

ABSTRACT

THE EFFECT OF VOICING CHANGES ON THE HARMONIC SPECTRA OF ORGAN FLUE PIPES

by Ray W. Stilwell

This study sought to investigate the changes in the steady-state overtone structure of an organ flue pipe, when that pipe was subjected to the types of adjustments and manipulations performed by pipe organ voicers, tuners, and maintenance men. Specifically, the following areas were investigated: 1) the effects of variations in wind pressure; 2) the effects of regulating the toe and flue openings of a pipe; 3) the effects of nicking the mouth of a pipe; 4) the influence of the shape of the upper lip; 5) the effects of increasing the cut-up of the upper lip; 6) the influence of the width of the flue opening; 7) the effects of raising or lowering the languid.

A room was acoustically deadened to minimize reflections of sound which might influence the test results. The pipe tones were then recorded on magnetic tape, and the tapes were later reproduced and fed into a Bruel and Kjaer harmonic analyzer. The charts produced by this machine

were reduced to graphs for presentation. The results of the tests showed that:

- 1) There can be a great loss of harmonic energy if correction is not made for a lowering of wind pressure supplied to the pipe.
- 2) Correction for variations in wind pressure by adjustments of the toe hole in the pipe has a negligible effect on the pipe's harmonic spectrum.
- 3) Correction for variations in wind pressure by adjustments of the flue opening in the pipe does affect the pipe's harmonic spectrum.
- 4) Differing sound levels and harmonic spectra are present at the mouth and at the top of a pipe.
- 5) Nicking the mouth of a pipe results in a loss of harmonic energy at the high end of the spectrum.
- 6) The sharpness or dullness of the bevel on the upper lip of the pipe has relatively little effect on the harmonic spectrum.
- 7) An arched upper lip tends to discourage the formation of higher partials.
- 8) The height of the languid is an important factor in obtaining the best tone from a pipe and in minimizing wind noise.

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ON THE HARMONIC SPECTRA OF
ORGAN FLUE PIPES

By

Ray W. Stilwell

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R. W. S.

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CHAPTER I

INTRODUCTION

Organ building, like blacksmithing, is an art learned chiefly by apprenticeship. Techniques are passed on from one worker to another largely by word of mouth, and while a number of books have been written on the general subject of organ building, many books do not explain in detail certain facets of organ building.¹

The voicing of organ pipes is one such area. Therefore, this study was undertaken to discover how voicing changes affect the overtones emitted by organ pipes.

In the past, analyses of organ tones have been carried out,² but these tests have largely consisted of analyzing the difference between, for example, a flute and a diapason, or a string and a reed. This study, however, sought to analyze the change in the tone of a single pipe when the various voicing adjustments were performed on it.

¹Barnes, William Harrison. The Contemporary American Organ. J. Fischer & Bro., New York, 1937, p.104.

²Boner, C. P. "Acoustic Spectra of Organ Pipes." Journal of the Acoustical Society of America, 10 (1938) 32-40.

The voicing adjustments used in the tests were those frequently employed by organ builders in the course of manufacturing and tonally finishing an organ, and also by tuners and maintenance men in maintaining an organ.

The Rev. Noel Bonavia-Hunt, in his work "The Church Organ," listed the following conditions and factors as influencing the tone of a flue pipe:

1. The scale (diameter) of the pipe body
2. The width and height of the mouth
3. The shape of the languid
4. The adjustment of the relative positions of the upper and lower lips and of the languid of metal pipes
5. The shape and position of the cap of a wooden pipe
6. The character of the nicking
7. The pressure and volume of the wind supplied from the wind-chest
8. The size of the bore of the pipe-foot
9. The employment of various devices and accessories
10. The material of which the pipe is made

Further, the Rev. Mr. Hunt listed factors that should tend to increase upper partials:

1. Small scales (diameters)
2. Low cut-up of mouth
3. Concave and bevelled upper lip
4. Raised and acute-bevelled languid
5. Fine nicking

Hunt listed these factors as discouraging the formation of the upper partials:

1. Large scales (diameters)
2. High cut-up of mouth
3. Convex and thick, arched, or leathered upper lip

4. Depressed, obtuse-bevelled, and inverted languid
5. Bold nicking³

Some of the factors cited above are not variables within the control of the voicer. For example, the material of which a pipe is made, its diameter, and the width of its mouth are decided at the time of manufacture and are not easily changed afterward. Therefore, the voicing adjustments selected for the tests were those which could be performed without extensive metal work on the pipes.

In designing the tests, certain questions, based on the factors cited above, were kept in mind. Specifically, the questions to which answers were sought were these:

1. Is there a difference in sound output level between the mouth of the pipe and the top of the pipe?
2. Is there a difference in overtone structure between the sounds emitted by the mouth of the pipe and those emitted by the top of the pipe?
3. All other factors remaining equal, how does a variation in the wind pressure being supplied to a pipe affect the harmonic spectrum of the sounds emitted by the pipe?
4. If correction for the variation in wind pressure is made in one or more ways, how then does the wind pressure affect the harmonic spectrum, if at all?
5. How does nicking the mouth of the pipe affect the steady state harmonic spectrum of the pipe?

³Barnes. op. cit., pp. 101-102.

6. What are the effects of more or fewer nicks? Is any change in spectrum related to the spacing or depth of the nicks?
7. Will a sharpening of the bevel on the upper lip of the pipe affect, or offset, any effects of nicking?
8. Is the harmonic spectrum emitted by a pipe related to whether that pipe has a straight or curved upper lip? What is the relation to the height of the cut-up and the shape of the bevel? Does a change in wind pressure have any bearing on these factors?
9. How does the width of the flue opening affect the pipe tone?
10. How does the height of the languid, in relation to the lips of the pipe, affect the tone? How critical is this adjustment?
11. Are adjustments of the languid related to any other adjustments? How?

Answers to these questions required that the following factors be tested: wind pressure and adjustment of the toe hole in the pipe; nicking of the languid and lower lip; the sharpness or roundness of the bevel on the upper lip; the straight or arched upper lip; the height of the cut-up of the upper lip; the width of the flue opening; and the height of the languid in relation to the lips. See Figure 1, Cross-Section of an Organ Pipe, and Figure 2, Front View of an Organ Pipe.

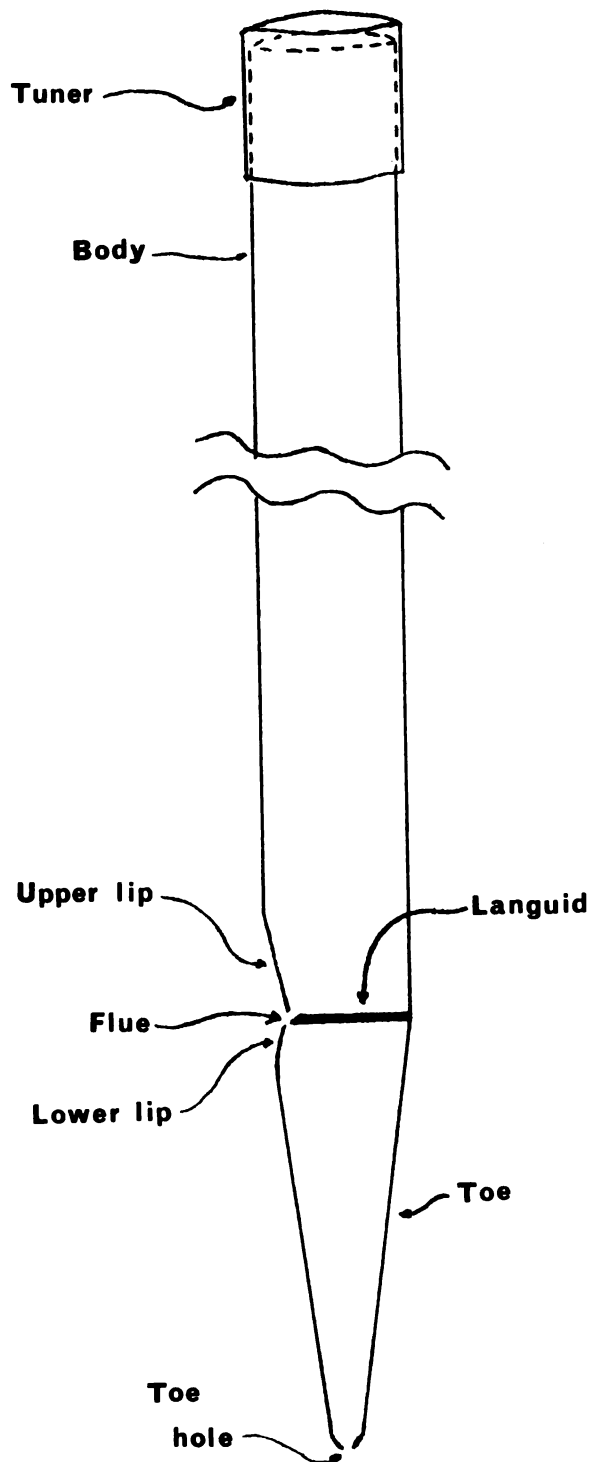


FIGURE 1

CROSS-SECTION OF AN ORGAN PIPE

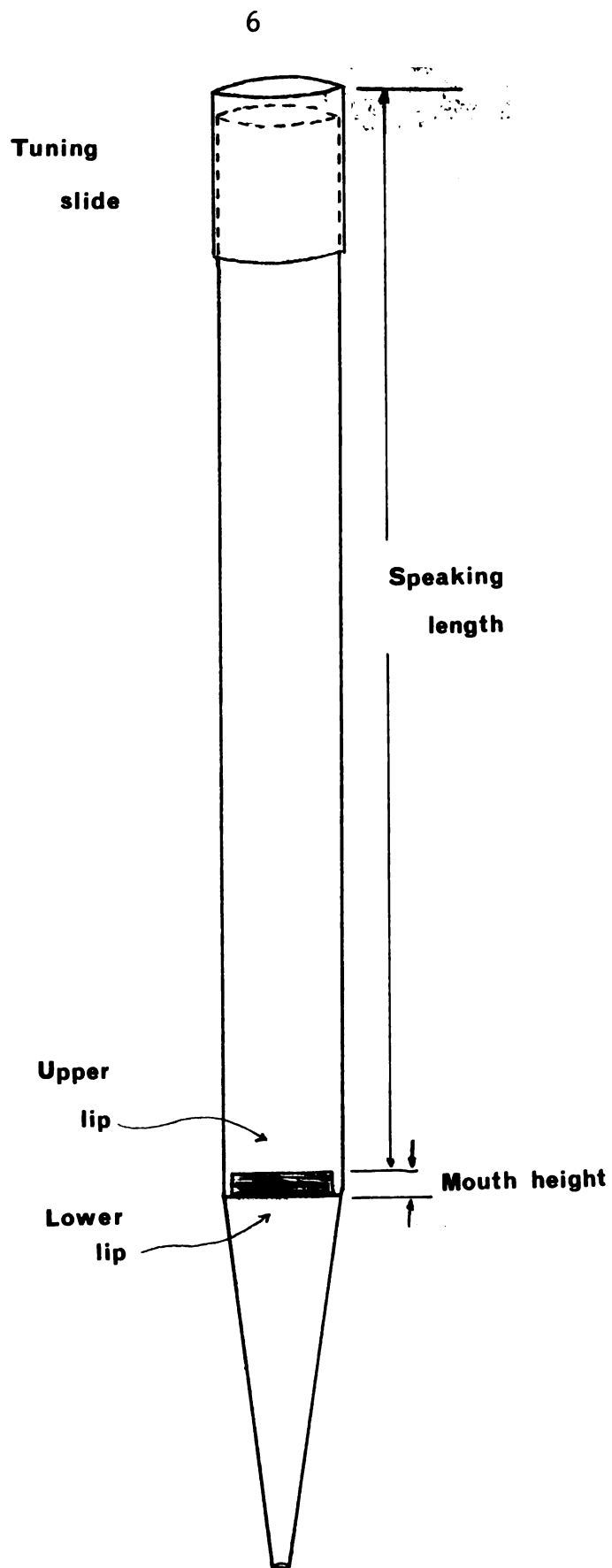


FIGURE 2

FRONT VIEW OF AN ORGAN PIPE

CHAPTER II

PROCEDURE

General description of the method of testing

A blower furnished variable wind pressure to a small windchest on which was placed the pipe under test. A microphone near the pipe converted the acoustical energy to electrical energy, which was fed to a tape recorder. The recorded tapes were later reproduced and fed directly into a harmonic analyzer, resulting in a printed graph of the harmonic energy contained in the sound of the pipe.

Detailed description of the testing apparatus

The following paragraphs outline the conditions and precautions observed in designing and constructing the testing apparatus.

Acoustical treatment of the recording room. At least one researcher noted that reflections in the area in which the testing was carried out could influence the results.⁴

Therefore, a room measuring approximately eight by ten feet was treated to minimize reflections and standing waves. The treatment consisted of $\frac{1}{2}$ -inch thick rug padding on the walls and ceiling, a rug on the floor, and heavy drapery on the

⁴Mercer, Derwent M. A. "The Voicing of Organ Flue Pipes." Journal of the Acoustical Society of America, 23 (1951) 50.

walls. Good separation was desired between the sounds emitted at the mouth of the pipe and those emitted at the top of the pipe, since it was expected that these two openings would emit tones of differing volume levels and possibly differing harmonic spectra.⁵ No persons were present in the room while recordings were being made, inasmuch as movement in the vicinity of the pipes was found to affect oscilloscope patterns of the pipe under test.

