic Speech Power

The phonetic speech power is the maximum value of the average speech power, for 0.01-second intervals, of a vowel or consonant sound.

### 3.24 Peak Speech Power

The peak speech power is the maximum value of the instantaneous speech power over the time interval considered.

### 3.25 Discrete Sentence Intelligibility

The discrete sentence intelligibility is the percentage of the total number of spoken sentences which are correctly understood, when each sentence conveys a simple idea and is of a form to test the observer's acuteness of perception rather than his intelligence.

### 3.26 Discrete Word Intelligibility

The discrete word intelligibility is the percentage of the total number of spoken words which are correctly understood when the words are spoken so as to have no contextual relation between them.

### 3.27 Syllable Articulation

The syllable articulation is the percentage of the total number of spoken meaningless syllables which are correctly recognized.

### 3.28 Sound Articulation

The sound articulation is the percentage of the total number of spoken fundamental sounds which are correctly recognized when the sounds are spoken in meaningless syllables.

### 3.29 Vowel, Consonant, Initial Consonant, or Final Consonant Articulation

The vowel, consonant, initial consonant, or final consonant articulation is the sound articulation analyzed to show the percentage correctly recognized of the total number of vowels, consonants, initial consonants, or final consonants, respectively, which were used in the articulation tests.

### 3.30 Individual Sound Articulation

The individual sound articulation is the sound articulation analyzed to show the percentage correctly recognized for a particular sound such as "e."

### 3.31 Phon

The phon is the unit of loudness level as specified in definition 3.15.

## 4. SOUND TRANSMISSION

Note on Terminology: Because of the similarity of electrical, mechanical, and acoustical transmission theory the same terminology is used in the three cases. Where confusion is likely to occur the term mechanical or acoustic should be prefixed to the general term, e.g., acoustic transfer impedance, but unless otherwise specified the following definitions apply not only in acoustics but in mechanics as well. While acoustics is a branch of mechanics it is found convenient to distinguish an acoustic system from a mechanical one using the former term whenever elastic wave motion is an essential feature.

The terms and definitions of this section pertain to single-frequency pressures or driving forces, and volume velocities or velocities in the steady state, and to transmission systems having properties which are independent of the magnitudes of these pressures and velocities. The forces, pressures, velocities, etc., can be represented mathematically by complex exponential functions of the time. Under these conditions the factors involving the time cancel out in the ratios called for in the definitions, leaving complex numbers independent of time. Solutions based on complex exponential functions under these conditions give the solution for real sinusoidal oscillations.

### 4.1 Acoustic Impedance

The acoustic impedance of a sound medium on a given surface lying in a wave front is the complex quotient of the sound pressure (force per unit area) on that surface by the flux (volume velocity, or linear velocity multiplied by the area), through the surface. When concentrated rather than distributed impedances are considered, the impedance of a portion of the medium is defined by the complex quotient of the pressure difference effective in driving that portion, by the flux (volume velocity). The acoustic impedance may be expressed in terms of mechanical impedance, acoustic impedance being equal to the mechanical impedance divided by the square of the area of the surface considered. The unit is the acoustic ohm.

NOTE: Velocities in the direction along which the impedance is to be specified are considered positive.

### 4.2 Acoustic Resistance

The acoustic resistance of a sound medium is the real component of the acoustic impedance. This is the component of the acoustic impedance that is responsible for the dissipation of energy. The unit is the acoustic ohm.

### 4.3 Acoustic Reactance

The acoustic reactance of a sound medium is the imaginary component of the acoustic impedance. It is the component of the acoustic impedance which may result from the effective mass or from the compliance of the medium. The unit is the acoustic ohm.

### 4.4 Acoustic Ohm

An acoustic resistance, reactance, or impedance is said to have a magnitude of one acoustic ohm when a sound pressure of one dyne per square centimeter produces a volume velocity of one cubic centimeter per second.

### 4.5 Acoustic Inertance

The acoustic inertance of a sound medium is that coefficient which, when multiplied by $2\pi$ times the frequency gives the imaginary part of the acoustic impedance which results from the inertia or effective mass of the medium. The unit is the gram per centimeter to the fourth power.

### 4.6 Acoustic Stiffness

The acoustic stiffness of a sound medium is that coefficient which when divided by $2\pi$ times the frequency gives the imaginary part of the acoustic impedance which results from the compliance of the medium or the volume displacement per unit pressure. The unit is the dyne per centimeter to the fifth power.

