Phys.
Thesis case

METHOD OF TESTING AND VOICING ORGAN PIPES

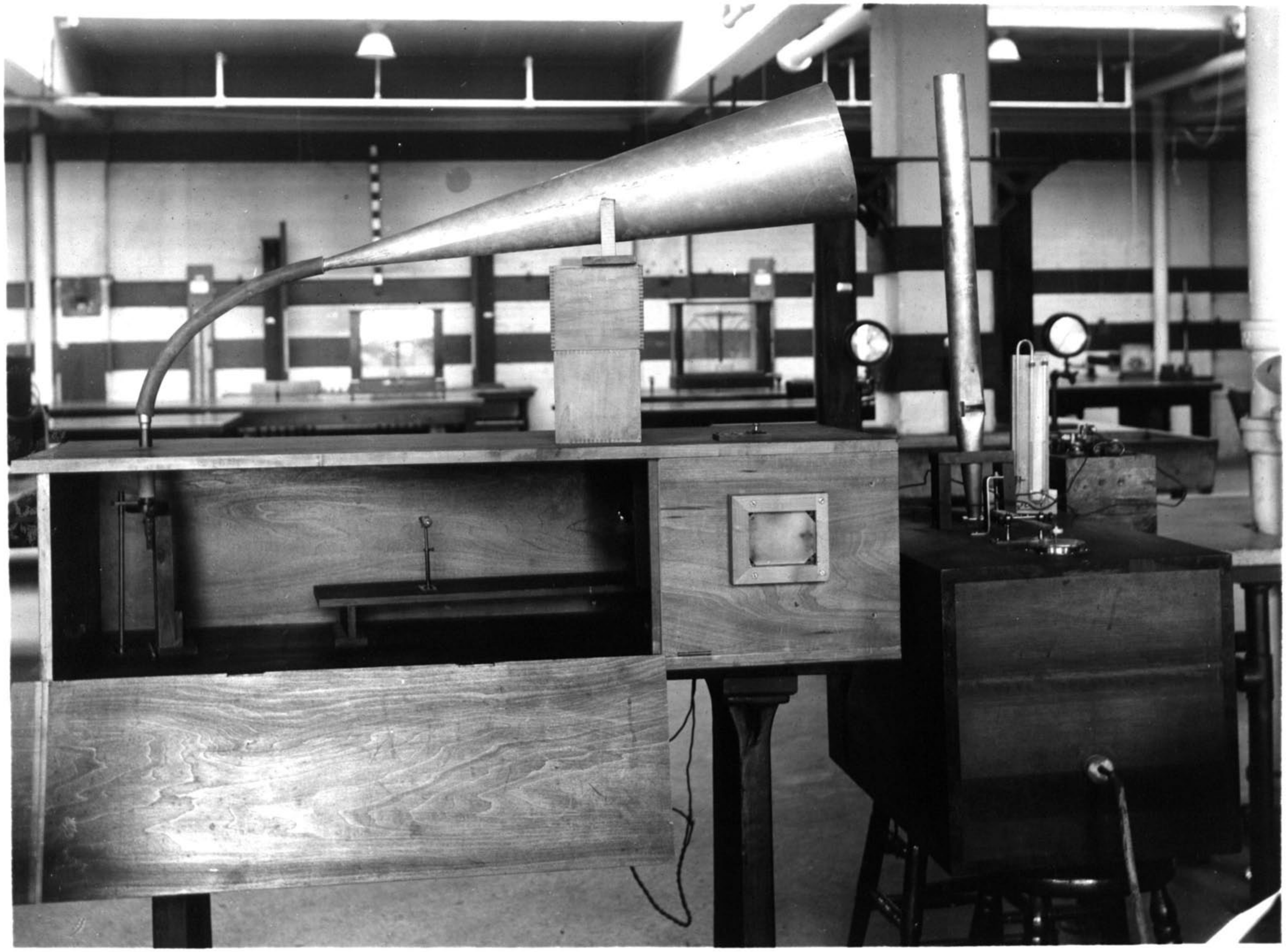
A thesis presented to the Faculty of the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science without specification of department.

By ____________________

Dated August 9, 1922.

ACKNOWLEDGEMENT

I wish to express my appreciation of the kind help and consideration of Professor C. L. Norton, Professor W. S. Franklin, Mr. J. T. Norton, and Mr. E. Benson.



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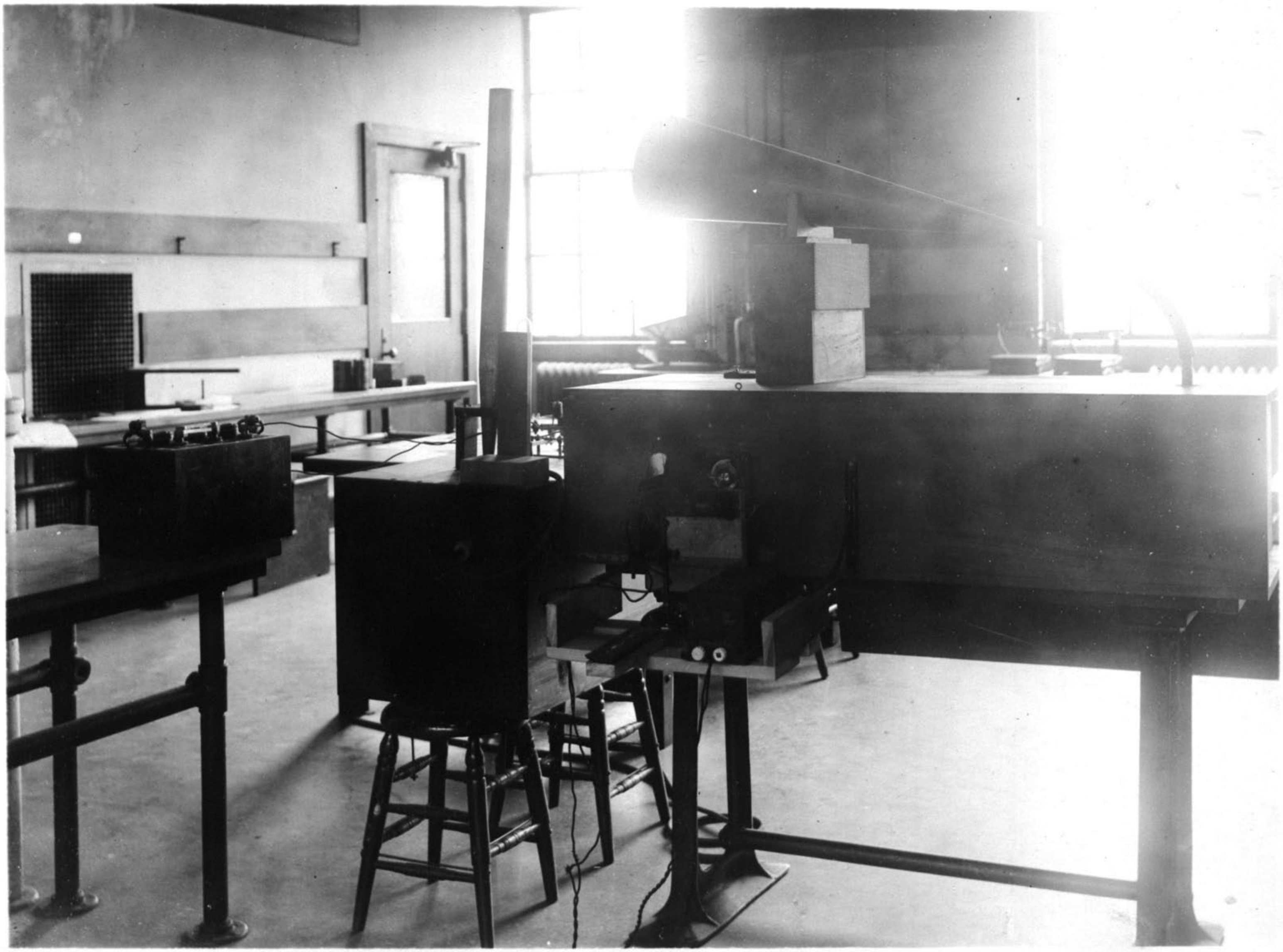