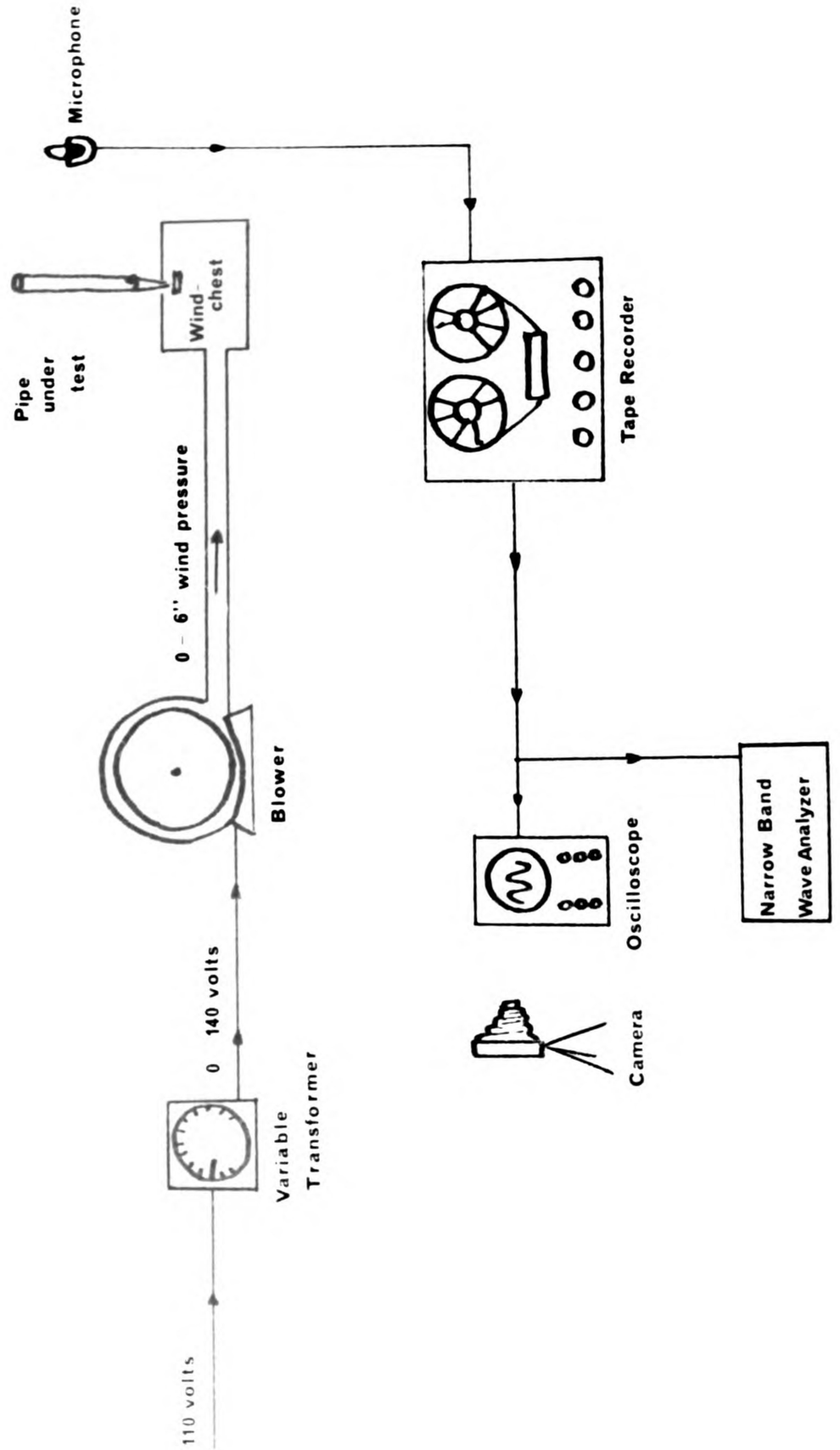
Wind supply. The blower used to furnish wind for the experiments consisted of a vacuum cleaner rotor powered by an electric hedge trimmer motor. A variable transformer allowed any voltage from zero to 140 volts to be supplied to the unit, resulting in a wind pressure continuously variable from zero to six inches of pressure.⁶

Windchest and valve. The main concern of this study is with the steady-state tone of a pipe rather than with its attack or release. However, before the project was undertaken, one qualification considered was that the speech of the pipe

⁵Skinner, Ernest M. The Modern Organ. H. W. Gray Co., New York, 1917, p. 24.

⁶"Inches" refers to inches of water measured in a U-shaped glass tube (water manometer), the means of measurement generally employed by organ builders.

FIGURE 3
SYSTEM BLOCK DIAGRAM



must be musically acceptable, not speaking with excessive wind noise, nor gurgling (alternating between the fundamental and first harmonic), nor blowing over to the octave. To this end, a small windchest approximately seven inches square and three inches high was fitted with an electropneumatic valve, so that the speech and attack of the pipe could be checked frequently during testing.

Further, these conditions served to simulate the actual conditions of a pipe on a chest.

Wind pressures and pressure measurement. Wind pressures of 2, 2½, 3, 4, and 5 inches were used for the tests. These pressures were selected as being representative of some commonly-used pressures.⁷ Lower and higher pressures are sometimes encountered, but only under special conditions, such as with high-pressure reed stops.

The wind pressure was measured in the chest rather than in the foot of the pipe itself.⁸ While the latter procedure might be more scientifically accurate, the former

⁷Norman, Herbert, and H. John Norman. The Organ Today. Barrie and Rockliff, London, 1966, p. 124.

⁸Ibid., p. 123.

method was chosen for two reasons: 1) modification of the feet of the pipes would have been necessary to carry out this form of measurement; and 2) measurement of the pressure in the pipe foot is not a technique used by organ builders.

Pipes used for the tests. The pipes used for the tests were new, unvoiced open diapason or principal pipes. The pipes varied somewhat as to scale (diameter), pitch, and other details of construction, but all of the pipes finally selected for testing were pitched at $C=523.3$ cycles per second. Pipes of differing details were intentionally used, in order to ascertain whether a specific procedure yielded a constant result with varying pipes.

Procedure used in tuning the pipes. Some method of easily and repeatedly retuning the pipes was needed. A Heath sine-wave audio generator was calibrated to a 523.3 cps tuning fork, and the generator output was fed to a loudspeaker in the testing room. This provided a continuous source of 523.3 tone for tuning. The pipes were tuned either by adjusting the tuning collar at the top of the pipe, or in some instances, by adjusting the toe hole at the bottom of the pipe, controlling the amount of air, and thereby the pitch. (Increasing the air pressure causes the pitch to

rise.) The type of test determined which of these two methods of tuning was used. In some tests, the toe hole adjustment was made to compensate for other adjustments on other parts of the pipe.

Method used in recording the pipe tones on magnetic tape.

The sounds emitted by the pipes were picked up by an Astatic Model 77 cardioid dynamic microphone located 12 inches from either the mouth or top of the pipe under test. The electrical signals thus produced were fed into a Magnecord Model 1024 half-track tape recorder operating at $7\frac{1}{2}$ inches per second. A Knight wideband oscilloscope connected to the output of the tape recorder allowed the oscilloscopic patterns to be seen and photographed. (See Figure 1, System Block Diagram, and Graph 1, Recorder and Microphone Response Curves.)

The recorded tapes were made into loops for continuous playback from an Ampex 351 tape recorder into the harmonic analyzer.

Oscilloscopic graphs. A 35-millimeter reflex camera was used to photograph the patterns produced on the oscilloscope. These provided a good comparison of waveform complexity, although exact harmonic content was most easily determined through the use of the harmonic analyzer.

The harmonic analyzer. While the oscilloscope was used during testing to obtain preliminary results (for example, to confirm that the tops and mouths of the pipes emitted differing spectra), the detailed harmonic analyses were made through the use of a Bruel and Kjaer Narrow Band Harmonic Analyzer. This machine is a sophisticated form of variable sharp-cutoff ($\pm 3\%$) filter, producing a peak on a machine-recorded chart for each frequency present. The chart thus produced is calibrated in decibels.

The harmonic charts. The continuous recordings produced by the wave analyzer, as described above, were reduced to graph form for ease in presentation and comparison.

Calibration of the tape recording system. This study was conducted to discover what changes in harmonic spectra were produced by voicing changes in the pipes. Absolute determination of the harmonic content was not necessary, only a measurement of the change of the relative strengths of the partials. For that reason, a calibrated microphone and tape recorder system was not used, since any variation in system response was constant for all of the tests and therefore self-cancelling.

CHAPTER III

TEST RESULTS

In examining these test results, the reader should refer to Table 2, Use of Pipes, and to the graphs herein provided.

Test 1: Wind pressure

The first test was partly intended as a check of the equipment and procedures. For this reason, the test was designed with a quite predictable outcome, i.e., an increase in harmonic development with increase in wind pressure, all other factors remaining equal. There was no alteration to the pipe other than a variation in wind pressure supplied to it via the chest.

The five pressures mentioned earlier were used, and Graphs 1-5 show the harmonic spectra obtained at the mouth of the pipe. Graph 1 shows seven partials gradually decreasing in strength. Graph 2, with wind pressure increased from 2 to $2\frac{1}{2}$ inches, shows a great increase in harmonic development, 12 partials. It also demonstrates a phenomenon pointed out to this writer by Mr. Hermann Schlicker, of the Schlicker Organ Company, that at very low pressures, small changes in pressure result in large

TABLE 1

DIMENSIONS OF PIPES USED FOR TESTING

Pipe Number	Diameter	Speaking Length	Wall Thickness	Mouth Height	Bevel Shape
1	2.7 cm.	26.5 cm.	.1 cm.	.5 cm.	
2	2.9 cm.	28.5 cm.	.1 cm.	.55 cm.	
3	2.8 cm.	28.3 cm.	.1 cm.	.55 cm.	

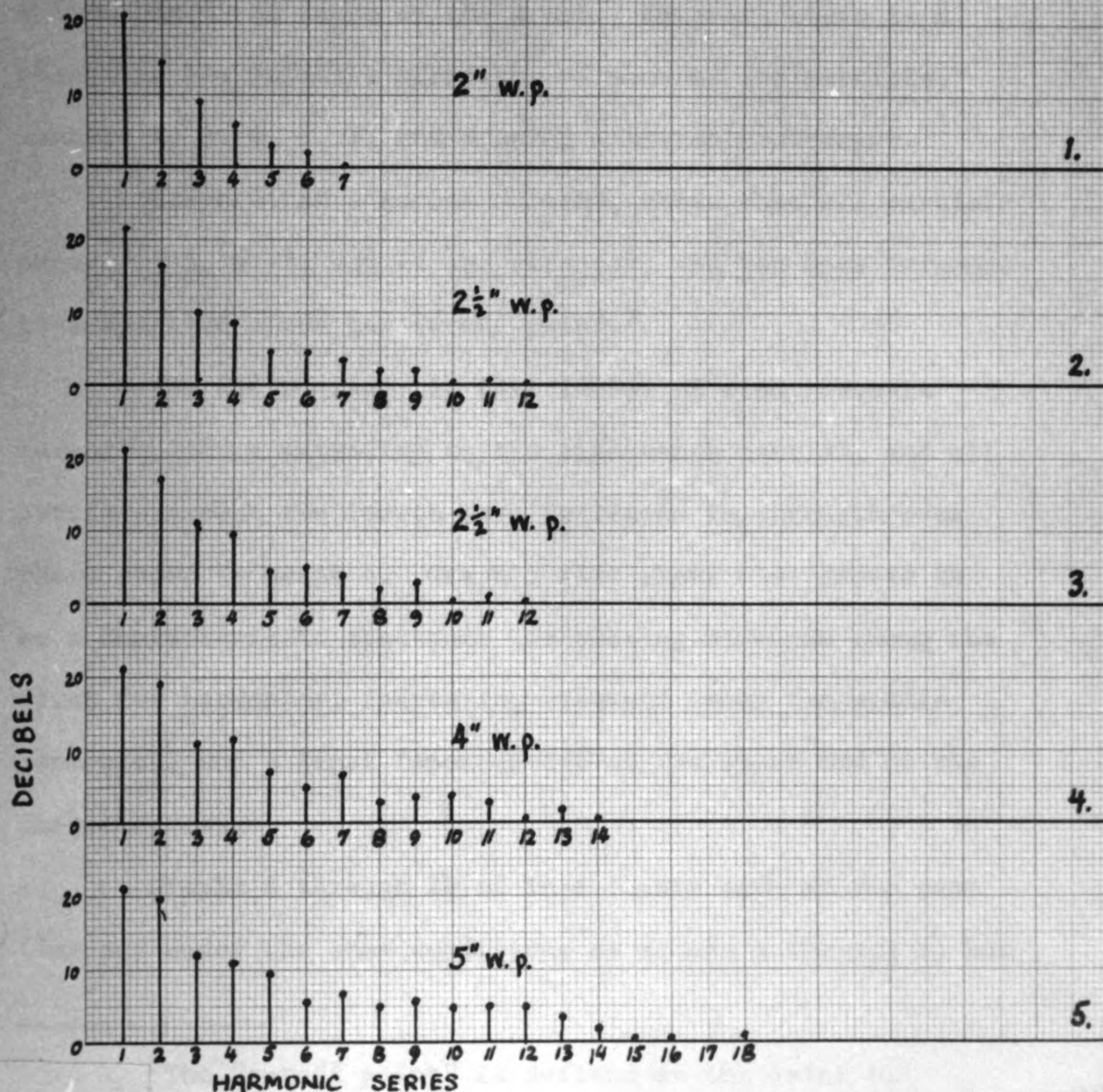
TABLE 2

USE OF PIPES

Pipe Number	Test in Which Used
1	1 (Wind pressure)
1	2 (Wind pressure)
1	7 (Flue)
1	8 (Languid)
2	9 (Languid)
3	5 (Nicking)
3	6 (Upper lip)

TEST No.1: WIND PRESSURE

No changes made in toe opening.
Recording made at pipe mouth.



changes in tone. An added half-inch of wind did not make as much difference at, for example, 5 or 6 inches of wind, as will be demonstrated.

Graph 3, at 3 inches of wind, again shows 12 partials within the 25 dB range of the graph. However, there is a change in the relative strengths of some of the partials, numbers 2, 3, 4, 6, 7, and 9 being measurably stronger.

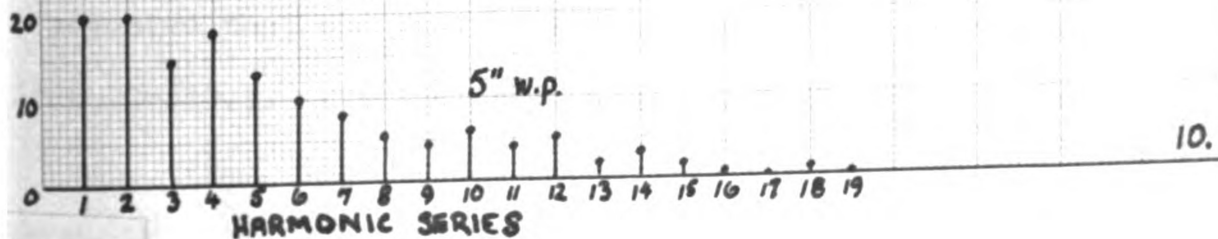
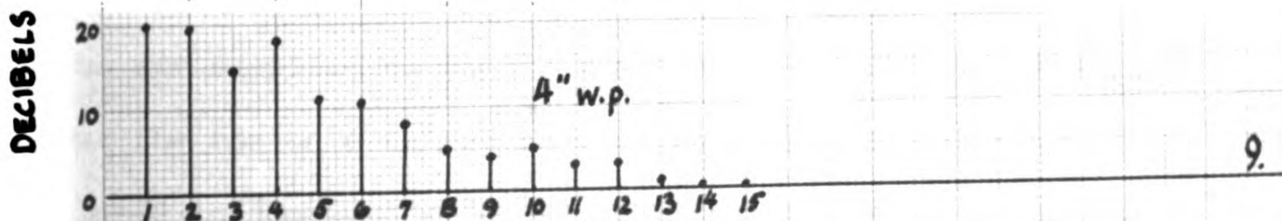
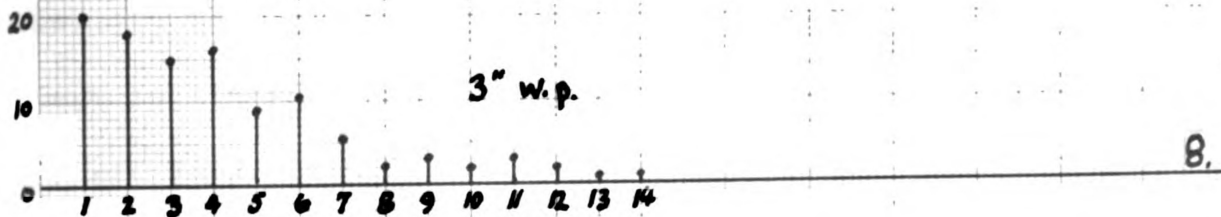
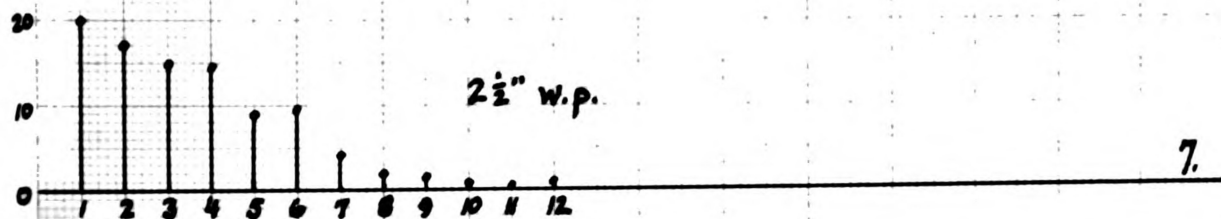
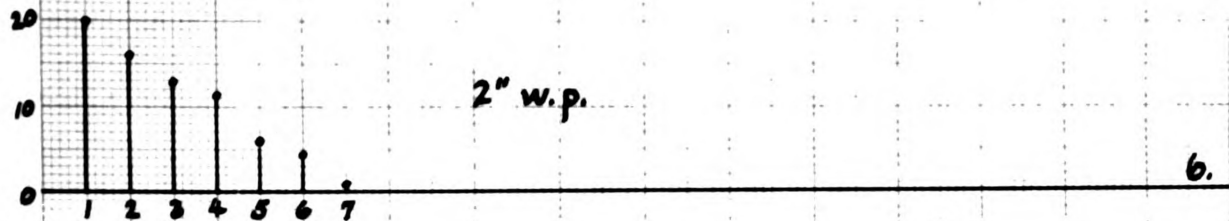
Graph 4, at 4 inches of wind, shows that all partials except 1, 3, 6, 8, and 12 are stronger, and two more harmonics have appeared above the cutoff point.⁹

The fifth graph, at five inches of wind, reveals harmonic energy extending to the eighteenth partial, and all partials except the fourth have increased in strength over those shown in graph 4. Graph 5 also shows what proved to be a characteristic spectrum: decreasing strength among the first few harmonics, increasing strength among the middle harmonics, and a final tapering-off at the upper end of the frequency range.