### 4.7 Acoustic Compliance

The acoustic compliance of a sound medium is the reciprocal of the acoustic stiffness of the medium.

### 4.8 Mechanical Impedance

The mechanical impedance of a mechanical system is the complex quotient of the alternating force applied to the system by the resulting alternating linear velocity in the direction of the force at its point of application. The unit is the mechanical ohm or the dyne second per centimeter.

### 4.9 Driving-Point Impedance

The driving-point impedance is the complex quotient at any driving-point, of the force (or sound pressure) by the velocity (linear or volume) of vibration at that point.

### 4.10 Resonance (Velocity Resonance)

Resonance exists between a body, or system, and an applied sinusoidal force if any small change in the frequency of the applied force causes a decrease in velocity at the driving point; or if the frequency of the applied force is such that the absolute value of the driving-point impedance is a minimum.

NOTE: In the case of a singly resonant system consisting of a mass reactance, a stiffness reactance, and a resistance in series, the frequency of resonance as defined above is also the frequency at which the mass and the stiffness reactances are numerically equal, and hence the frequency at which the applied sinusoidal force and the resulting sinusoidal velocity are in phase.

### 4.11 Resonant Frequency

A resonant frequency is a frequency at which resonance exists. The unit is the cycle per second.

NOTE: In cases where there is a possibility of confusion it is necessary to specify the type of resonant frequency, i.e., displacement resonant frequency, or velocity resonant frequency.

### 4.12 Displacement Resonance

Displacement resonance exists between a body, or system, and a sinusoidally applied force if any small change in frequency of the applied force causes a decrease in the amplitude of displacement.*

### 4.13 Anti-Resonant Frequency

An anti-resonant frequency of any device is a frequency at which the current, the velocity, or the displacement at the driving point will have a minimum magnitude when driven by a constant force. The unit is the cycle per second.

NOTE: In cases where confusion might exist it is necessary to specify whether velocity or displacement anti-resonance is meant.

### 4.14 Anti-Resonance

Anti-resonance is the condition existing at an anti-resonant frequency.

### 4.15 Forced Vibration

A forced vibration is any vibration that is imposed upon a system by external force and whose frequency is controlled thereby.

### 4.16 Free Vibration

A free vibration is any vibration which exists in a system after all driving forces have been removed from the system.

### 4.17 Natural Frequency ($f_0$)

The natural frequency of any system is the frequency at which its vibrating element will vibrate after the external force displacing it from its normal position has ceased to act. The unit is the cycle per second.

### 4.18 Natural Period

The natural period is the reciprocal of the natural frequency. The unit is the second.

### 4.19 Conjugate Impedance

Two impedances are said to be conjugate to each other when their effective resistances are equal and their reactances are equal in magnitude but are opposite in sign.

### 4.20 Transfer Impedance

The transfer impedance between two points is the complex ratio of an applied sinusoidal

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* DISCUSSION: In the case of a system whose motion can be described by the equation:

$$M\frac{d^2x}{dt^2}+R\frac{dx}{dt}+Sx=A\cos\omega t$$

the characteristics of the different kinds of resonance in terms of the constants of the above equation are given in the table:

| | Resonance | At displacement resonance | At the natural frequency |
|---|---|---|---|
| Frequency | $\frac{1}{2\pi}\sqrt{\frac{S}{M}}$ | $\frac{1}{2\pi}\sqrt{\frac{S}{M}-\frac{R^2}{2M^2}}$ | $\frac{1}{2\pi}\sqrt{\frac{S}{M}-\frac{R^2}{4M^2}}$ |
| Amplitude of displacement | $\frac{A}{R\sqrt{\frac{S}{M}}}$ | $\frac{A}{R\sqrt{\frac{S}{M}-\frac{R^2}{4M^2}}}$ | $\frac{A}{R\sqrt{\frac{S}{M}-\frac{3R^2}{16M^2}}}$ |
| Amplitude of velocity | $\frac{A}{R}$ | $\frac{A}{R\sqrt{1+\frac{R^2}{4MS-2R^2}}}$ | $\frac{A}{R\sqrt{1+\frac{R^2}{16MS-4R^2}}}$ |
| Phase of displacement with reference to applied force | $\frac{\pi}{2}$ | $\tan^{-1}\sqrt{\frac{4MS}{R^2}-2}$ | $\tan^{-1}\sqrt{\frac{16MS}{R^2}-4}$ |

For small values of $R$, there is little difference between the three cases discussed above.

force (or sound pressure) at one point to the resultant velocity (or volume velocity) at the second point.