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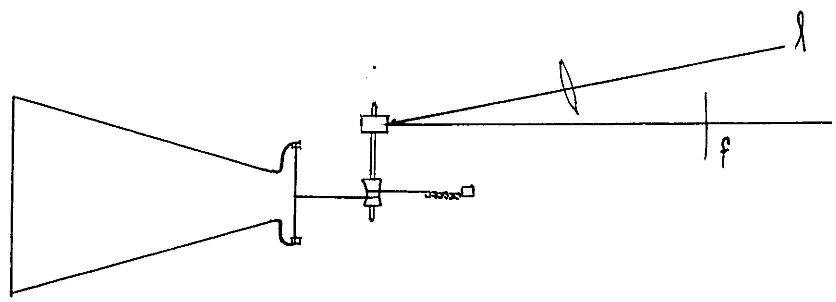
PART I.

THE OBJECT OF PROBLEM

The object of this piece of experimental research is to provide a means of voicing organ pipes by a cheap and uniform method. By "voicing" we mean "the art of producing the tone desired from pipes by defining the amount of wind admitted, and by establishing regular proportions in the relation of the sizes of mouth, windway, width of nicking, et cetera". Trained and highly paid men voice the pipes by ear at the present time. The scarcity of men qualified for this kind of artistic work, the cost of securing such men, and the personal equation necessarily involved present some of the serious difficulties of organ manufacture. The dissatisfaction to manufacturer and customer can be readily imagined when one expert disagrees with another as to the final and proper voicing of the pipes. Uniformity, if secured in only one factory, is desirable. I am not prepared to express an opinion as to the loss in tonal differences and artistic effects which might be caused by such standardization.

The idea in mind is to produce an instrument which will demonstrate the differences between correctly voiced and incorrectly voiced pipes in a manner unmistakably evident to the layman. The instrument invented by Dayton Clarence Miller, called the "phonodeik", presented a solution, since it relies on vision, the most sensitive and inherently trained sense we possess. After the initial construction and adjustment, the phonodeik is operated very readily for demonstration. The following diagram presents the instrument in its simplest form.



p 79 "The Science of Musical Sounds"
D. C. Miller.

A horn to intensify and concentrate the sound is attached to a sensitive diaphragm which vibrates in response to any sound stimulus. Beyond the diaphragm is a tiny mirror cemented to a small spindle which turns in jeweled bearings. A silk fibre is attached to the center of the diaphragm, passed once around that part of the spindle which is fashioned like a pulley, and thence attached to a tension spring. Light from a pin-hole source, being focused onto the mirror, is reflected to a moving film. Slight modifications on this arrangement are explained later.

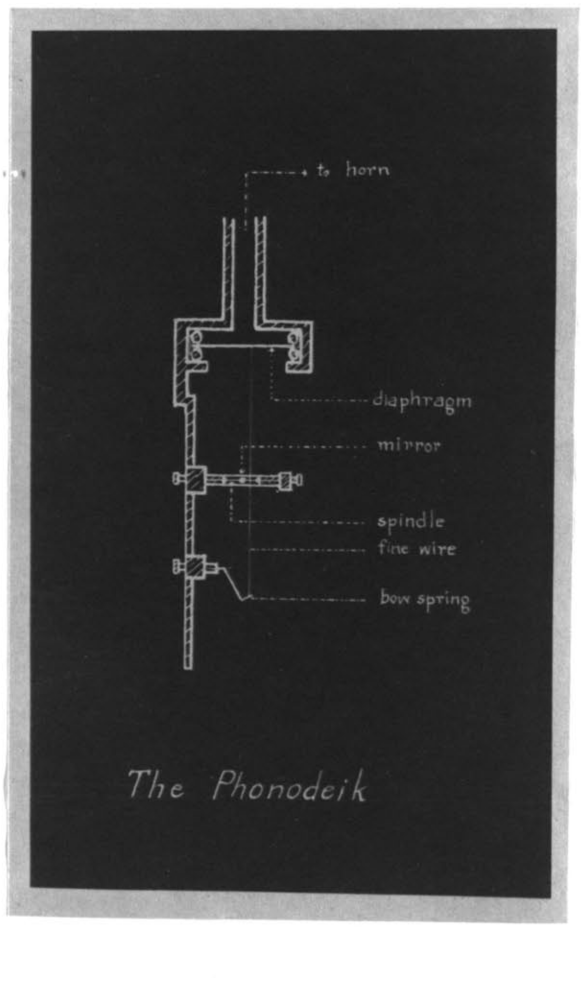
With such an instrument we can secure photographically a trace of the characteristic wave form for any sound; i.e. for any sound to which the instrument is sensitive. For example, for a very high pitched note the diaphragm breaks up into so many vibrating parts that interference occurs and no response is evident. Only with a very delicately made and finely adjusted instrument in which friction and inertia are reduced to a minimum can an experimenter hope for a visible response to a wide range of pitch in both fundamental and overtone.

First then we must procure a correctly voiced pipe within the range of sensitivity of our instrument. Of course it is necessary for our instrument to respond thru-out the range of frequencies used in an organ. By sounding the pipe with the air pressure that gives a pleasant mellow sound, the characteristic wave form may be photographed. We modify the instrument so that we can view the wave on a ground-glass plate. The wave form of an unvoiced or partially voiced organ pipe can now be viewed and compared with the chosen standard. We proceed to nick the mouth, and adjust the upper and lower lips until the wave form approaches and finally becomes exactly similar to our standard wave. For convenience I would suggest tracing the standard wave onto the viewing plate and hence facilitate comparison.