Graphs 6 through 10 of Test 1 were made at the same time and under the same conditions as graphs 1 through 5, but

⁹The "cutoff point" is defined as the point at which the desired signal can no longer be separated from the residual noise level of the measuring equipment.

TEST No. 1: Wind Pressure
No change made in toe opening.
Recording made at top of pipe.



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they were recorded at the top of the pipe rather than at the mouth. The same overall patterns of harmonic development seem to appear here, but with some differences in relative strengths of partials.

In almost every case there was numerically a greater harmonic development at the top of the pipe than at the mouth. However, the overall sound output measured from 3 to 7 dB lower at the top of the pipe than at the mouth. (The levels of the graphs were equalized for comparison.)

In all cases in graphs 6-10, partials 3, 4, and 5 are stronger at the top of the pipe than at the mouth. Graphs 8, 9, and 10 also show one additional partial as compared to graphs 1-5, recorded at the mouth. However, these additional partials are extremely weak, and further testing would be necessary to determine if they would result in any audible change in timbre, because of masking by the stronger partials.

Test 2: Wind pressure

In the second wind pressure test, the pressure of the air supplied to the pipe was varied exactly as before, but the toe hole in the base of the pipe was opened or closed to compensate for the change. The toe opening was so adjusted that the pipe would be returned to the standard pitch, $C=523.3$. (Variation in pressure without compensation

causes a change in pitch.) As may be ascertained from graphs 11-15 and 16-20, there was very little change in output of harmonic energy with change in wind pressure when the compensation was made. Partial 3, 4, 5, and 6 were stronger at the top of the pipe, as they were in Test 1. The ninth partial is very weak at the mouth of the pipe in all sections of Test 2. This did not occur in Test 1. The reason for this is not known at this time.

In Test 2, there is also a less gradual tapering-off of harmonic energy as compared with Test 1. In all parts of Test 2, the first four partials are strong, and the rest drop off rather sharply -- a 7 or 8 dB drop, compared with a 2 to 6 dB drop between partials 4 and 5 in Test 1. The slight "bump" near partials 9-10-11 is still evident. Less harmonic development is present at the high end of the spectrum in Test 2, since the pipe was originally adjusted for the mid-point of wind pressure, approximately 3 inches. It should also be noted that while there are one or two more partials present at the top of the pipe in Test 1, the reverse is true in Test 2; in fact, graphs 18 and 19 show two less harmonics than 13 and 14, which latter were recorded at the pipe mouth. In general, however, all graphs in

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10

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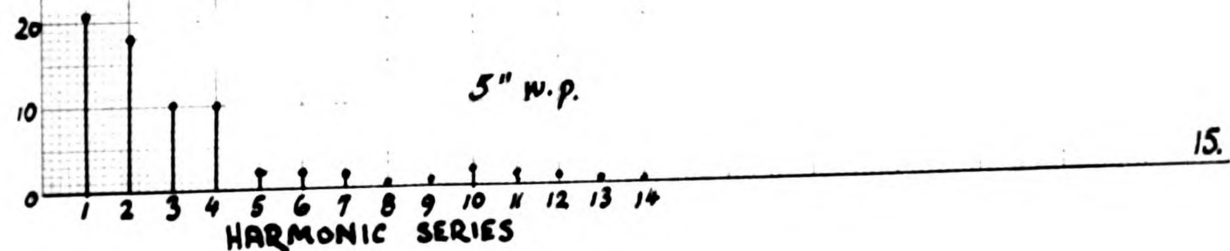
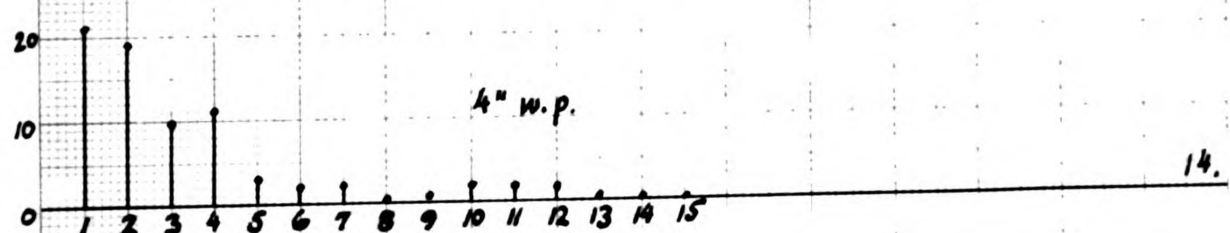
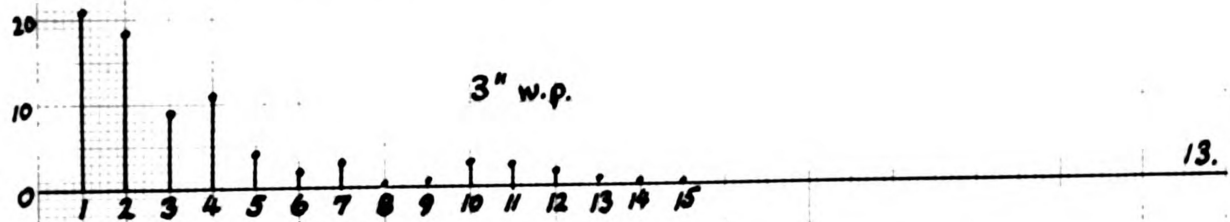
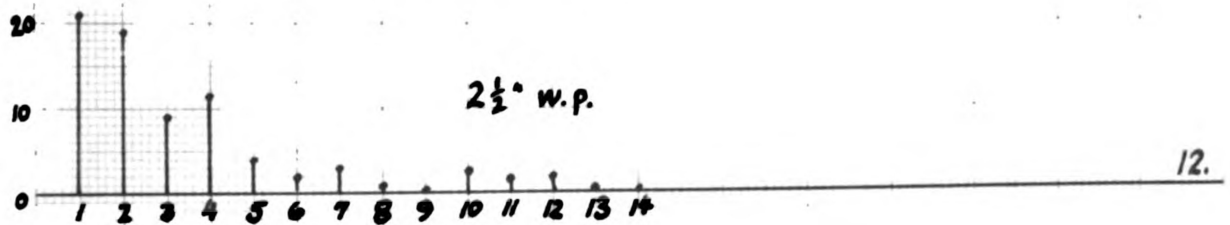
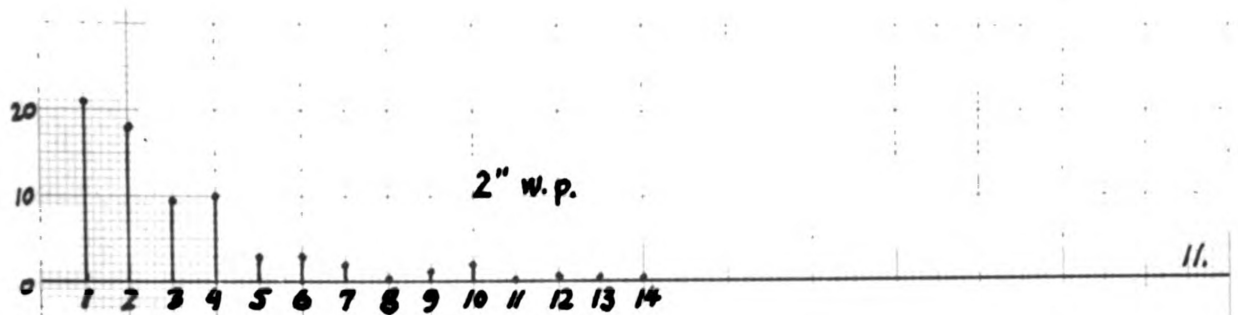
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TEST No. 2: WIND PRESSURE

Toe opening gradually closed to
correct for increased
wind pressure.

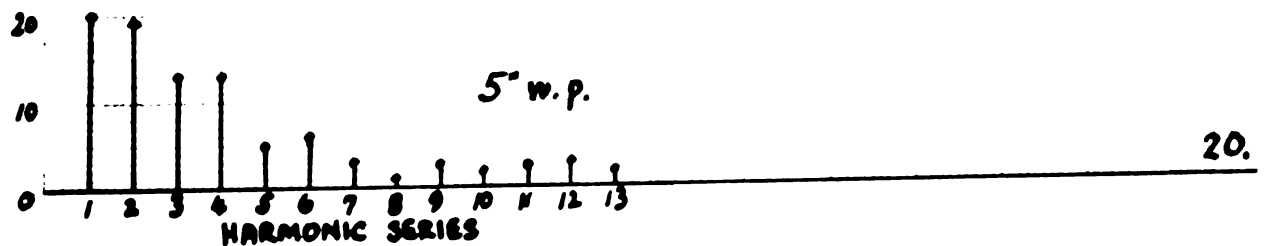
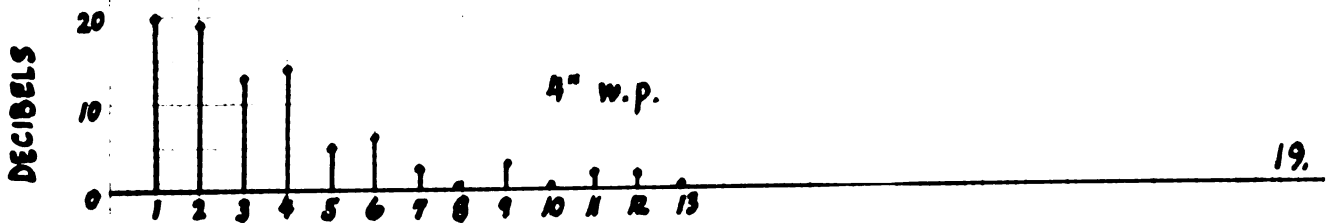
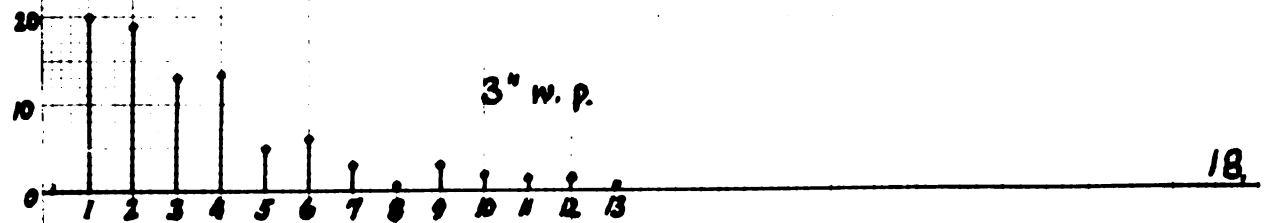
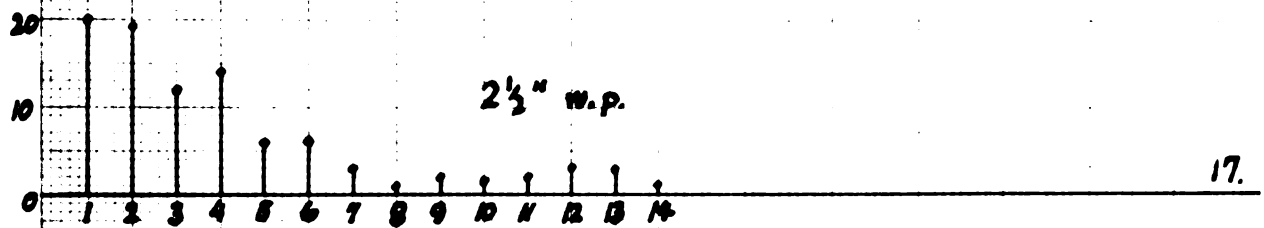
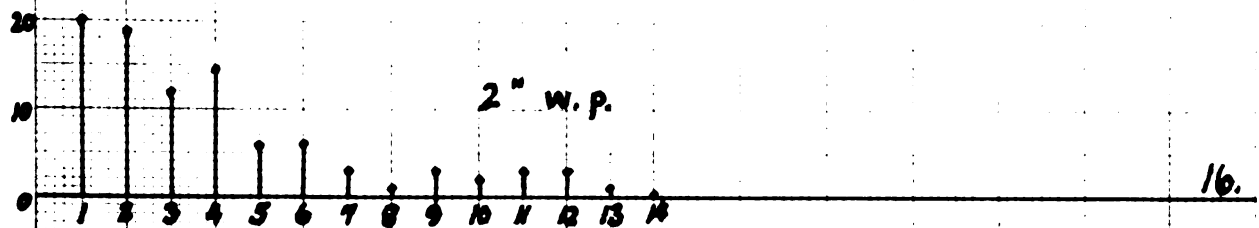
Recording made at pipe mouth.



TEST No. 2: WIND PRESSURE

Toe opening gradually closed
to correct for increased
wind pressure.

Recording made at top of pipe.



Test 2 were similar enough that any audible difference in higher partials might tend to be masked by lower ones.

Tests 3 and 4

Test 3 was a test of the noise level and frequency of sounds produced by the blower. The results may be found in Appendix A.

Test 4 was an analysis of a middle "C" string-tone pipe. No voicing tests were conducted on this pipe. Results may be found in Appendix B.