### 4.21 Insertion Loss

The insertion loss caused by the insertion of a system in another system is the proportional loss in power delivered to that part of the original system beyond the point of insertion due to the inserted system. The unit is the decibel.

### 4.22 Transducer Loss

The transducer loss of a piece of apparatus between two given terminals is the proportional loss caused by inserting the apparatus, assuming that as a reference standard the source and the load were connected through an ideal transducer. The unit is the decibel.

### 4.23 Propagation Constant ($P$)

The propagation constant ($P$) of a uniform system, or of a section of a system of recurrent structure is the natural logarithm of the complex ratio of the steady-state velocities (linear or volume) at two points separated by unit distance in the uniform system (assumed to be of infinite length), or at two successive corresponding points in the system of recurrent structure (assumed to be of infinite length). The ratio is determined by dividing the value of the velocity at the point nearer the transmitting end by the value of the velocity at the point more remote.

NOTE: Single frequency pressures and velocities are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

### 4.24 Neper

The neper is a unit of the same nature as the decibel but differs from it in magnitude. When used for expressing power ratios the number of nepers "$N$" by which the power $P$ exceeds the power $P_0$ is given by, $N=\frac{1}{2}\log_e P/P_0$ or if used for expressing the current, velocity, voltage, or force ratios when these are working into the same or equal impedances $N=\log_e a_1/a_0$. One neper is equivalent to 8.686 decibels.

### 4.25 Attenuation Constant ($A$)

The attenuation constant is the real part of the "propagation constant." The unit is the neper.

NOTE: In the case of a symmetrical structure, the real parts of both the transfer constant and the propagation constant are identical, and hence either one may be called simply the attenuation constant.

In the case of a portion of smooth line of infinite length the attenuation constant is the natural logarithm of the absolute value of the ratio of the currents at the beginning and end of the length under consideration.

### 4.26 Phase Constant ($B$)

The phase constant is the imaginary part of the "propagation constant." The unit is the radian.

NOTE: In the case of a symmetrical structure, the imaginary part of both the transfer constant and of the propagation constant are identical and have been called the "wave-length constant" as well as the "angular constant."

### 4.27 Iterative Impedance

The iterative impedance of any transducer, having an input and an output, is the impedance which will terminate the output in such a way as to make the input impedance equal to this terminating impedance.

### 4.28 Image Impedance

The image impedance of any transducer, having an input and an output, is the impedance which will terminate the transducer in such a way that at either junction the impedances in both directions are identical.

NOTE: This is equivalent to stating that the image impedance at either end is the geometric mean of the open- and the short-circuit impedances of the transducer as measured from that end. The image impedance of any symmetrical transducer is the same as its iterative impedance.

### 4.29 Transfer Constant ($\theta$)

The transfer constant of any passive transducer is one-half the natural logarithm of the complex ratio of the steady-state product of the force and the velocity, or the pressure and volume velocity entering the transducer to that leaving the transducer when the latter is terminated in its image impedance.

NOTE: Single frequency forces and velocities are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

### 4.30 Image Attenuation Constant

The image attenuation constant is the real part of the "transfer constant." The prefix "image" may be omitted if there is no danger of confusion.

### 4.31 Image Phase Constant

The image phase constant is the imaginary part of the "transfer constant." The prefix "image" may be omitted when there is no danger of confusion.

### 4.32 Cut-off Frequency ($f_c$)

The cut-off frequency of any non-dissipative structure is the divisional frequency immediately on one side of which the attenuation constant is zero and immediately on the other side of which the attenuation constant is not zero. The cut-off frequency of a dissipative structure is the cut-off frequency which would exist in a non-dissipative structure having the same constants for the reactive elements.

### 4.33 Force Factor

The force factor of an electromechanical transducer is the complex quotient of the resulting force in the mechanical system when blocked and the current in the electrical system; or the complex quotient of the resulting open-circuit voltage in the electrical system and the velocity in the mechanical system.

The force factor of an electroacoustic transducer is the complex quotient of the resulting blocked pressure in the acoustic system and the current in the electrical system; or the complex quotient of the resulting open-circuit voltage in the electrical system and the volume velocity in the acoustic system.

### 4.34 Blocked Impedance

The blocked impedance of a transducer is the impedance measured at the input when the impedance of the output system is made infinite.