PART II.

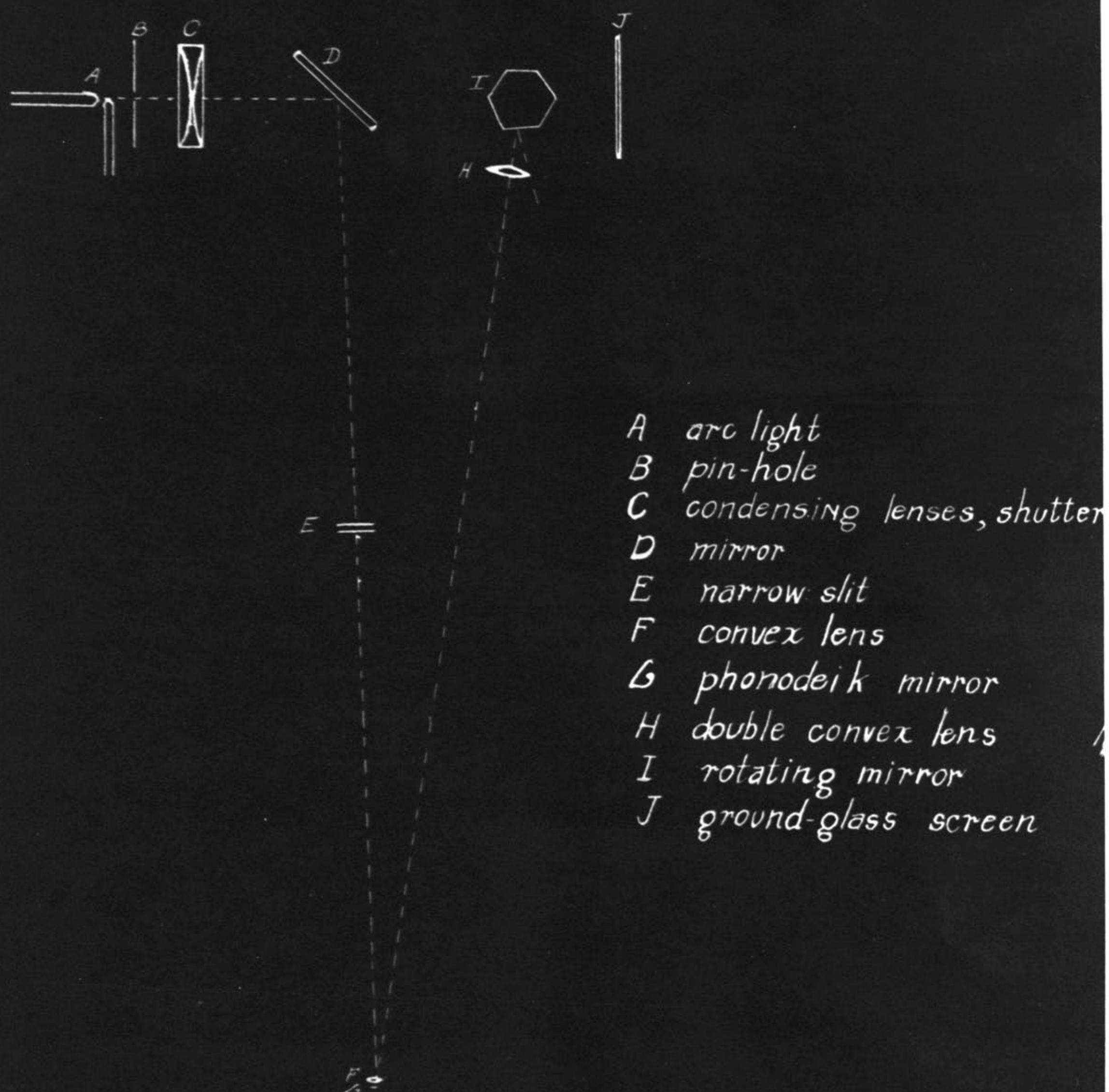
With the exception of a few modifications that are described later, the apparatus was made and assembled by John T. Norton in the spring of 1921.

The phonodeik proper consists of a mica diaphragm, a spindle set in steel bearings, a small plane mirror, a fine copper wire, and a light but fairly stiff bow spring. Narrow rubber rings on either side of the diaphragm which is 2 inches in diameter hold it securely in place, yet allow free vibration when disturbed. A very fine copper wire is passed thru a pin hole in the center of the diaphragm and firmly attached to it with beeswax. The wire is passed once around the spindle and attached with wax to the bow spring. The spindle is 0.23 inches long and has a weight of 0.23 grain



(15 milligrams) including the mirror. Its polished conical ends rest in polished sockets in hardened steel pins, thus insuring a minimum of friction. A plane mirror 0.08 inch square is mounted on the spindle. The glass for this mirror is from an ordinary cover glass which is silvered, cut into small pieces, and then tested for planeness. An attempt is made and successfully I believe, to preserve the plane surface of the mirror by mounting it on an extremely thin piece of mica cut to the same dimensions, using shellac on the corners for cement. The mirror plus mica is then attached to the spindle by a small touch of shellac. Hence the distortion due to the drying of the shellac is effective only in the more flexible mica. The bow spring is made from the main spring of a watch and is held firmly in the casing by two small screws.

To secure this delicate apparatus and adjustment from building vibrations the box is mounted on felt strips and the table on cork pads. The motor also is placed on strips of rubber tubing. The mechanical jar due to the mechanism which operates the camera shutter was very evident on the screen until it was placed outside and free from the box. Even with these precautions, excessive jar is noticeable, as is evident on all my final results.



Optical system

THE OPTICAL SYSTEM

Briefly the optical system consists of a source of light, a condensing lens, an oscillating mirror, a lens to focus the light from this oscillating mirror, a rotating mirror and a screen on which to view the focused light.

A box, 52" x 19 1/2" x 13 1/2" , holds all the necessary optical apparatus with the exception of the arc light and its lenses. The phonodeik proper is held on a standard in one end of the box, a small motor to rotate the hexagonal mirror being in the opposite end. The box is painted black inside in order to absorb all light that is not meant to fall directly on the mirrors and screen.

Our source of light, the arc, its lenses, camera shutter, and apparatus to operate the shutter are placed outside and behind the box, a small hole being bored into the box for entrance of the light. In front of the arc, a pin-hole is placed in order to eliminate an excessive amount of light from entering the box. I am not attempting to secure an image of the pin-hole but merely to focus a portion of the beam issuing from this pin-hole. After passing thru two lenses to condense the beam of light and render it practically parallel, it is reflected from a mirror placed at an angle of forty-five degrees. This arrangement keeps all the extraneous direct light behind the box and also permits a more flexible manipulation of the light within the box. It is far simpler to move the light by adjusting a mirror rather than an arc light.