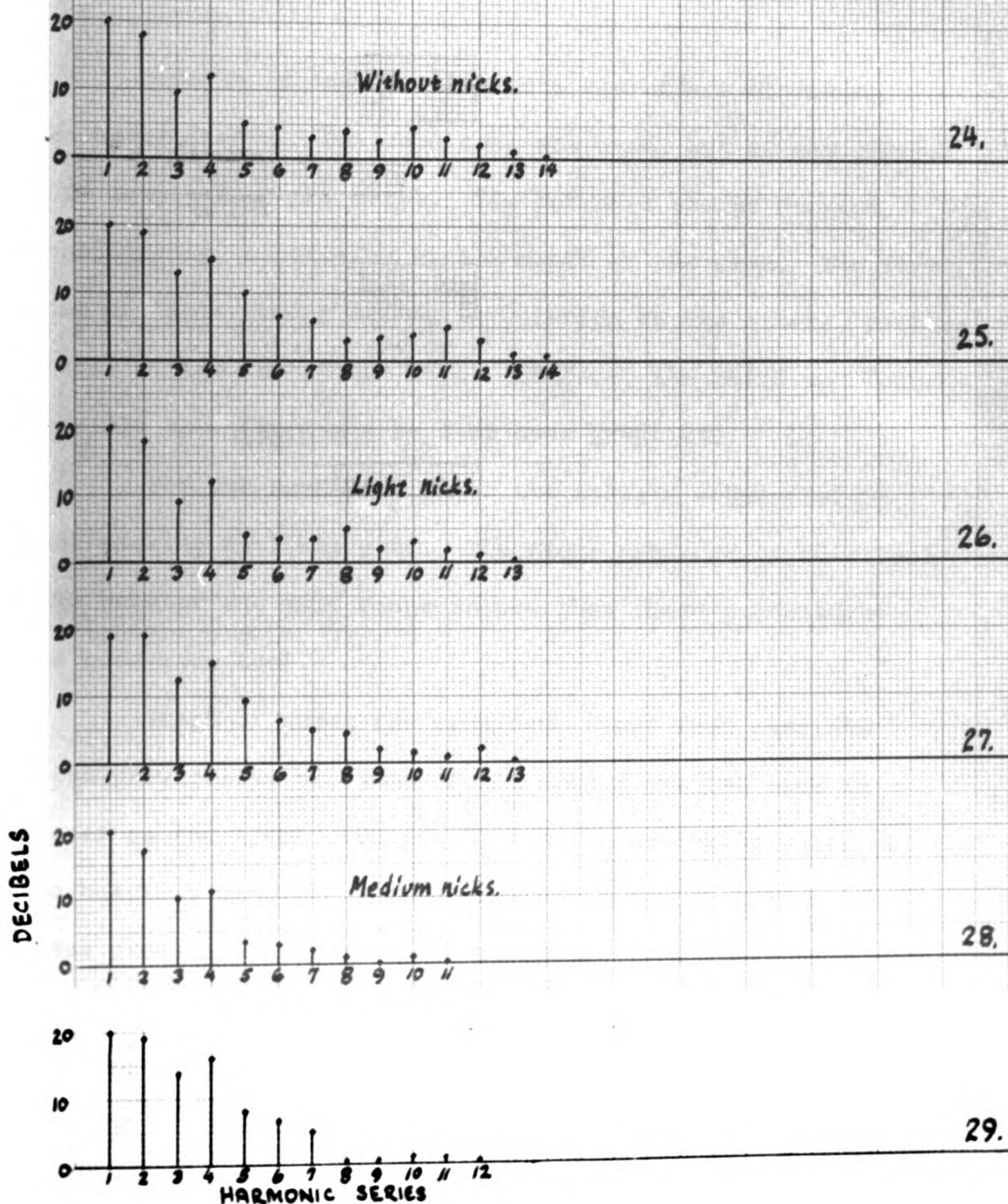
Test 5: Nicking

All parts of Test 5 were performed at 3 inches wind pressure, with the pipe speaking normally and tuned to C=523.3. Graphs 24 and 25 show the spectra at the mouth and top of the pipe before nicking.

The effect of lightly nicking the front of the languid may be seen in graph 26 (mouth) and graph 27 (top). A small enough nicking tool was not readily available commercially, so one was made by grinding down the end of a small file. The resulting tool was almost razor-sharp but was somewhat more wedge-shaped than a razor.

The nicks were very lightly made, about $\frac{1}{2}$ mm. into the metal and spaced 2 mm. apart. It can easily be seen that even this small change had a decided effect upon the

TEST No. 5: NICKING
 24, 26, 28 at pipe mouth.
 25, 27, 29 at top of pipe.
 3" wind pressure.



tone. The highest partial present, 14, has now dropped below the cutoff point on the graph, and all partials except 1, 2, and 4 are at a lower level, as much as 2 dB at partial 10.

Graphs 28 and 29 illustrate the effect of making the nicks deeper. The same tool was used, but it was pressed more deeply into the metal. The harmonic energy dropped considerably, especially at the mouth of the pipe. The first four partials remain strong in relation to the others, particularly at the top of the pipe. In fact, the third and fourth partials have increased by 1 dB over graph 27.

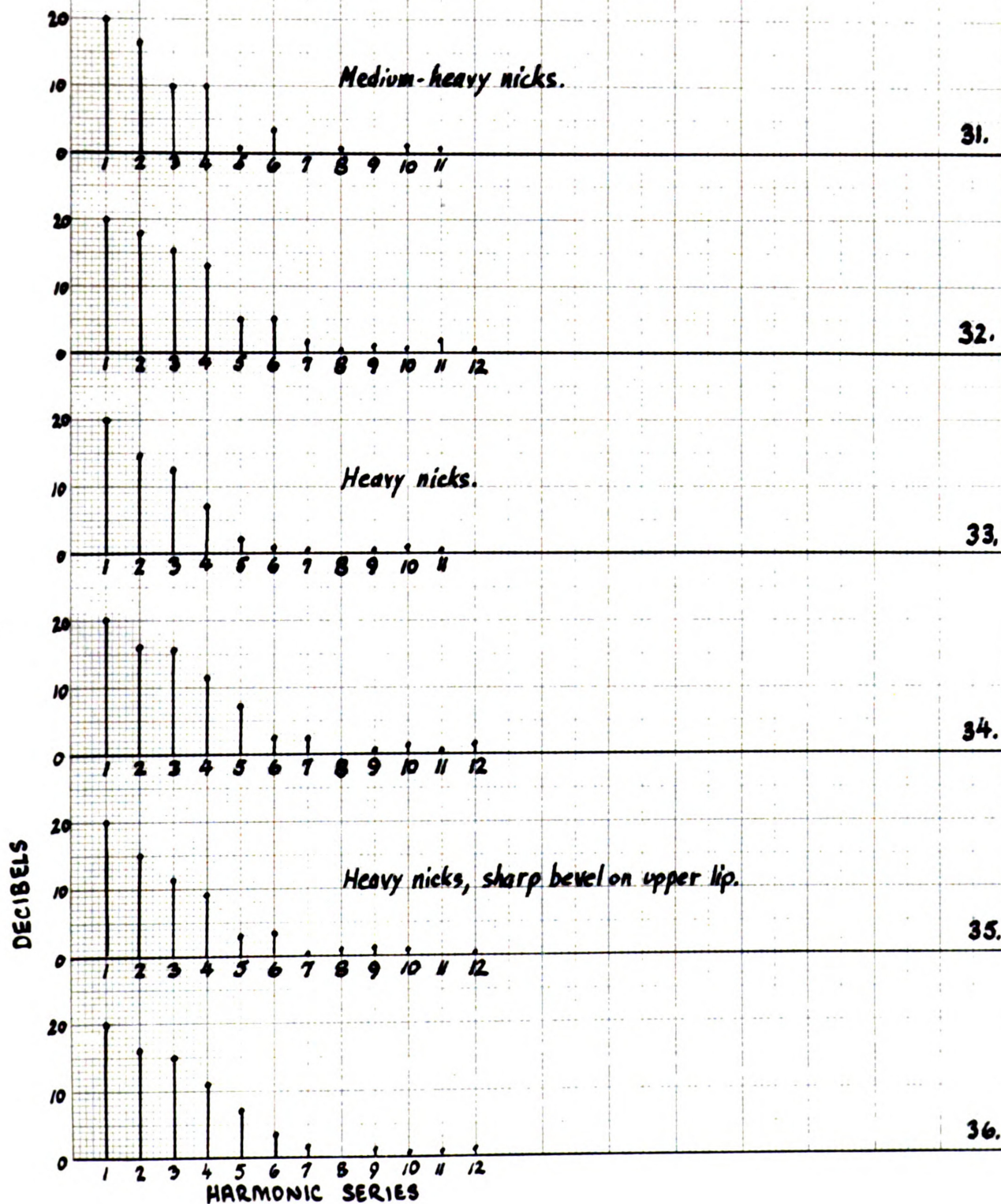
For the next portion of the test, a commercially-made nicking tool was used. The nicks produced by this tool were heavier and more wedge-shaped than those produced by the home-made tool.

Graph 31 shows the prominent first four partials noted previously, but some of the others are too weak to appear on the graph. Graphs 33 and 34 show the results of the heaviest possible nicks, probably somewhat heavier than those used in practical organ building. The first four partials are not as strong; there is now a gradual tapering downward from numbers one to seven. Eight is missing, and the rest are extremely weak.

TEST No. 5: NICKING

31, 33, 35 at pipe mouth

32, 34, 36 at top of pipe.

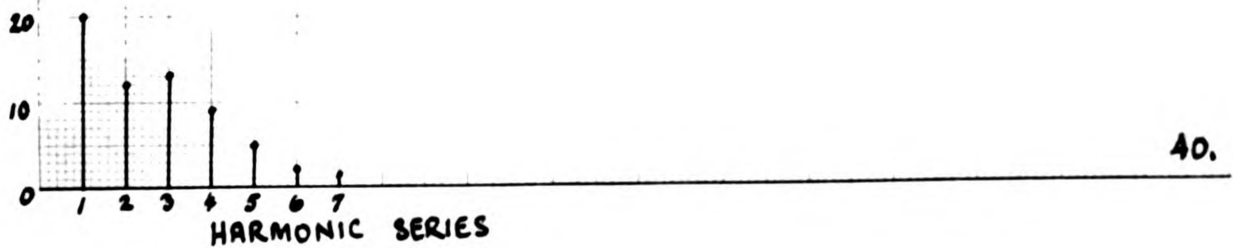
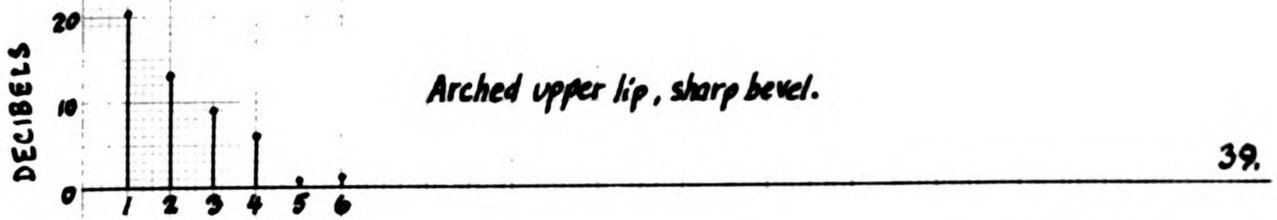
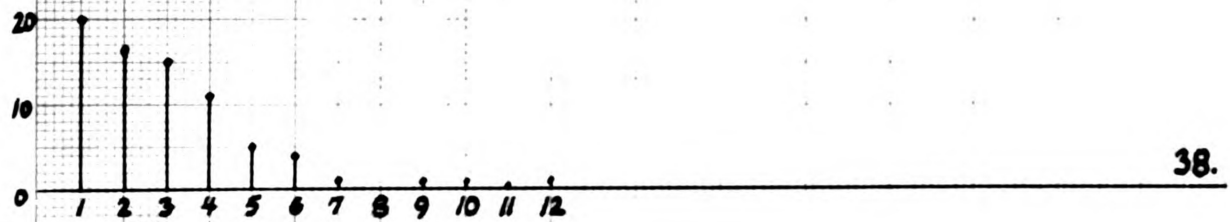
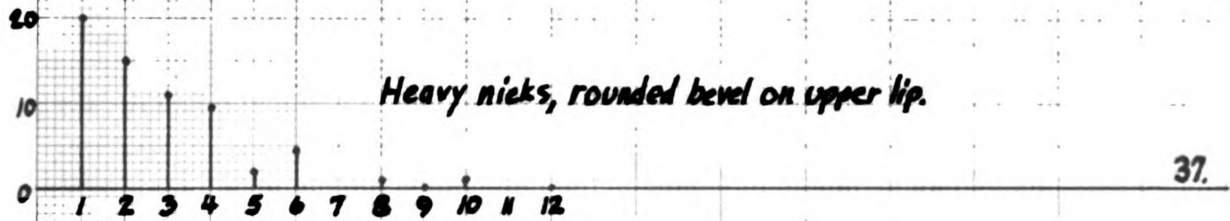


TEST No. 5: NICKING

37: mouth of pipe
38: top of pipe

TEST No. 6: UPPER LIP

39: mouth of pipe
40: top of pipe



Next, an attempt was made to restore some of the missing harmonic energy by combining the heavy nicks with a more sharply bevelled upper lip (graphs 35-36). The change was not so significant as expected. This sharpened bevel was then rounded off (graphs 37-38). This alteration had virtually no effect on the spectra, certainly no audible change; the only differences evident: partial 6, 1 dB higher in graph 37; partial 5, 2 dB lower in graph 38. It was expected that the rounding-off of the bevel would have a noticeable effect, but this was not borne out. In fact, it may be stated that, with heavy nicking, the sharpness or dullness of the upper lip had no real effect.

Test 6: Shape of upper lip

The difference between the straight or arched upper lip is another matter; here, a considerable change was encountered--a larger change than had been anticipated. Graphs 39 and 40 show the results of this.

The same pipe was used as in the foregoing tests, with nicks, at a wind pressure of 3 inches. With the arched upper lip, graph 39 shows but six partials above the cutoff point, and the fifth is weak. Graph 40, recorded simultaneously at the top of the pipe, shows one additional partial, but the rapid dropping-off is again evident.

Graphs 41 and 42 show the results of straightening the upper lip (removing the arch) but raising the cut-up 7 mm. The bevel on the upper lip was sharp, not rounded. Wind pressure was 3 inches.

It can be seen that part of the lost harmonic energy has been restored. There is more overtone development at the mouth than at the top of the pipe. This would be logical to expect, since the change was made at the mouth. Of interest here is the "trail" of partials (7 through 14) all at approximately the same level.