NOTE: For instance, in the case of an electromechanical transducer the blocked impedance is the impedance measured at the electrical terminals when the mechanical system is blocked or clamped.

### 4.35 Normal Impedance

The normal impedance of a transducer is the impedance measured at the input of the transducer when the output is connected to its normal load.

### 4.36 Motional Impedance

The motional impedance of a transducer is the vector difference between its normal and its blocked impedance.

## 5. TRANSMISSION SYSTEMS

### 5.1 Acoustic System

An acoustic system is a system adapted for the transmission of sound.

### 5.2 Symmetrical Transducer (Symmetrical Network)

A symmetrical transducer is a structure whose input and output image impedances are equal.

### 5.3 Dissymmetrical Transducer (Dissymmetrical Network)

A dissymmetrical transducer is a transducer whose input and output image impedances are unequal in magnitude or phase or both.

### 5.4 Selective Transducer (Selective Network)

A selective transducer is a structure designed to give some predetermined insertion loss-frequency or phase shifting frequency characteristic.

### 5.5 All-Pass Transducer (All-Pass Network)

An all-pass transducer is a structure whose attenuation constant is zero for all frequencies from zero to infinity.

### 5.6 Equivalent Network

An equivalent network is a network of impedances, which, at a given frequency or over the entire range of frequencies, is the equivalent of another network.

### 5.7 Wave Filter

A wave filter is a selective transducer which introduces a negligible insertion loss over a certain finite range (or ranges) of frequencies and a relatively large insertion loss at all other frequencies.

### 5.8 Low-Pass Wave Filter

A low-pass (*LP*) wave filter is a selective transducer which efficiently passes waves of all frequencies from zero up to a certain frequency—called the cut-off frequency—and effectually bars waves of all higher frequencies.

### 5.9 High-Pass Wave Filter

A high-pass (*HP*) wave filter is a selective transducer which efficiently passes waves of all frequencies down to a certain frequency—called the cut-off frequency—and effectually bars waves having frequencies lower than the cut-off frequency.

### 5.10 Band-Elimination Wave Filter

A band-elimination (*BE*) wave filter or a "low- and high-pass" wave filter is a selective transducer which efficiently passes waves of all frequencies from zero up to a certain frequency, $f_1$; effectually barring waves of all frequencies between $f_1$ and a higher frequency $f_2$, and efficiently passing waves having a frequency higher than $f_2$.

### 5.11 Band-Pass Wave Filter

A band-pass (*BP*) wave filter is a selective transducer, which efficiently passes all waves between two given frequencies, and effectually bars all waves whose frequencies lie outside of this range.

### 5.12 Composite Wave Filter

A composite wave filter is a network of serially connected wave filter sections some or all of which are different in their transfer constants but adjacent sections of which are equal in their image impedances at their junction.

### 5.13 Constant Resistance Structure

A constant resistance structure is one whose iterative impedance in at least one direction is a pure resistance and is independent of the frequency.

### 5.14 Transducer

(American Standard Definitions of Electrical Terms—C42-1941: 65.20.600)

A transducer is a device by means of which energy may flow from one or more transmission systems to one or more other transmission systems.

NOTE: The energy transmitted by these systems may be of any form (for example, it may be electrical, mechanical or acoustical), and it may be of the same form or different forms in the various input and output systems.

### 5.15 Passive Transducer

A passive transducer is one in which the power supplied to the second system is obtained exclusively from the power available from the first system.

### 5.16 Ideal Transducer

An ideal transducer for connecting two specific systems is a passive transducer which converts the maximum possible power from the first system to the second.

### 5.17 Electroacoustic Transducer

An electroacoustic transducer is a transducer which is actuated by power from an electrical system and supplies power to an acoustical system or vice versa.

### 5.18 Ideal Electroacoustic Transducer

An ideal electroacoustic transducer for connecting two specific systems is a passive transducer which converts the maximum possible power from the electrical system to the acoustical system or vice versa.

## 6. MUSIC

### 6.1 Tone

A tone is a sound giving a definite sensation of pitch.

### 6.2 Pitch

Pitch is a sensory characteristic arising out of frequency, which may assign to a tone a position in a musical scale.

NOTE: The pitch of any tone is commonly indicated by the frequency of a simple tone of specified intensity corresponding in pitch to the tone.

### 6.3 Simple Tone (Pure Tone. See 1.2)

A simple tone is one which consists of a single frequency.

### 6.4 Compound Tone

A compound tone is one which consists of more than a single frequency.