Next a narrow slit is placed in the beam in order to produce a horizontal line of light, which then passes thru a lens of 26 inch focal distance placed about 0.1 inch from the phonodeik mirror. It is reflected back thru this lens to a double convex lens of 10 inch focal distance. This lens when placed at a certain angle to the beam narrows it in the vertical plane, so that we now have a point of light which on being reflected from the hexagonal rotating mirror is sharply focused on a ground glass screen.

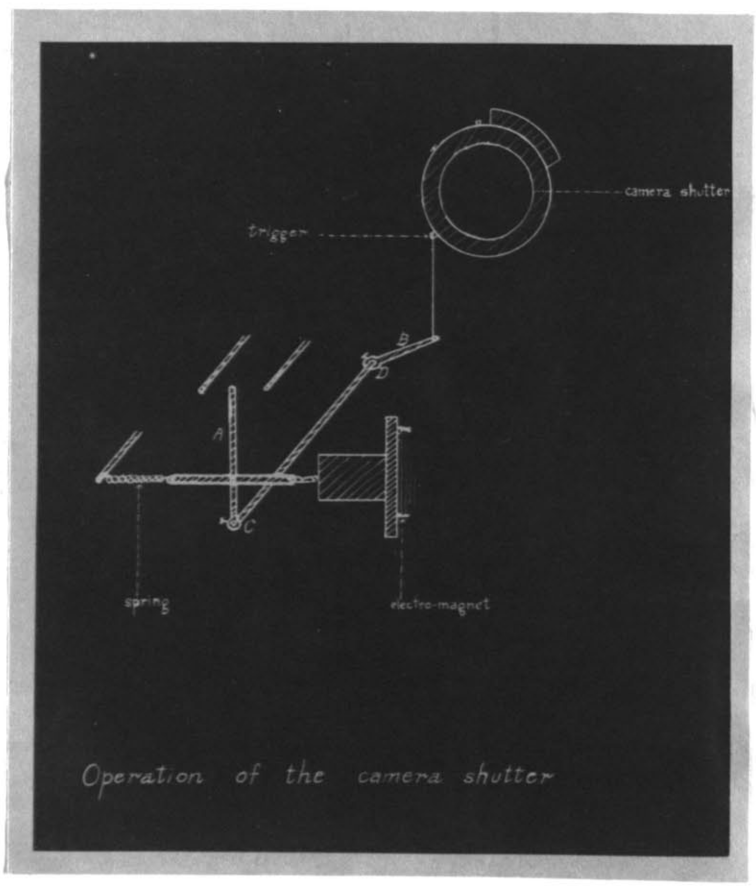
The spectacle lens which is placed just in front of the phonodeik mirror is stopped down with a black paper diaphragm, so as to eliminate aberration and reflection effects. Another optical difficulty, i. e. two reflections from a glass surface mirror, is avoided in the case of the rotating mirror by using a silver surface for the reflector. These surfaces were made by silvering French plate glass and polishing the silver surface.

Diaphragms shut off both diffused and reflected light within the box from the screen, so as to permit only the focused point of light to fall upon the screen.

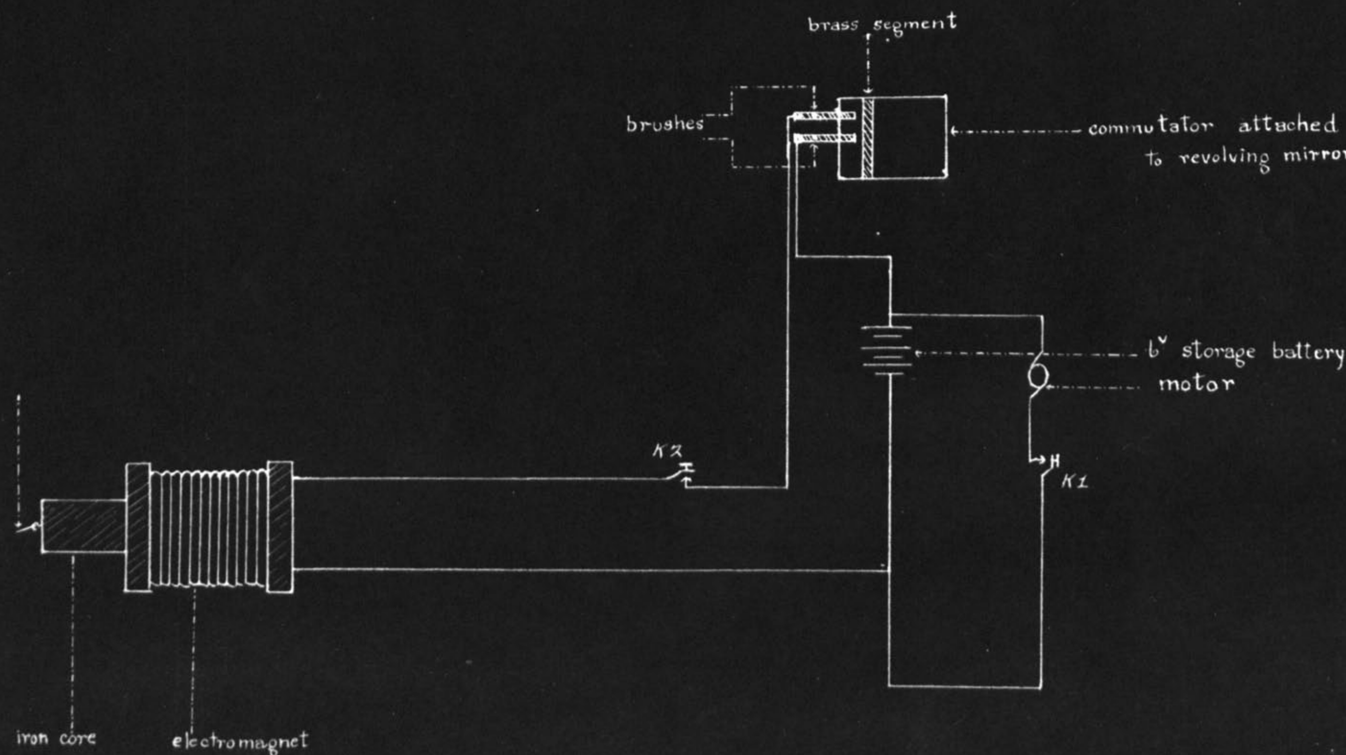
THE ELECTRICAL MOTIVE SYSTEM

OPERATION OF THE CAMERA SHUTTER

The rotating mirror was constructed of a piece of hexagonal brass rod mounted on bearings vertically and driven thru a worm and gear by a small motor run on a 6 volt storage battery. The faces of the hexagnnal rod were trued up parallel to the axis and pieces of French plate glass were fastened to the faces. A hard rubber cylinder is attached to the top of the rotating mirror into which a brass segment is inserted. Two metal brushes connected to the solenoid electro magnet thru the battery make contact on this segment o once every revolution. Two keys placed in the top of the box operate the motor and shutter, making it possible to run the motor without closing the shutter.