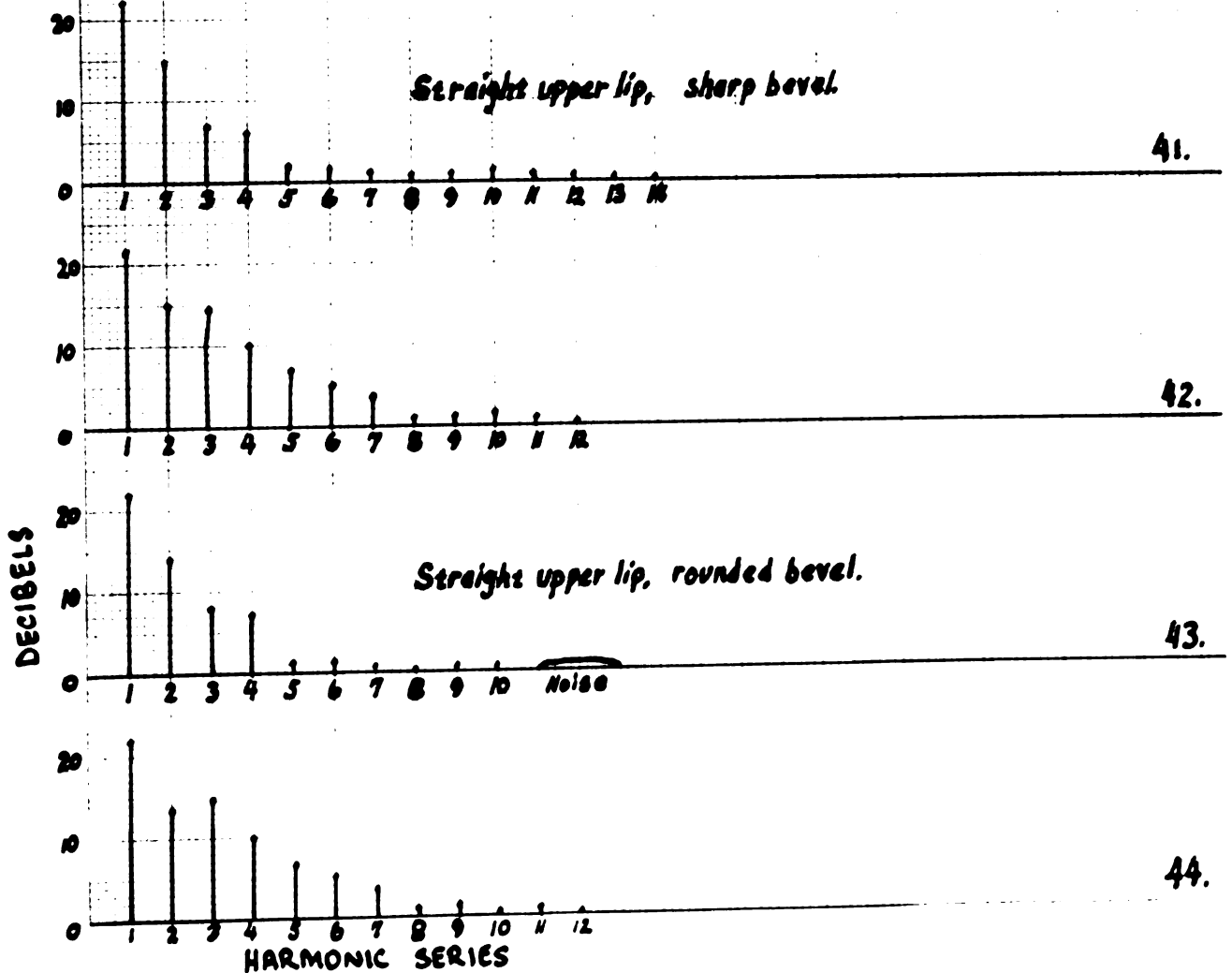
When the sharp bevel (graphs 41-42) was rounded off (graphs 43-44), there was a small drop in harmonic output, but the significant change was the appearance of a small band of noise in the space occupied by partials 11 through 13. Apparently a certain amount of air turbulence had been introduced by this operation. This noise was not evident at the top of the pipe but was present in the vicinity of the mouth.

Increasing the cut-up another 2mm. (graphs 45-46) produced an exaggeration of the conditions just described. In addition to increasing the cut-up, the wind pressure was raised to 4 inches. At the mouth of the pipe, the fundamental was in a different proportion to the other partials (11 dB over partial 2) and the noise band had increased

TEST No. 6: UPPER LIP

41, 43: mouth of pipe

42, 44: top of pipe



considerably in strength. This noise was audible and also was evident in the harmonic analysis.

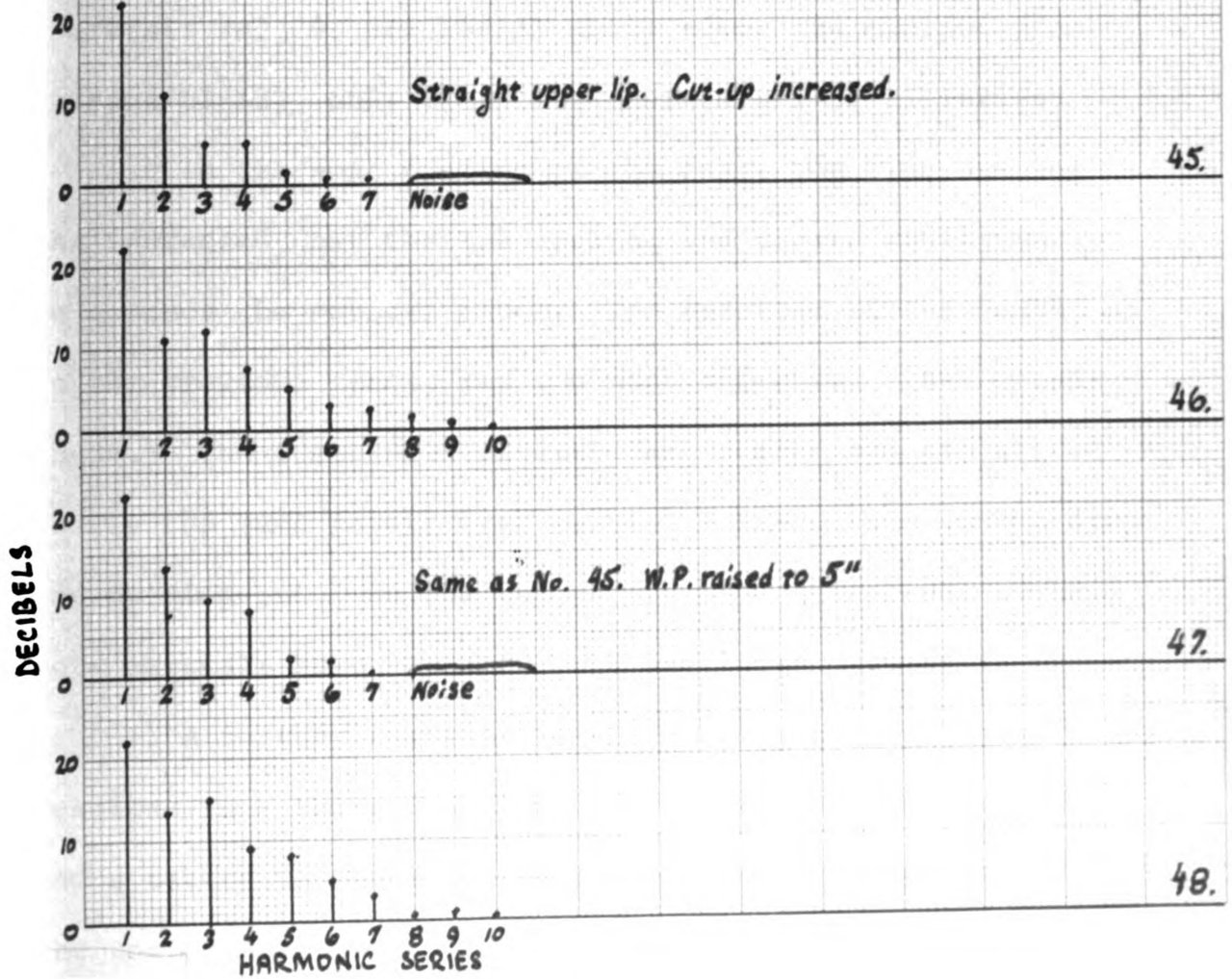
An increase in wind pressure to 5 inches with no change in the pipe produced graphs 47-48. The wind was increased in an effort to restore some of the harmonic energy lost through the high cut-up and rounded bevel. There was a small increase, but the noise increased also. There was, however, an evening-out of the harmonics as compared with graphs 45-46.

Test 7: Flue opening

This test investigated the influence of the width of the flue opening (the windway between the lower lip and the front edge of the languid). A new pipe was used for this series of tests. Graphs 49-50 show the analysis of this pipe's tone before the flue tests. It may be seen that this pipe, in its "natural" (unaltered) state, possessed a much more developed harmonic structure than the pipe used for the first group of tests. The new pipe was voiced normally, without nicks, on 3 inches wind pressure.

The width of the flue opening is a means of regulating the volume of the pipe tone, as is the opening at the toe of the pipe. It was demonstrated earlier that adjustment of the toe opening had a negligible effect on the tonal

TEST NO. 6: UPPER LIP
 45, 47: mouth of pipe
 46, 48: top of pipe



spectrum. Adjusting the flue, however, does have considerable effect, especially when the toe and flue adjustments are used in conjunction.

The flue was opened slightly (approximately $\frac{1}{2}$ mm.) and the pipe was retuned. The toe opening was not changed. The result was the appearance of one additional partial above the cutoff point, and a slight overall change in the shape of the spectrum. Graphs 49-50 may be said to have three peaks (partials 2-3, 9, and 14-15) while after the manipulation (graphs 51-52), only two peaks (partials 2-3, 11) exist.

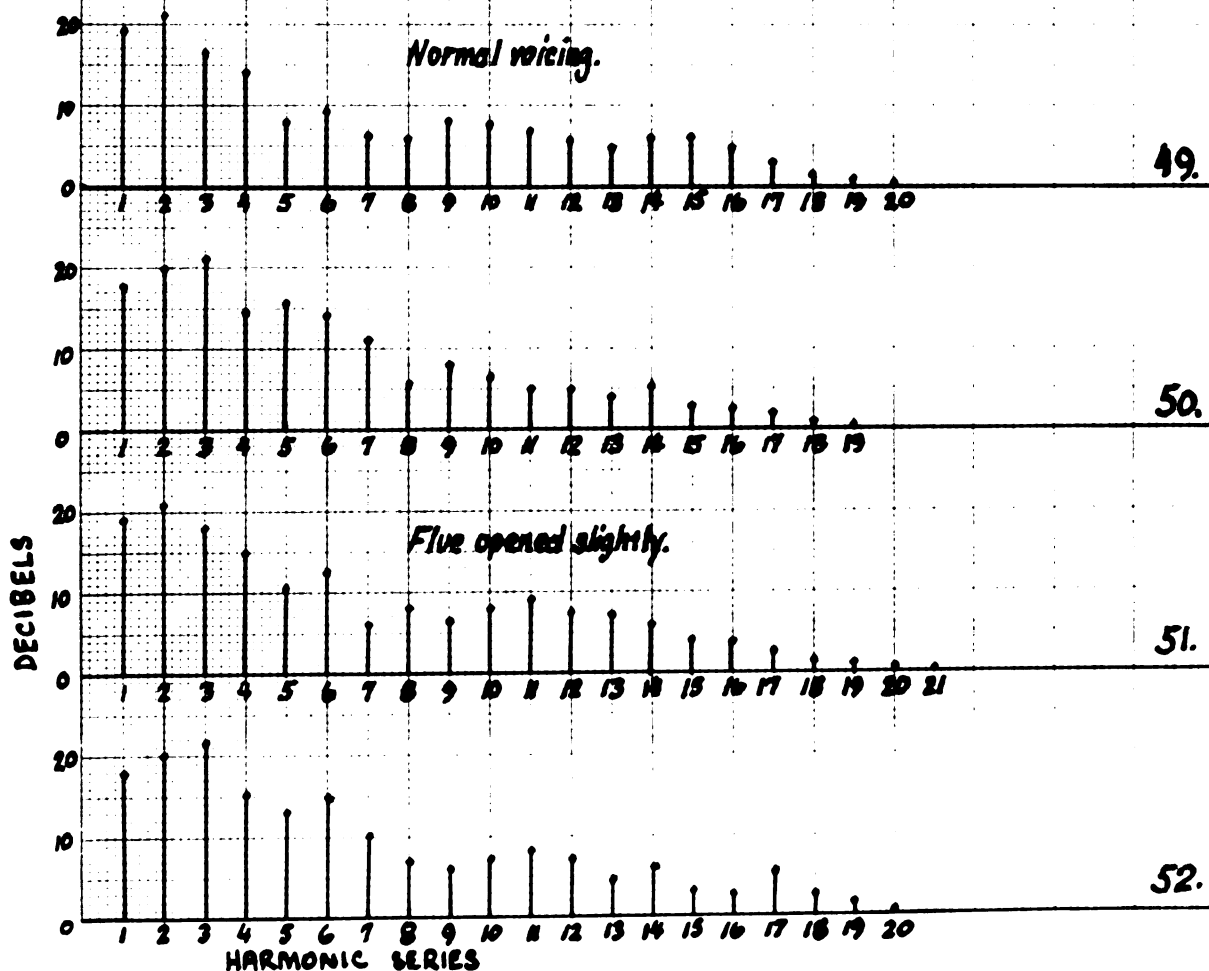
In the next portion of the test, the flue opening was increased, but the toe opening was closed sufficiently to correct the musical pitch. The spectrum at the mouth, as in the previous tests, was the most affected. (See graphs 53-54.) The first four partials are strong and are all at nearly the same level; from partial 5 there is a sudden drop and evening-out. At the top of the pipe (graph 54) three more partials have appeared, but one lower partial is missing.

A further increase in the flue opening (graphs 55-56) resulted in a sharp dropping-off of the number of partials and a return to the three-humped pattern of graphs 49-50. The toe opening was not changed.

TEST No. 7: FIVE OPENING

49,51: mouth of pipe

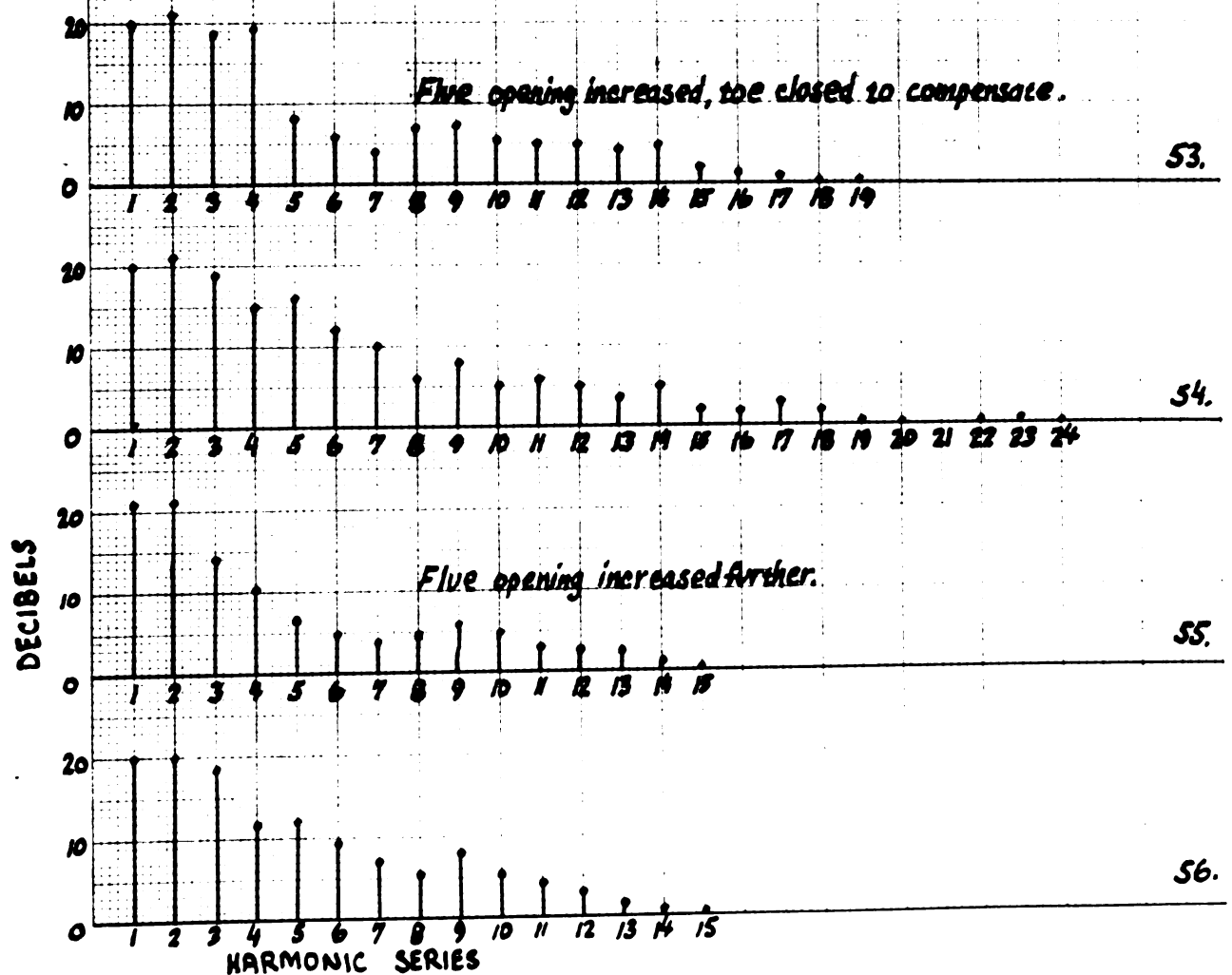
50,52: top of pipe



TEST No. 7: FLUE OPENING

53, 55: mouth of pipe

54, 56: top of pipe



Test 8: Height of languid

For the next test, the pipe was returned to "normal" voicing. Comparison of graphs 49-50 with 59-60 show that this was closely achieved.