### 6.5 Partial Tone

A partial tone is any component of a compound tone. (See 1.11.)

### 6.6 Fundamental Tone

The fundamental tone of a compound tone is that one of its partials which has the lowest frequency. (See 1.8.)

### 6.7 Harmonic

A harmonic is a partial whose frequency is an integral multiple of the fundamental frequency. (See 1.9.)

### 6.8 Interval

The interval between two tones is a measure of their difference in pitch, and is usually numerically represented by the ratio of their frequencies. (See Table I.)

### 6.9 Note

A note is a conventional sign used to indicate the pitch, or duration, or both, of a tone.

### 6.10 Octave

An octave is the interval between any two tones whose frequency ratio is 2 : 1. (See 1.7.)

### 6.11 Equally Tempered Half-Tone

An equally tempered half-tone is the interval between any two tones whose frequency ratio is the twelfth root of two.

### 6.12 Cent

A cent is the interval between any two tones whose frequency ratio is the twelve-hundredth root of two.

NOTE: 1 octave = 12 equally tempered half-tones = 1200 cents.

### 6.13 Scale

A scale is a series of tones ascending or descending in frequency by definite intervals, suitable for musical purposes.

### 6.14 Just Scale (Untempered Scale)

A just scale is a musical scale employing only intervals found in the harmonic series. (See Table I.)

TABLE I. A just scale (see 6.14).

| Interval | Frequency ratio from starting point | Cents from starting point |
|---|---|---|
| Unison | 1 : 1 | |
| Semitone | 16 : 15 | 111.731 |
| Minor tone | 10 : 9 | 182.404 |
| Major tone | 9 : 8 | 203.910 |
| Minor third | 6 : 5 | 315.641 |
| Major third | 5 : 4 | 386.314 |
| Fourth | 4 : 3 | 498.045 |
| Augmented fourth | 45 : 32 | 590.224 |
| Diminished fifth | 64 : 45 | 609.777 |
| Fifth | 3 : 2 | 701.955 |
| Minor sixth | 8 : 5 | 813.687 |
| Major sixth | 5 : 3 | 884.359 |
| Harmonic minor seventh | 7 : 4 | 968.826 |
| Grave minor seventh | 16 : 9 | 996.091 |
| Minor seventh | 9 : 5 | 1017.597 |
| Major seventh | 15 : 8 | 1088.269 |
| Octave | 2 : 1 | 1200.000 |

NOTE: The following theoretical just intervals are also used in musical acoustics and musical theory.

| Name of interval | Description | Frequency ratio | Value in cents |
|---|---|---|---|
| Comma of Didymus | excess of major tone over minor tone | 81 : 80 | 21.506 |
| Comma of Pythagoras | excess of 12 just fifths over 7 octaves | 531441 : 524288 | 23.460 |
| Skhisma | excess of Pythagorean over Didymean comma (almost exactly equal to the difference between a just and an equally tempered fifth) | 32805 : 32768 | 1.954 |

### 6.15 Equally Tempered Scale

The equally tempered scale is a division of the octave into twelve equal intervals, called equally tempered half-tones. (See Table II.)

NOTE: Tones belonging to the equally tempered scale may be identified without the use of musical notation by the method used in Tables II and III annexed to these definitions. In this method the name of the tone ($A$, $B$, $C$, etc.) is given followed by a subscript number indicating the place of the key corresponding to it on the pianoforte keyboard. The tone of lowest frequency is therefore denominated $A_1$. The tone of highest frequency is $C_{88}$. Middle $C$ is $C_{40}$; and so on.

### 6.16 American Standard Pitch

The standard pitch for America is based on the frequency 440 cycles per second for tone $A_{49}$ on the pianoforte keyboard. (See Table III.)

TABLE II. Equally tempered scale (see 6.15).