Operation of the camera shutter



Electrical system for operation of rotating mirror and camera shutter

The iron core of the electromagnet is held partway out from the solenoid by a tension spring. Between the spring and iron core there is a small flat bar which is screwed to the center of a lever arm. This lever fits over and is screwed rigidly to a small round bar on the other end of which a second lever arm is attached. This second lever is fastened by way of a wire to the camera trigger of the shutter. When the iron core is pulled magnetically to the right (see above diagram) by closing Key 2 (see diagram; "Electrical system for operation of rotating mirror and camera shutter") the lever arm, A, moves in the same direction, rotating the bar, CD, clockwise and consequently moving lever B down and carrying the trigger of the shutter with it. The shutter may be set for "instantaneous" exposure; i.e. the time of the exposure is synchronous with the time necessary for the image from one of the six faces of the rotating mirror to cross the screen. To accomplish this result the brass commutator must be turned until the brushes touch it just as the image from one face starts to cross the screen.

SOUNDING THE ORGAN PIPES

The pipe is placed in a rubber socket lined with chamois and sounded by means of the air blast supplied by the Institute. This blast of variable pressure is controlled and regulated by a wind chest and its accompanying valve, as described below in "Difficulties attendant on Construction."

A horn of sheet zinc leading to the diaphragm is placed near the opening of the pipe. It is 30 inches long by 9 inches in diameter at its large opening, thus giving a medium flare as suggested by Mr. Miller. A horn of medium flare gives a good distribution of response with definite resonance for a large range of frequencies.

PART III.

DIFFICULTIES ATTENDANT ON CONSTRUCTION AND ADJUSTMENT OF APPARATUS

THE MIRROR

At first J. T. Norton used a small piece from a galvanometer mirror. This mirror was concave of about the right curvature to produce a sharp image of a source of light on the screen. But for a mirror sufficiently thin, the radius of curvature is uncertain and especially so when a small piece is cut from it and cemented to the spindle. After much labor in silvering concave mirrors, which Mr. Wolff of Pinkham and Smith Company is very expert at grinding, I resorted to a plane mirror and spectable lens. The lens of 26 inch focal distance was placed as near as possible to the phonodeik plane mirror, which arrangement resulted in a sharp focus on the screen. Distortion due to the passing of light thru the lens is avoided by the very slight angle of reflection from the mirror.

I had difficulty in producing light sufficient to effect a photographic plate at first. However, with the above described arrangement and by careful adjustment of the arc light I could produce a sharp trace of light on the plate. The hand arc which I used also produced its trials. An automatic arc would be no especial improvement since the continual adjustment of the carbons throws the pin hole source off center. A high powered tungsten lamp with reflectors might be satisfactory as a source.

BOW SPRING AND FINE WIRE ADJUSTMENT

Instead of using a tension spring as in Mr. Miller's phonodeik, I used a bow spring made from the main spring of a watch. At first I attempted to use hammered copper, but discovered that it was too flexible and did not hold the mirror in one set position when the diaphragm was at rest.

The adjustment of the fine wire that passes around the spindle is extremely important. Either the wire will slip on the spindle if the tension is too slight or the spindle will be held rigid and immovable if the tension is too great. In between these two limits there is a wide range of adjustment and for any adjustment the wave form for a sound appears different from the form for any other adjustment. However, I believe that the actual wave form changes but very slightly. The variation is largely evident in the amplitude of the response, the overtones showing as kinks in the wave down to even less than 1/8 inch amplitude.

WIND CHEST

One of my greatest difficulties was to produce an air blast of constant pressure. Evidently no comparative study of pipes is possible without a means of sounding them similarly. A small wind chest which I used initially was very unsatisfactory. I had an air tight box made, 18" x 18" x 30" to serve as a reservoir for the air. A hole 2 inches in diameter, was bored in the top over which a chamois covered cap valve rested, whose pressure over the hole could be regulated by a spring and lock nut. But again I found the pressure varying with every rise and fall in the main tank. A more sensitive manipulation of the valve was made possible by attaching it to one end of a lever arm to the other end of which a tension spring is fastened. The fulcrum of the lever was constructed of a piece of steel screwed to the bar, whose pointed ends rested freely in steel sockets. A fairly uniform and trustworthy pressure can be relied upon with this valve, altho considerable vibration occurs at low pressures. A water manometer is attached to the wind chest for reading off the pressures.

DUST AND TARNISH

Dust is the greatest enemy to the crudely made apparatus. Mr. Miller incloses his instrument in air tight and dust proof casings. Dust accumulates on the mirror producing diffraction bands of light and dark; on the spindle and its bearings increasing friction and hence lost motion, and on the mirrors and lenses.

Tarnishing of the silver surfaces of the rotating mirror necessitates almost daily polishing. Resilvering would be necessary at short intervals if the instrument was to be used for any length of time. Glass surfaces would be practicable if the wave is to be viewed and not photographed or if the angle of reflection is made so small that the second image merges with the first.

PART IV.

OPERATION OF APPARATUS

A point of light is focused upon the screen . The pipe is sounded and the mirror is rotated. When a sound is produced, the transverse vibration of the diaphragm is communicated as a rotatory motion of the mirror about a horizontal axis by the friction of the fine wire on the spindle, the spindle being rocked to and fro on its pivots. This vertical displacement of the beam of light is stretched out into an accompanying horizontal displacement by reflection from the mirror rotating about a vertical axis.

To take a picture of the wave, the shutter is closed and set for"instantaneous" exposure. A photographic plate, adjusted in place of the screen, is exposed by closing the circuit thru the electromagnet that operates the shutter. The water manometer is read before and after exposing the plate.

PART V.

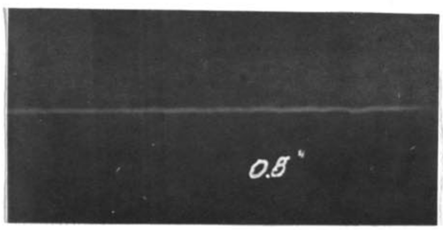
RESULTS OF EXPERIMENTATION

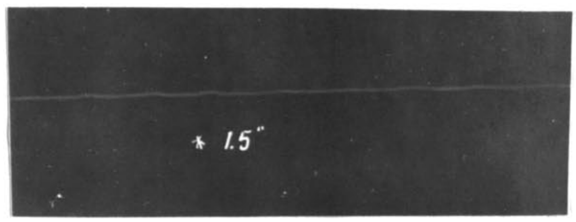
The problem deals with metal pipes, the most variable of the organ pipes. They are made generally of tin and zinc, easily subject to change from handling, temperature variations, and perhaps several other causes we do not understand. I experimented with two open diapason pipes, Middle C. The diapason is the background of organ tone. Its quality is due to the lower harmonics which it speaks. The open metal diapason should have a rich mellow tone with more character than the purer tone from the stopped diapason. Middle C should be sounded at 1 1/2 inches of water. The standard pipe that I am using speaks best at 1 3/4 inches. I have designated the standard pipe, voiced by an expert at the factory as Pipe 1 and the partially voiced pipe voiced roughly by J. T. Norton as Pipe 2. Alto I shall call Pipe 1, the standard. I very much doubt its present voicing, since it left the factory 18 months ago and probably has seen much abuse since then.