Test 8 was concerned with the height of the front edge of the languid in relation to the upper and lower lips. The pipe, before testing, had a well-developed train of harmonics. (See graphs 59-60.) Raising the languid a very small amount, less than .5 mm., resulted in a small change in the spectrum at the mouth of the pipe and a larger change in the spectrum at the top of the pipe (graphs 61-62). The change at the mouth consisted of a 3.5 dB increase in partial 5 and a loss of two partials at the top end of the graph. At the top of the pipe, however, there was a marked increase in harmonic energy in the area of partials 17 to 23. Although it could not be ascertained audibly, it is suspected that this energy was in the form of wind noise or turbulence of some sort, rather than true harmonic energy.¹⁰

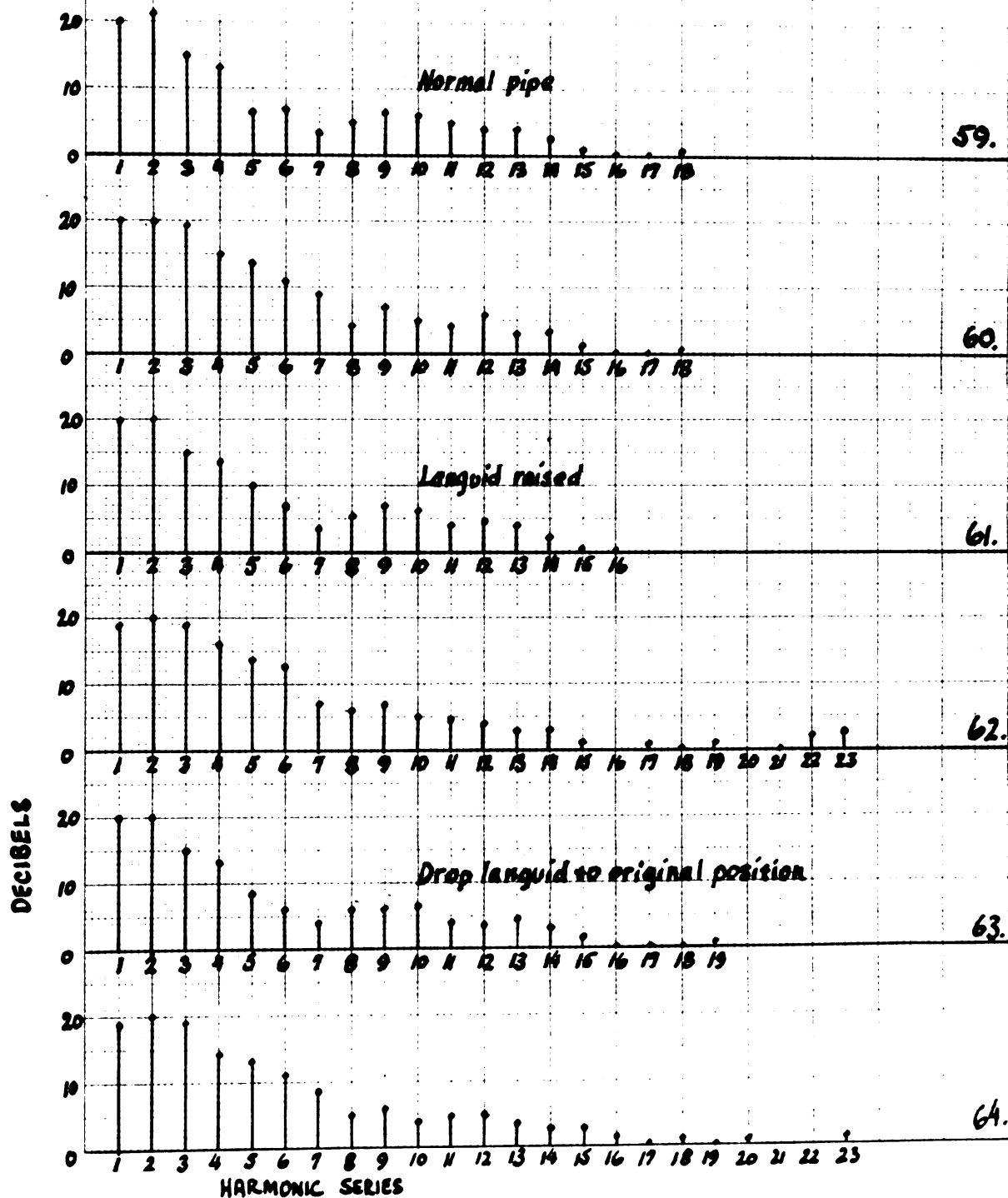
¹⁰With a fundamental of 523.3 cps, the 23rd partial is at a frequency of 12,035.9 cycles per second. (See Table 1.) With the type of harmonic analyzer used for these tests, it is difficult to determine true peaks at such a high frequency. The peaks come closer together with increasing frequency; the 24th partial, for example, is 12,559.2 cps, and the distances between peaks on the machine-recorded graph become so small

TABLE 3
HARMONIC SERIES ON C = 523.3

Series	Pitch*	Frequency
1	C	523.3
2	C	1,046.6
3	G	1,569.9
4	C	2,093.2
5	E	2,616.5
6	G	3,139.8
7	(B ^b)	3,663.1
8	C	4,186.4
9	D	4,709.7
10	E	5,233.0
11	(F [#])	5,756.3
12	G	6,279.6
13	(A)	6,802.9
14	(B ^b)	7,326.2
15	B	7,849.5
16	C	8,372.8
17	-	8,896.1
18	-	9,419.4
19	-	9,942.7
20	-	10,466.0
21	-	10,989.3
22	-	11,512.6
23	-	12,035.9
24	-	12,559.2
25	-	13,082.5
26	-	13,605.8
27	-	14,129.1
28	-	14,652.4
29	-	15,175.7
30	-	15,699.0

*Notes in parentheses are not in tune
with the tempered system of tuning.

TEST NO. 8: HEIGHT OF LANGUID
 59, 61, 63: mouth of pipe
 60, 62, 64: top of pipe

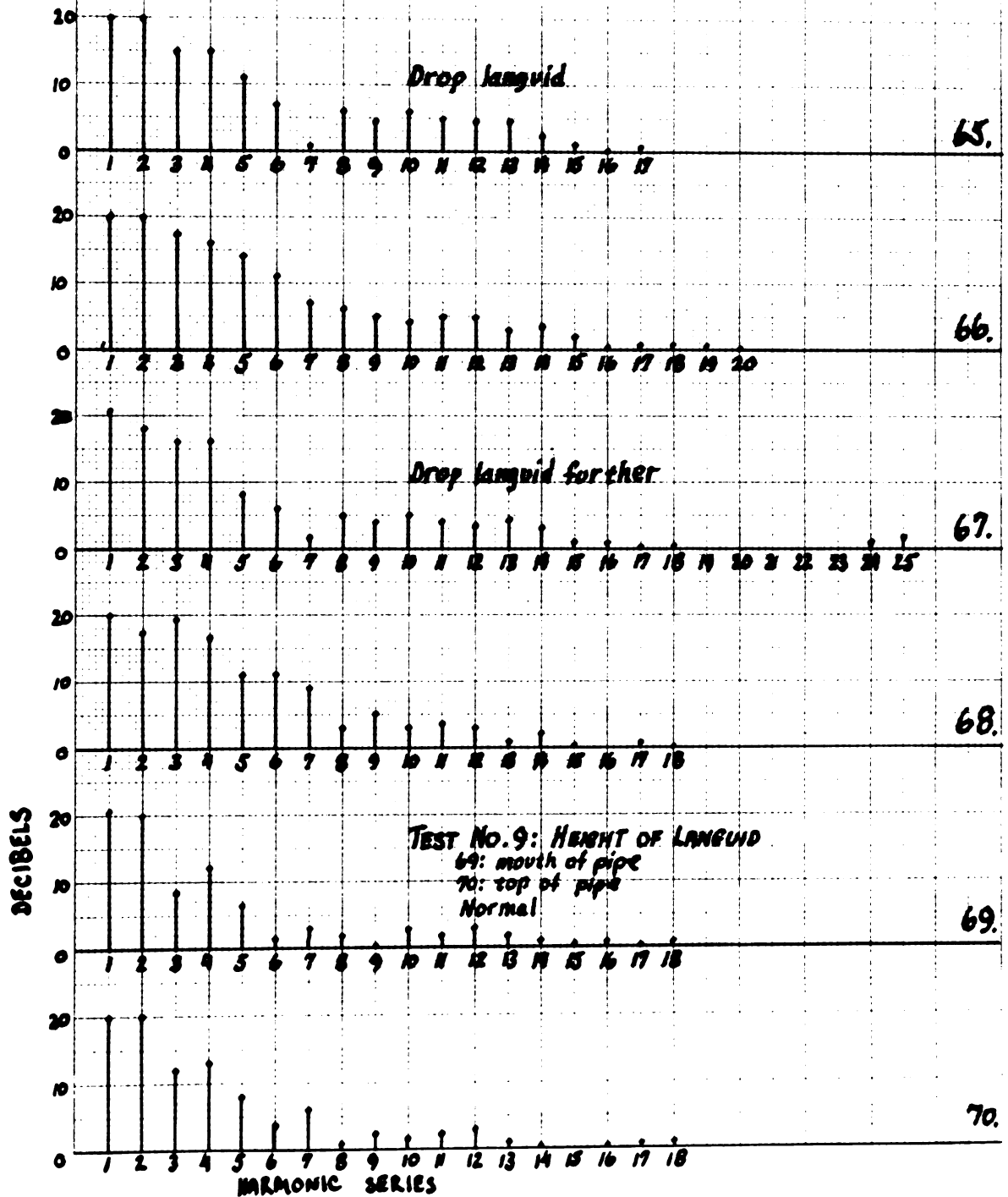


The languid was then lowered to a position approximating as closely as possible its position before raising. However, this was not completely achieved (graphs 63-64). The next operation, a further lowering of the languid, actually resulted in a spectrum closer to the "normal" pipe. Lowering the languid further, however, resulted in a reversal of the conditions encountered when raising the languid. Raising produced an increase in partials at the top of the pipes and a dropping-off at the mouth; lowering the languid produced the reverse effect, i.e., an increase in partials at the mouth of the pipe and a dropping-off at the top of the pipe. Details may be discerned by comparing graphs 61-62 with graphs 67-68. The latter two were produced with the languid approximately .75 mm. below the lower lip.

The languid cannot be adjusted alone without seriously upsetting the speech of the pipe. To compensate for the adjustments made on the languid, it was necessary to move the upper lip out when raising the languid, and to move it in when lowering the languid. The upper lip must

that individual harmonics cannot be distinguished, or disappear into the noise level. Thus, while this test produced an increase in energy at the high end of the spectrum, the nature of that energy is not yet certain, and more sophisticated equipment would be needed to draw a definite conclusion.

TEST No. 8: HEIGHT OF LANGUID
 65, 67, 69: mouth of pipe
 66, 68, 70: top of pipe



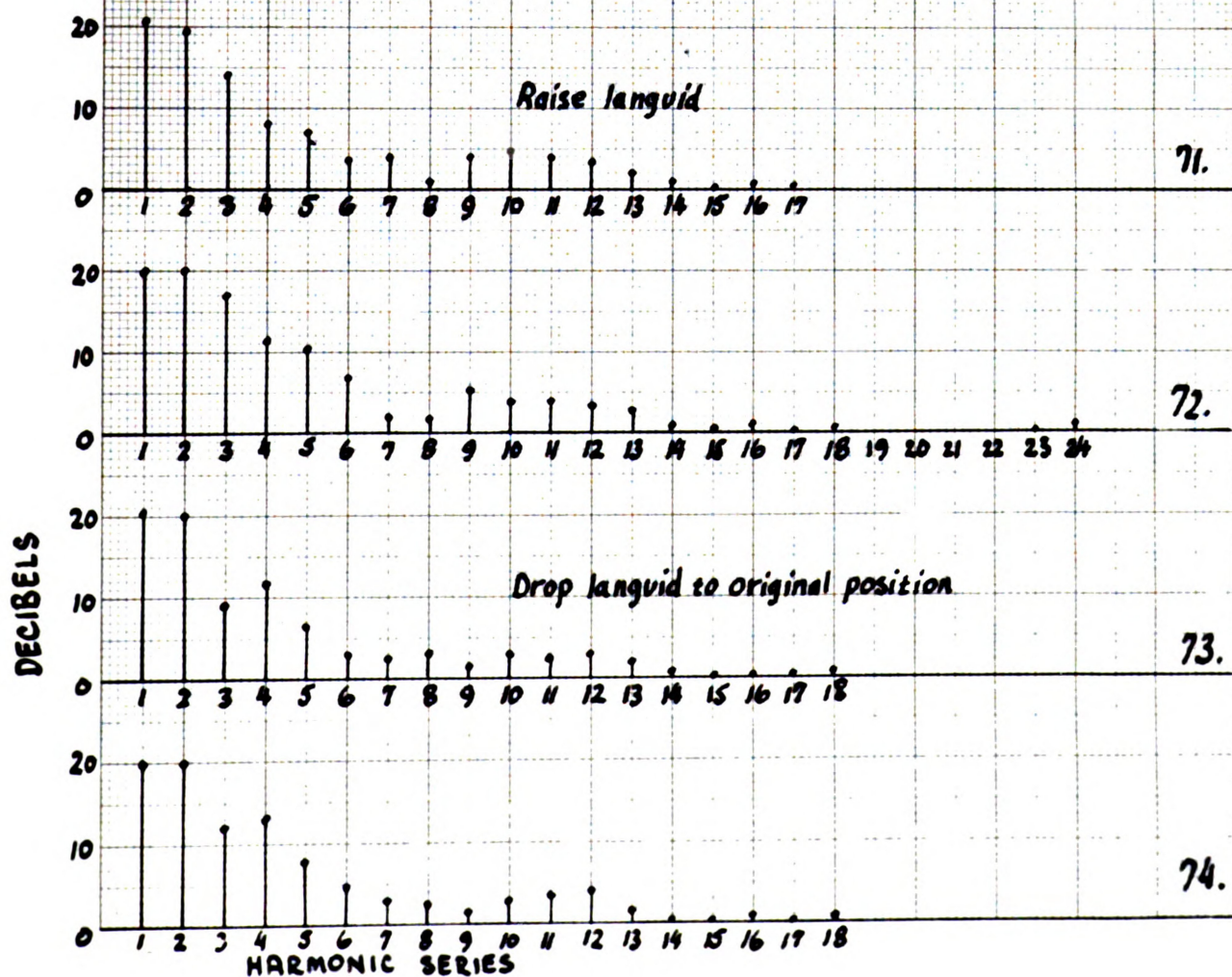
be moved, proportionally, a considerable distance to correct for only a minute movement of the languid. The ratio of movements is on the order of 4 to 1.