| Name and number of tone from $C_{40}$ in ascending order | Name of interval from $C_{40}$ as starting point | Frequency (cycles per second) at standard pitch $A_{49}=440$ cycles per second | Cents from starting point | Frequency ratio from starting point |
|---|---|---|---|---|
| $C_{40}$ | Unison | 261.626 | 0 | 1 : 1 |
| $C\sharp_{41}-D\flat_{41}$ | Half-tone | 277.183 | 100 | 1.059463 : 1 |
| $D_{42}$ | Whole tone | 293.665 | 200 | 1.122462 : 1 |
| $D\sharp_{43}-E\flat_{43}$ | Minor third | 311.127 | 300 | 1.189207 : 1 |
| $E_{44}$ | Major third | 329.628 | 400 | 1.259921 : 1 |
| $F_{45}$ | Fourth | 349.228 | 500 | 1.334840 : 1 |
| $F\sharp_{46}-G\flat_{46}$ | Augmented fourth<br>Diminished fifth | 369.994 | 600 | 1.414214 : 1 |
| $G_{47}$ | Fifth | 391.995 | 700 | 1.498307 : 1 |
| $G\sharp_{48}-A\flat_{48}$ | Minor sixth | 415.305 | 800 | 1.587401 : 1 |
| $A_{49}$ | Major sixth | 440.000 | 900 | 1.681793 : 1 |
| $A\sharp_{50}-B\flat_{50}$ | Minor seventh | 466.164 | 1000 | 1.781797 : 1 |
| $B_{51}$ | Seventh | 493.883 | 1100 | 1.887749 : 1 |
| $C_{52}$ | Octave | 523.251 | 1200 | 2 : 1 |

TABLE III. Frequencies of the tones of the equally tempered scale as used in music, named and numbered according to their positions on the pianoforte keyboard and calculated according to the American Standard Pitch (see 6.16).

| Name on pianoforte keyboard | 1st octave no. cycles per second | | 2nd octave no. cycles per second | | 3rd octave no. cycles per second | | 4th octave no. cycles per second | | 5th octave no. cycles per second | | 6th octave no. cycles per second | | 7th octave no. cycles per second | | 8th octave no. cycles per second | | Name on pianoforte keyboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A$ | 1 | 27.500 | 13 | 55.000 | 25 | 110.000 | 37 | 220.000 | 49 | 440.000 | 61 | 880.000 | 73 | 1760.000 | 85 | 3520.000 | $A$ |
| $A\sharp-B\flat$ | 2 | 29.135 | 14 | 58.270 | 26 | 116.541 | 38 | 233.082 | 50 | 466.164 | 62 | 932.328 | 74 | 1864.655 | 86 | 3729.310 | $A\sharp-B\flat$ |
| $B$ | 3 | 30.868 | 15 | 61.735 | 27 | 123.471 | 39 | 246.942 | 51 | 493.883 | 63 | 987.767 | 75 | 1975.533 | 87 | 3951.066 | $B$ |
| $C$ | 4 | 32.703 | 16 | 65.406 | 28 | 130.813 | 40 | 261.626 | 52 | 523.251 | 64 | 1046.502 | 76 | 2093.005 | 88 | 4186.009 | $C$ |
| $C\sharp-D\flat$ | 5 | 34.648 | 17 | 69.296 | 29 | 138.591 | 41 | 277.183 | 53 | 554.365 | 65 | 1108.731 | 77 | 2217.461 | | | $C\sharp-D\flat$ |
| $D$ | 6 | 36.708 | 18 | 73.416 | 30 | 146.832 | 42 | 293.665 | 54 | 587.330 | 66 | 1174.659 | 78 | 2349.318 | | | $D$ |
| $D\sharp-E\flat$ | 7 | 38.891 | 19 | 77.782 | 31 | 155.563 | 43 | 311.127 | 55 | 622.254 | 67 | 1244.508 | 79 | 2489.016 | | | $D\sharp-E\flat$ |
| $E$ | 8 | 41.203 | 20 | 82.407 | 32 | 164.814 | 44 | 329.628 | 56 | 659.255 | 68 | 1318.510 | 80 | 2637.021 | | | $E$ |
| $F$ | 9 | 43.654 | 21 | 87.307 | 33 | 174.614 | 45 | 349.228 | 57 | 698.456 | 69 | 1396.913 | 81 | 2793.826 | | | $F$ |
| $F\sharp-G\flat$ | 10 | 46.249 | 22 | 92.499 | 34 | 184.997 | 46 | 369.994 | 58 | 739.989 | 70 | 1479.978 | 82 | 2959.955 | | | $F\sharp-G\flat$ |
| $G$ | 11 | 48.999 | 23 | 97.999 | 35 | 195.998 | 47 | 391.995 | 59 | 783.991 | 71 | 1567.982 | 83 | 3135.964 | | | $G$ |
| $G\sharp-A\flat$ | 12 | 51.913 | 24 | 103.826 | 36 | 207.652 | 48 | 415.305 | 60 | 830.609 | 72 | 1661.219 | 84 | 3322.438 | | | $G\sharp-A\flat$ |

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