A very rapid photographic plate was necessary since the exposure was extremely short and the amount of light small. "Seed 30" plates, "Gilt Edge", were used. Contrast was sacrificed, but an attempt to remedy this fault was made in using contrast printing paper, Velvet Velox.

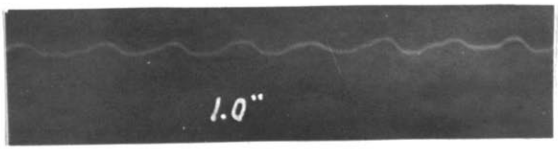
The prints for Pipe 2 are starred thus, *. The air pressure used is given on the prints in equivalent inches of water. The air pressures given on the first runs are not trustworthy, as the valve used on the wind chest was not sufficiently sensitive.

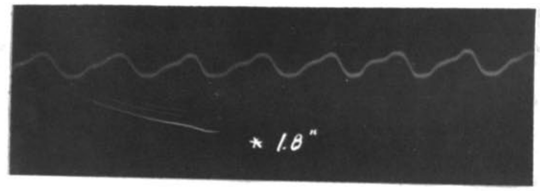
Pipe 1 and Pipe 2 were sounded thru a series of pressures from 0.8 inch to 4.0 inches. Pipe 2 did not begin to sound until an air pressure above 1.5 inches was used, indicating one fault in the voicing.

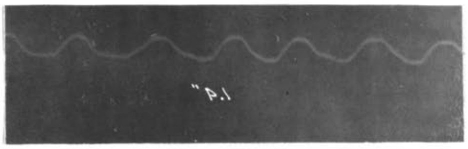


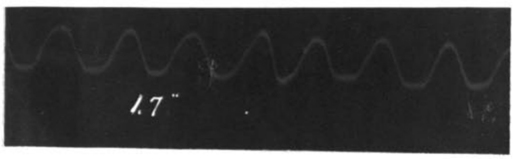


Pipe 2 then started to sound with a jerk and showed a considerable amplitude of vibration with only 0.3 inch increase in pressure. Pipe 1 showed a gradual increase in amplitude with a fairly even wave form indicating the fundamental with a trace of overtone.

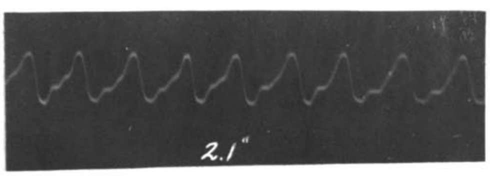


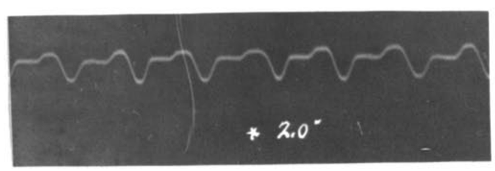






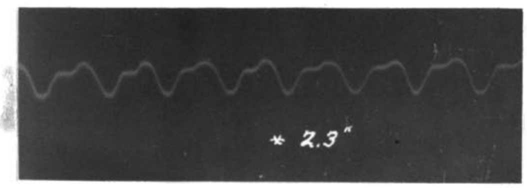
Pipe 1 and Pipe 2 now exhibit the octave and the first harmonic plainly.



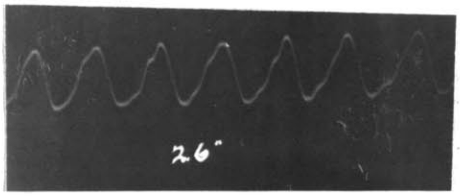


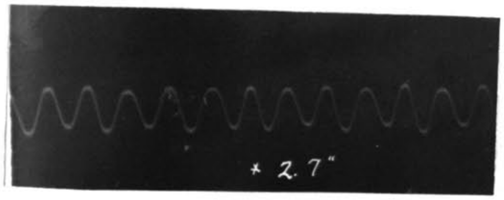
But as the prints show the quality of the sounds differ considerably. Pipe 1 is sounding at a pressure which seems to be the borderline for a change, a progressive harmonic perhaps. The harmonic analyser, if used on these curves, will determine what overtones are sounding at these points. It would be interesting to know later, when the method had been perfected, what overtones are responsible for the character of any pipe. With this knowledge the voicing of pipes would be a simple process.

The following prints for Pipe 2 show the eccentricity of response noticeably. The apparent change in the wave form between 2.1 inches and 2.3 inches is due to the change in speed of the rotating mirror.



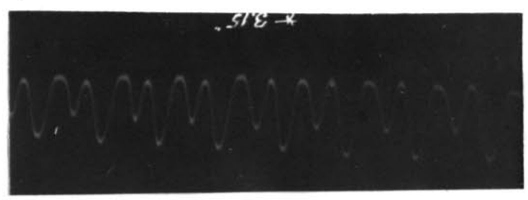
The first harmonics of low frequency appear in the wave form with no difficulty whatever. The response to higher harmonics however is what tests the instrument's sensitivity. On the low pressures the presence of the low pitched harmonics are visible, but in a fitful way. This result may be due to a wavering in the pipe, one of the irritating faults of a badly voiced pipe, or to a flickering in the air pressure supplied. Both conditions are present. With higher pressures the eccentricities of the wave trace seem to disappear. The low pitched harmonic is sounding strong and unreservedly, while the instrument disregards the higher pitched harmonic.





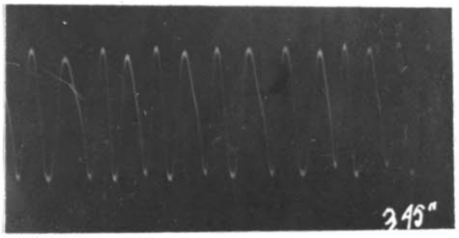
Pipe 2 shows in visible form exactly what the ear is experiencing, - a harsh tone. The sounding overtone is attempting to obliterate the fundamental and an unpleasant metallic quality is the result.