In the last portion of the tests, the languid adjustments described above were performed again, on a different pipe. Graphs 69-70 show this pipe in its "normal" unaltered state, before manipulation. (Tests 8 and 9 were identical except for the use of a different pipe. Graphs 59-60 correspond with 69-70, 61-62 with 71-72, and so on.) Upon comparison of the graphs of Test 8 with those of Test 9, it will be seen that, even though the individual spectra are not identical, the same types of changes took place. Raising the languid in both tests produced an increase in harmonic energy at the top of the pipe; lowering it produced an increase at the mouth, although this latter effect is not so pronounced an increase in Test 9 as in Test 8. In fact, as the languid was lowered even further (graphs 77-78), the two spectra, mouth and top, became almost identical, although the spectrum at the mouth averages about 1 dB higher except for the first two partials.

TEST No. 9: HEIGHT OF LINGUID

71, 73: moveh

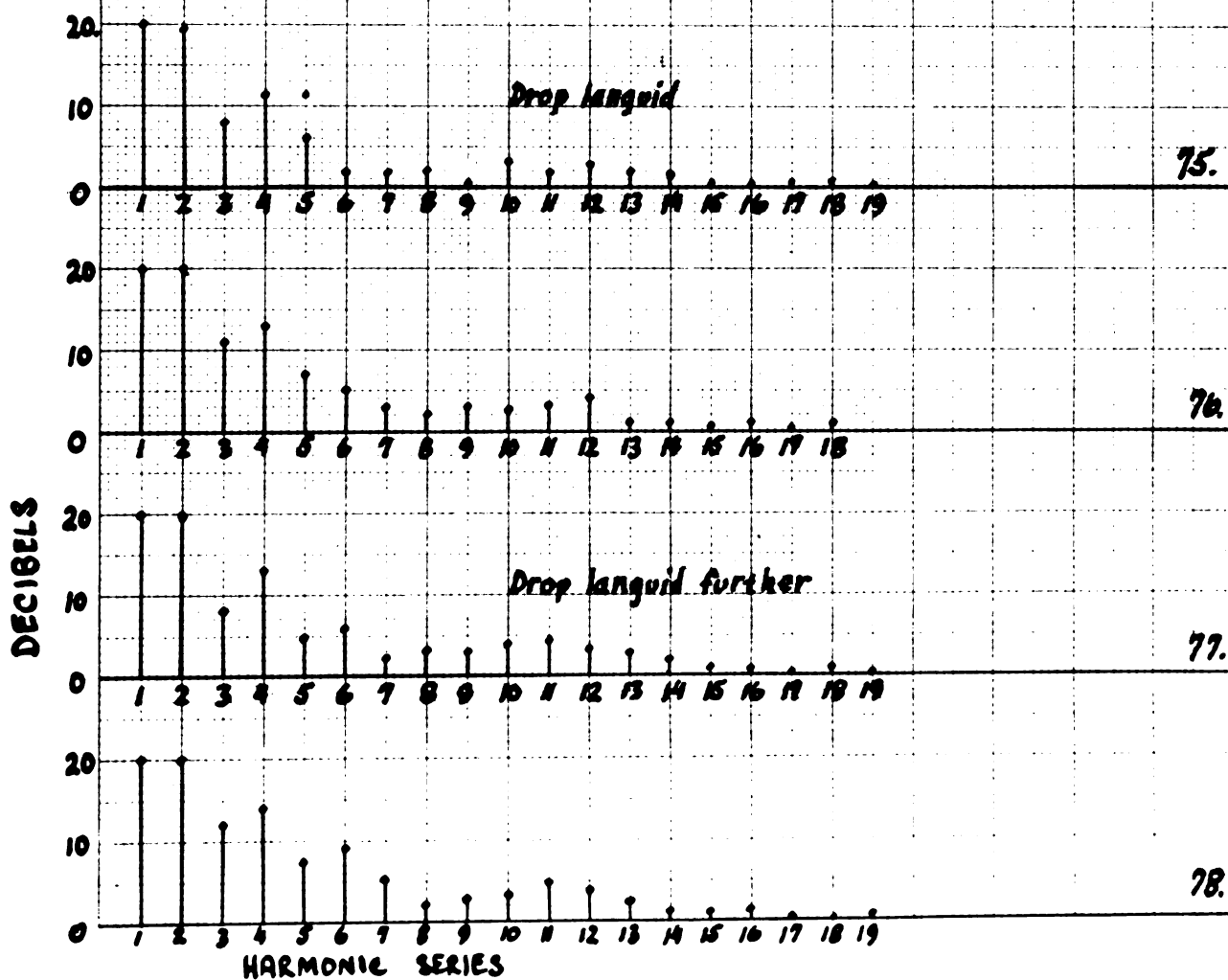
72, 74: top



TEST No. 9: HEIGHT OF LINGUIST

75; 77: mouth

76, 78: top



CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

The underlying purpose of this paper being to apply the research to practical organ building, and to relate scientific means to artistic ends, the test findings will be summarized here and applied to certain areas of practical organ design and building. Attempt will be made to provide answers to the research questions posed in Chapter I.

The results of Test 1 confirmed what at one time had been a matter of dispute among writers on the pipe organ. About a century ago, it was undecided whether the sound issued from the mouth or from the top of an organ pipe.¹¹ The test results presented herein show that while the sound output is not divided equally between the mouth and the top of the pipe, both areas are important and must have free, open access to the area into which the sound of the organ is speaking. The tops of the pipes should preferably not be above the opening in the organ chamber through which the organ tones make their egress. It would seem that a sound-reflective panel should be erected over the tops of

¹¹Skinner. op.cit. p.24.

the pipes and positioned in such a manner that the sounds are directed where desired.

There is, furthermore, a difference in overtone structure between the sounds emitted by the mouth of the pipe and those emitted by the top of the pipe. An examination of Chapter III, Test Results, will reveal to the reader the details of these differences, but noteworthy here is the fact that much of the higher portion of the tonal spectrum of a given pipe issues from the top of that pipe. Therefore, it is even more important that the sounds emitted by the tops of the pipes in an organ be provided ready access to the area into which the organ is intended to speak.

Tests 1 and 2: Wind pressures

Organ builders do not generally vary the wind pressure supplied to a pipe without in some way compensating for this change. Thus, while this test does not relate directly to organ building, it does demonstrate the loss of harmonic energy encountered when there is only a small drop in wind pressure supplied to the pipes. The loss is even more serious if the organ is already designed for, and operating on, low wind pressure, 3 inches or below. Therefore, it is important that the blower, reservoir, regulating

devices and wind conductors all be free of leaks and resistance to the wind and be in proper operating condition.

If variations in wind pressure are corrected by opening or closing the hole in the toe of the pipe, the change in the harmonic spectrum of the pipe is negligible. If, however, correction for wind pressure is made at the flue opening, the harmonic spectrum will be changed. The amount of the change depends on the amount of manipulation of the flue opening and whether or not the toe opening is adjusted concurrently.¹²

Tests 3 and 4

The results of Test 3, a test of blower noise, may be found in Appendix A, Graph 2, "Blower Noise." The results of Test 4, an analysis of a middle "C" string pipe tone, may be found in Appendix B, Charts 22 and 23.

Test 5: Nicking

As stated earlier in Chapter III, Test Results, nicking has a profound effect upon the overtone structure and must be done with care. Once made, the nicks cannot

¹²It is suspected that the toe opening affects the speech (attack) of the pipe more than it affects the overtone structure, but more exhaustive testing would be necessary to confirm or deny this.

be removed, and the tests showed that it is nearly impossible to correct for heavy nicking by any other means. It is also suspected that even extremely light nicking has more effect than organ builders formerly realized, especially on the overtones near the upper end of the spectrum.

Test 6: Upper lip

The sharpness or dullness of the bevel on the upper lip was found to have little influence on the overtone structure. It had been expected that all of the adjustments to be tested would have some effect, but this was not borne out; in fact, when heavy nicking was present, the sharpness or dullness of the upper lip had virtually no effect and could not be used to offset the effects of the nicking.

A difference was found to exist between the straight upper lip and the arched upper lip, and in this case a larger change was found than had been expected. However, whether or not a pipe possesses an arched upper lip is determined before the pipes are manufactured and is not a variable in the voicing process.

Test 7: Flue opening

Adjustment of the flue opening is another means of regulating the volume of a pipe's tone. While the toe opening was found to have little effect on the harmonic spectrum, the flue opening does have considerable influence. The flue adjustment is used primarily for pipes built with "open toes," that is, toe holes that are not intended to be adjusted.

It would be expected that opening the flue and closing the toe at the same time would tend to be mutually cancelling procedures, but this was not found to be the case. Opening the flue tends to cause a marked dropping-off of the upper partials.

In general, then, it appears that the adjustment of the flue opening, in conjunction with the toe opening, is of extreme importance if proper harmonic development of each pipe is to be expected. Further, these adjustments are sensitive, a small change resulting in a relatively large change in overtone structure.

Test 8: Height of languid

The height of the languid is generally adjusted in the course of the final tonal finishing of an organ.

Improperly adjusting the languid can result in excessive wind noise being produced by the pipe. The languid adjustments are related to manipulations of the lips of the pipe. For each languid alteration, a proper compensating adjustment must be made to the pipe lips.

Repetition of the languid tests on a different pipe showed that similar results could be obtained with a physically differing pipe.

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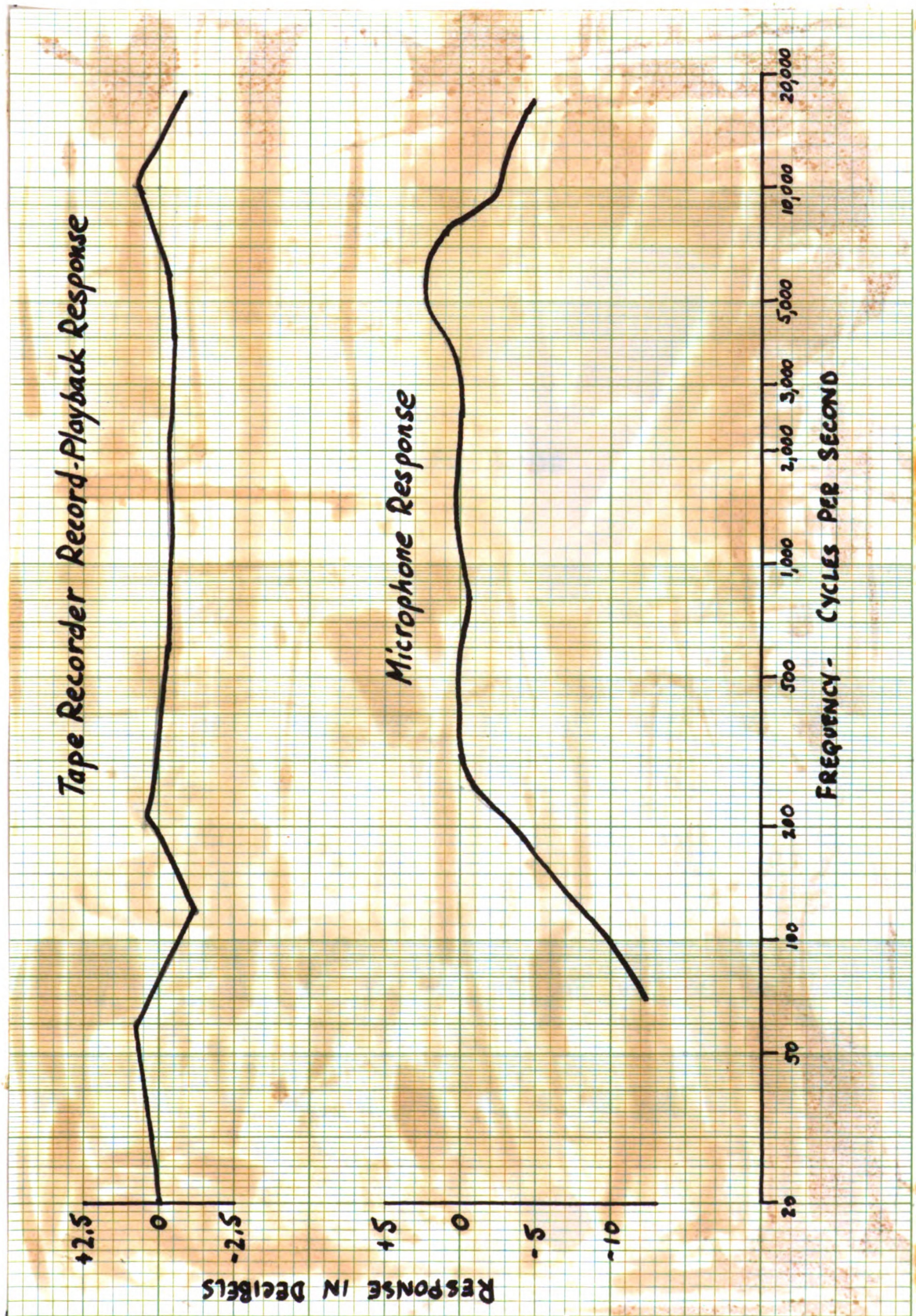
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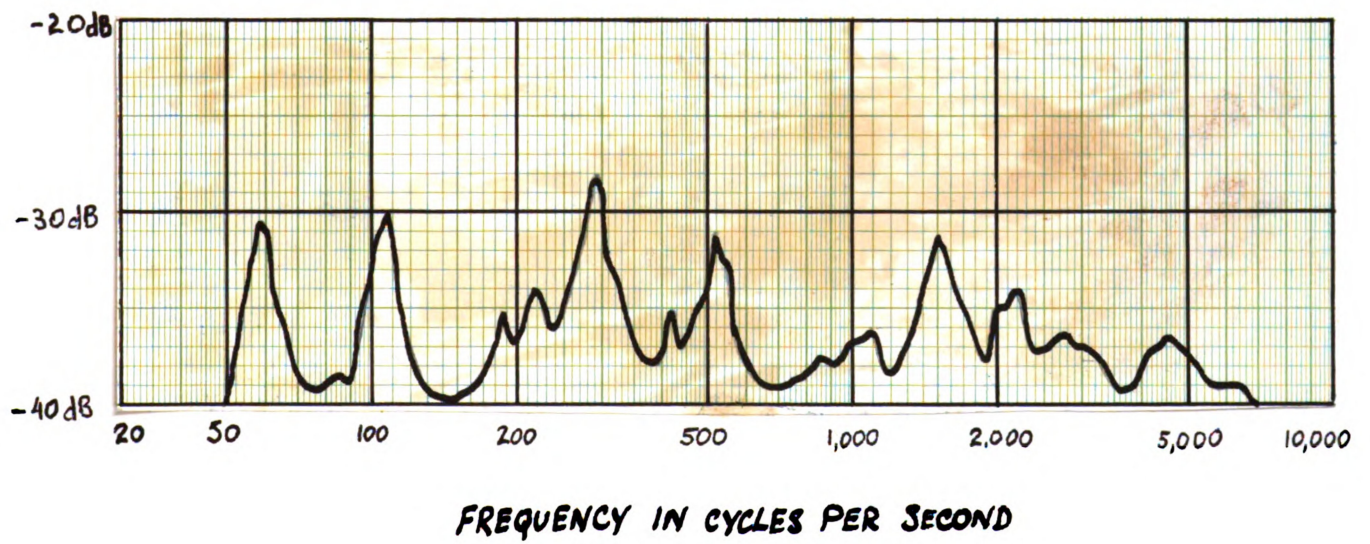
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APPENDICES