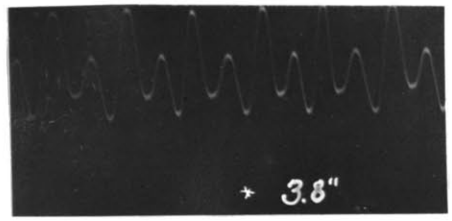
Pipe 1 now shows somewhat the same effect.

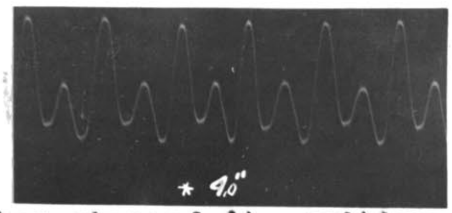


An interesting comparison can be made here on the percentage of overtone present. The ratio of the depth of the kink in the wave to the actual amplitude of the wave is computed in each case. For Pipe 1, 68% is overtone; for Pipe 2, 66%.

The following results are interesting only in showing the response to highly over blown pipes.





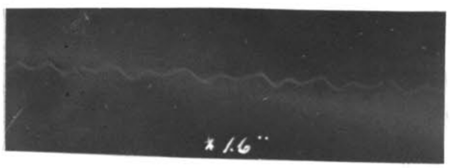


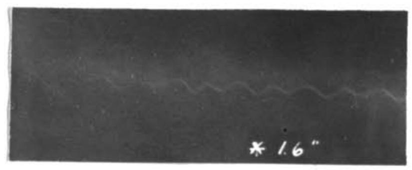
The kink in the wave for Pipe 2 has changed it position also.

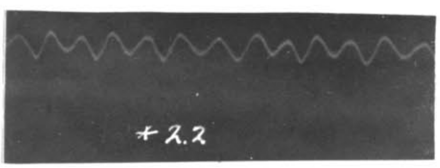
I then attempted to duplicate results, but with no success. I changed the celluloid diaphragm to one made of mica, a more resilient material than celluloid. Consequently I was forced to change the adjustments on the phonodeik and could not hope to duplicate any former results. Also I improved the rubber socket for the pipe by cutting it deeper and lining it with chamois in order to eliminate leakage about the "toe". The valve on the wind chest was also changed.

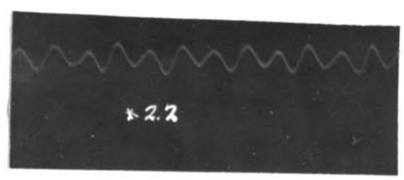
However, I was unfortunate in my final results. Practically every print from this point on will show the effect of building vibration. Repair on the walls outside the laboratory was begun the same week that I started to take final results. Some of the mechanical jars register almost the same magnitude as the kinks representing overtones.

I was able to duplicate the wave form on the same day even after lifting the pipes from the socket and replacing again. The following prints for Pipe 2 are taken from different plates, showing reasonable duplication. I use "reasonable", since the pressure is not to be relied upon entirely.

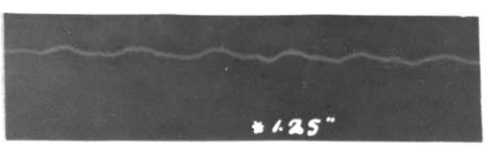


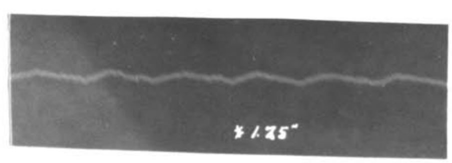




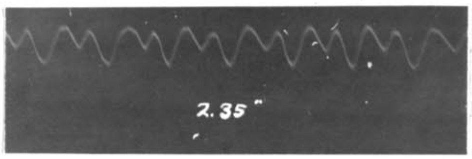


After a period of 3 days I was able to get the following duplication. The vibration due to hammering is very evident on these plates.

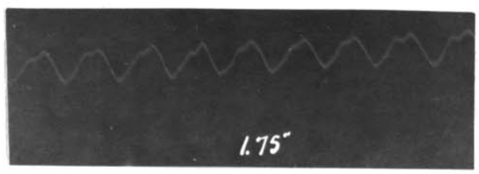


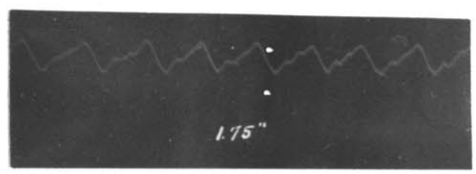


Duplication with the standard pipe was more certain than with the poorly voiced pipe, doubtless due to greater stability in the standard. These plates were exposed 2 days apart.



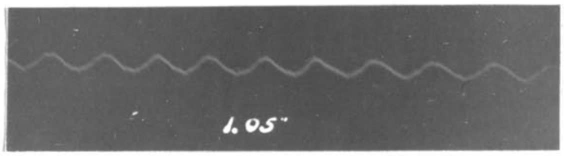
However after a few days interval both pipes show variation. The following were taken 5 days apart.

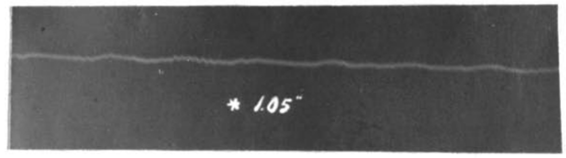




Perhaps it is not fair to blame the pipe, since the many recent jars in the building could have been the cause of a readjustment of the instrument. But I am convinced after a close examination of variations thru-out two months that the instrument is not at fault but that the pipe is the variable factor.

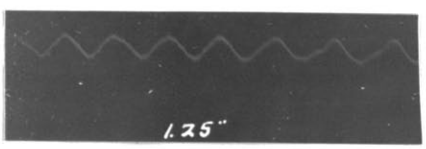
An attempt was made to improve on the voicing of Pipe 2 by deepening the nicks on the lower lips and also pressing the lips until the wave form resembled that of Pipe 1. The pipe responded at a lower pressure than heretofore, as to be expected.

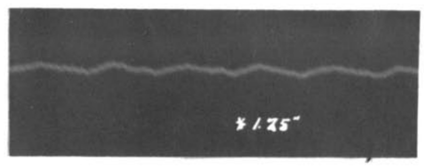


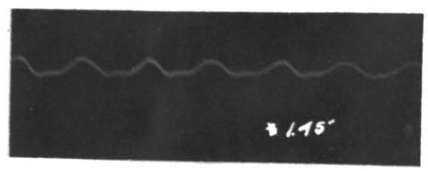


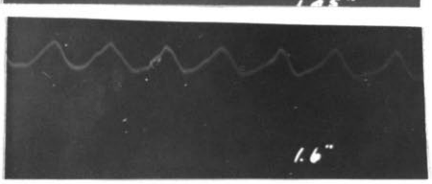
The standard pipe was run thru the same pressures for a new set of pictures, since the following changes had occurred: a new setting of the instrument had been made; the pipe had suffered a fall; and two weeks had elapsed since the first pictures were taken.

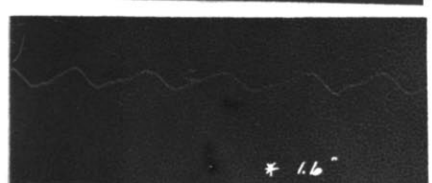
The next prints show a fitful response for both pipes. The print for Pipe 1 betrays a badly fogged plate.



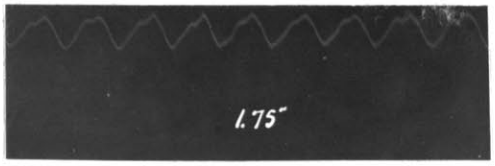


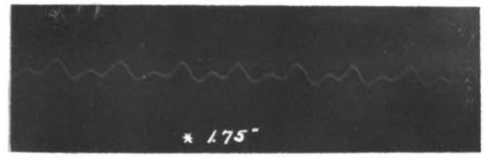






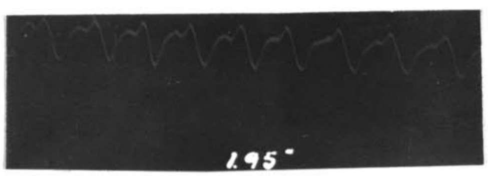
Pipe 2 is speaking at its best with a 1.6 inch pressure. The trace exhibits a simple tone, only two harmonics sounding I believe. This condition is considered satisfactory for the diapason of middle register. Yet the tone is muddy and windy, not so mellow and deep as the quality of Pipe 1. Pipe 1 speaks best at 1.75 inches to my inexpert ear.



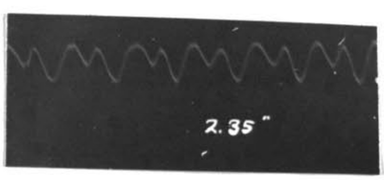


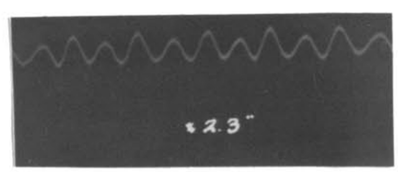
Pipe 2 at this pressure increases its shallow quality, showing its harmonics more definitely.

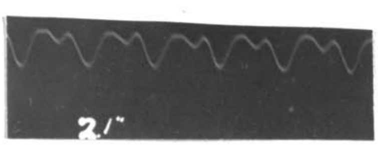
At the next pressure Pipe 1 exhibits a response similar to the above of Pipe 2, but in larger amplitude. The trace for Pipe 2 speaks for itself.

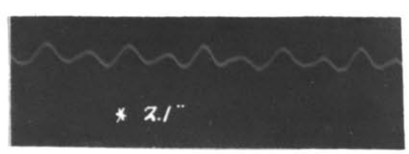


The unpleasant qualities present in the pipes are evident from the following prints. Many of the higher overtones are producing the dissonant quality.

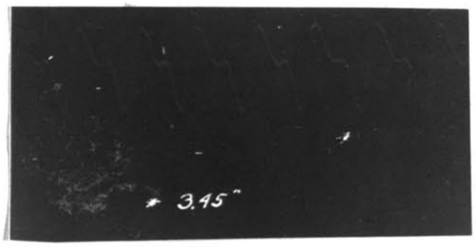




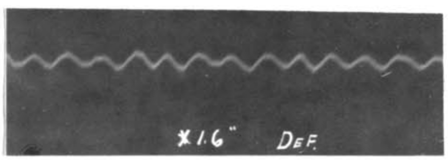


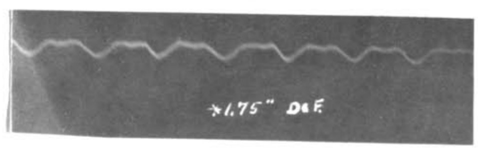


It is interesting to note the change in wave form for Pipe 2 overblown.



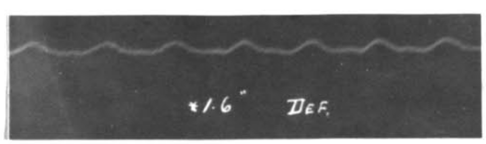
I then deformed the lips of Pipe 2 appreciably to change its timbre and photographed the wave at its former best speaking pressure.





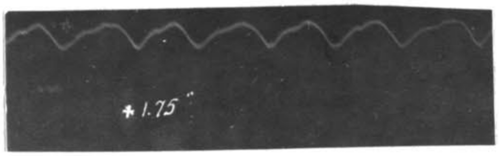
The pipe responded with a flat unmusical tone, showing no increase in sound with increase in pressure.

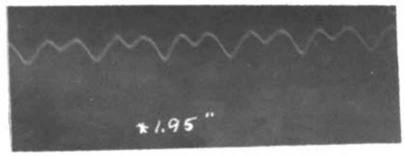
The upper lip was again depressed with this resulting wave form.



The tone has decreased with a concurrent increase in windiness.

In an attempt to return the pipe to its best speaking tone, I succeeded in the nearest approximation to the standard I had yet made. The amplitude of response and form of the wave resembled that of the final run for Pipe 1 very closely.





The effect on the ear was more pleasant than heretofore, altho the breathiness was still evident.

With a reliable and sensitive instrument the method appears sound and practicable. Perhaps I have not credited my instrument with proper reliability. The windy and shallow tone is betrayed by a loss in amplitude. The fault is found in insufficient windway or poorly shaped "foot". A muddy tone, caused partly by improper "nicking" is also evidenced in the amplitude. The quality of the tone aside from these noise conditions is detected unavoidably in the shape of the wave. If the instrument is sensitive to harmonics to be investigated (and D. C. Miller has proved the possibility of such an instrument) then we have a valuable asset to organ manufacture.

Our problem reduces to the question, - are there some qualities which a mechanical instrument can not isolate and portray? Is Mr. Robertson's statement to hold true

* that "A musical ear and cultivated taste are essentials -"? I have concluded that the pipes are extremely variable and hence offer many difficulties to experimentation. The expert voicer will tell you the same story. Not until the physicist and expert voicer collaborate on this problem, comparing mechanical results with the perception of the ear, do I believe a successful solution will be possible.

* p 241 F. E. Robertson (see Bibliography)

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1. Dayton Clarence Miller, "The Science of Musical Sounds."
2. Edwin H. Barton, " Textbook of Sound."
3. Edward Wheeler Scripture, "Elements of Experimental Phonetics."
4. R. Threlfall, "On Laboratory Arts."
5. F. E. Robertson, "A Practical Treatise on Organ Building."
6. W. and T. Lewis, "Modern Organ Building."
7. J. W. Hinton, "Organ Construction."