APPENDIX A

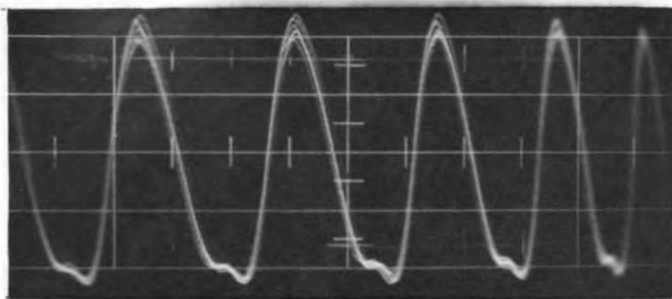


BLOWER NOISE

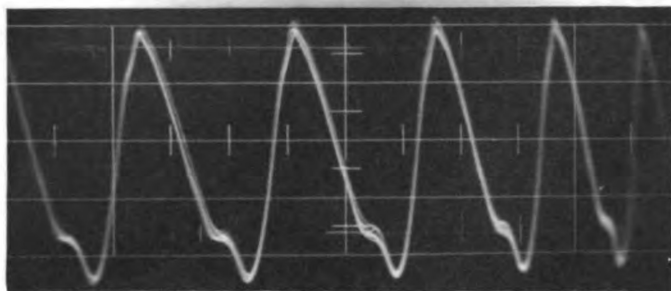
APPENDIX B

NOTE OF EXPLANATION

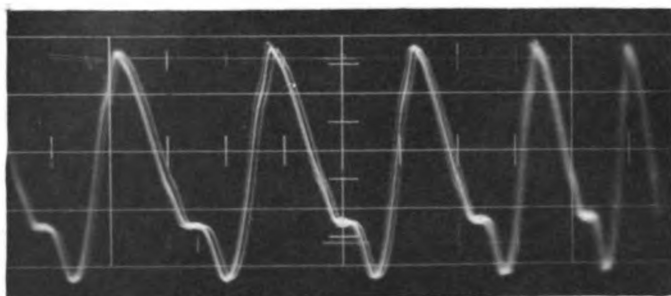
The numbers of the oscilloscopic graphs in Appendix B are in agreement with Harmonic Graphs 1-78 in Chapter III.



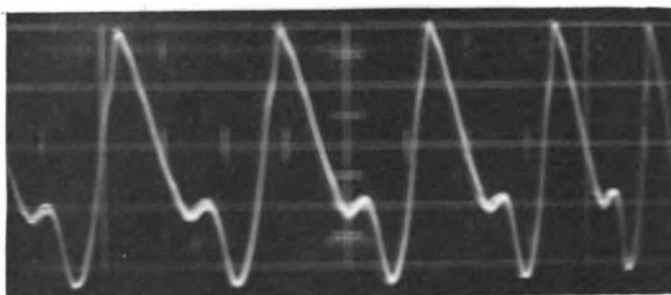
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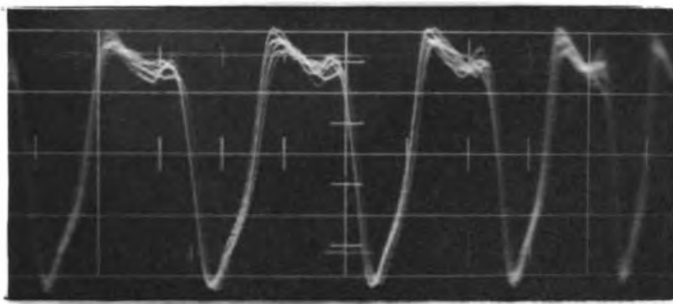
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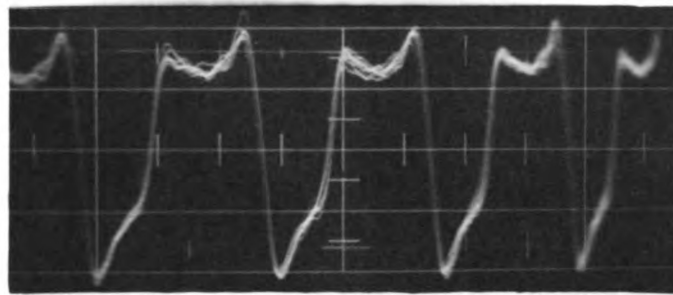
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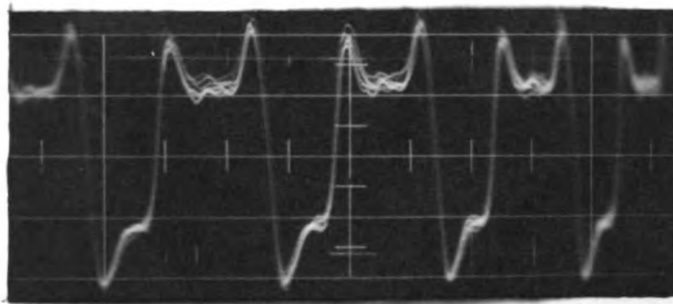
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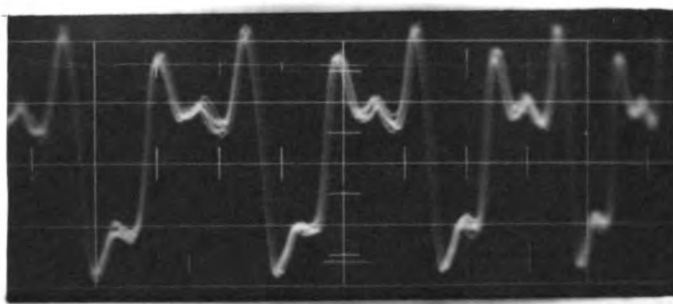
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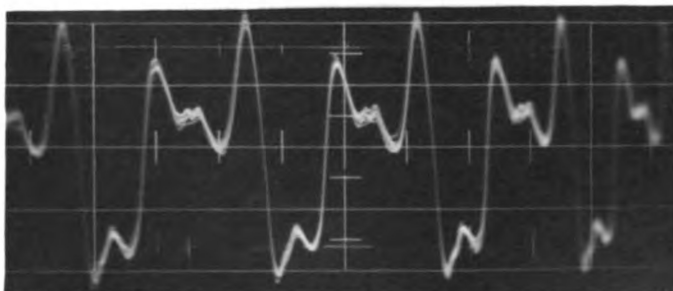
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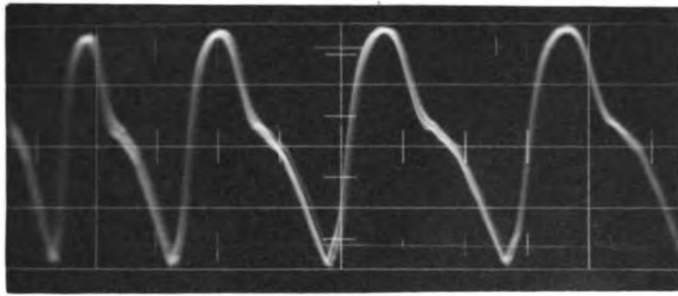
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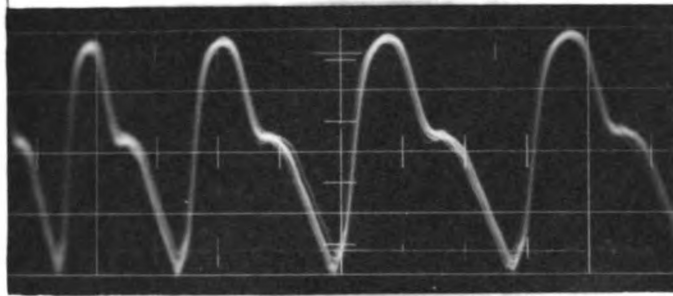
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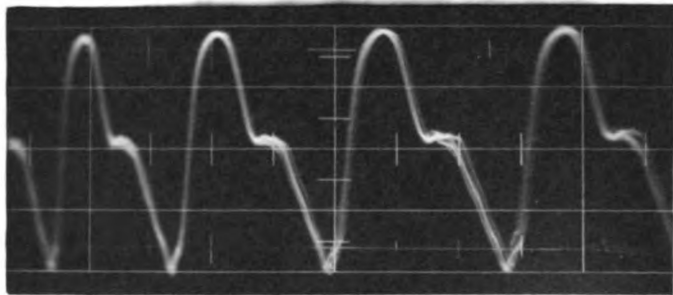
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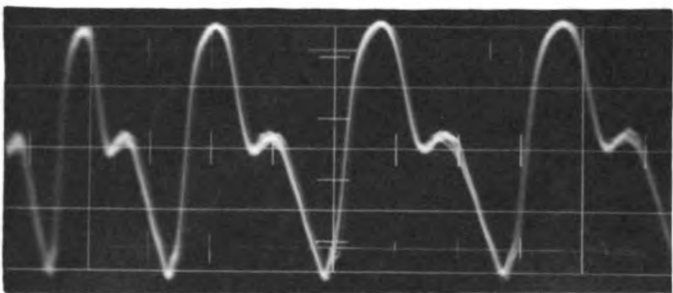
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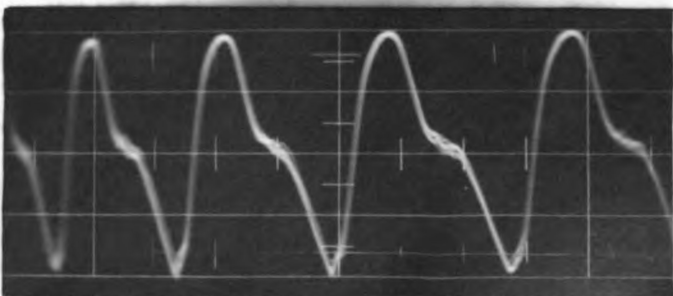
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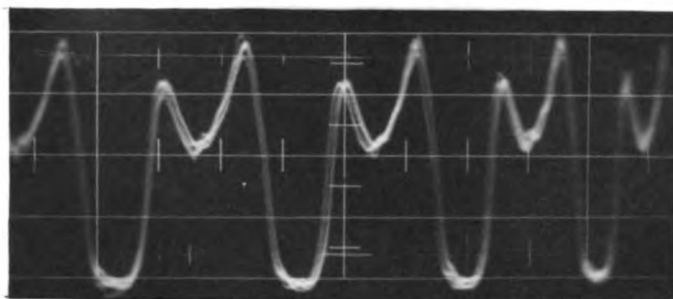
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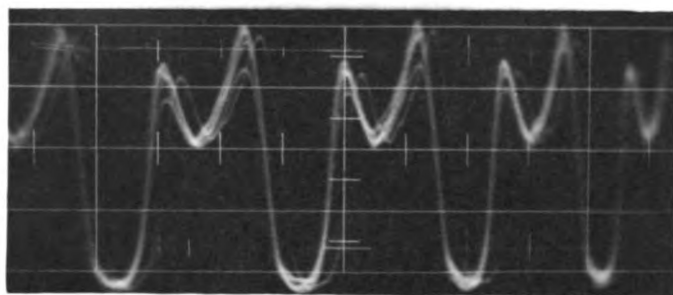
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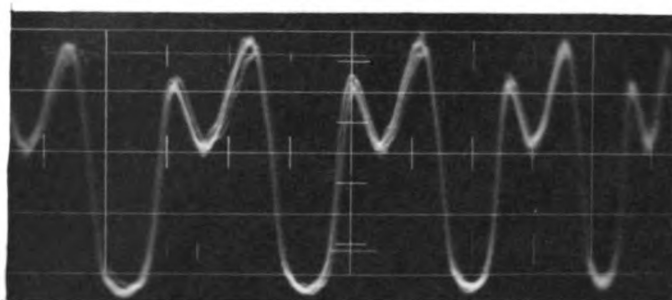
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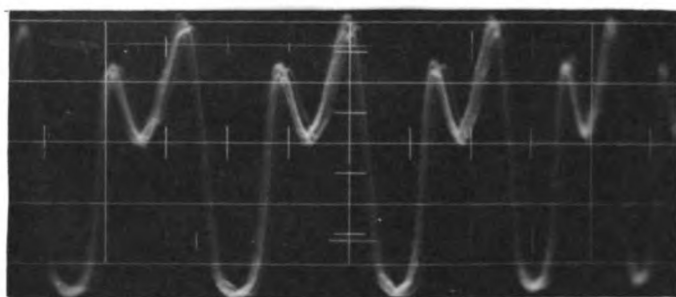
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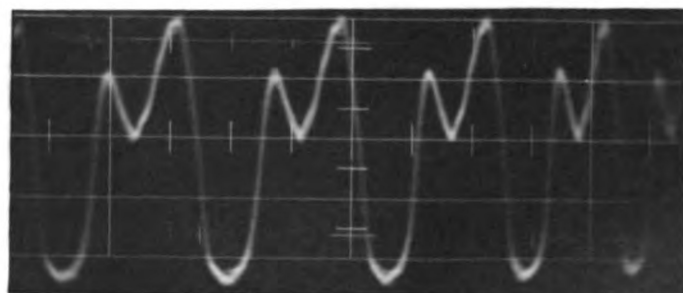
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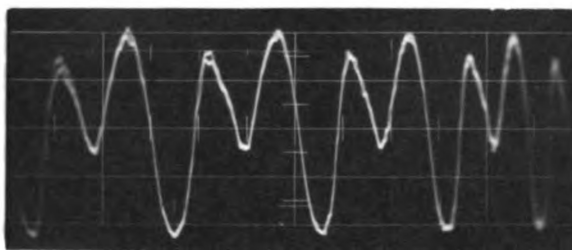
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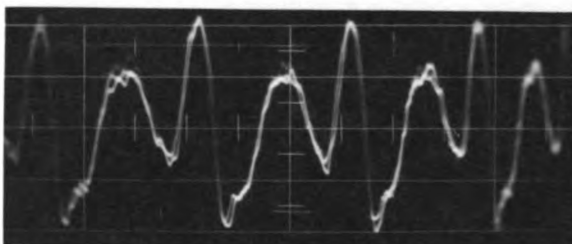
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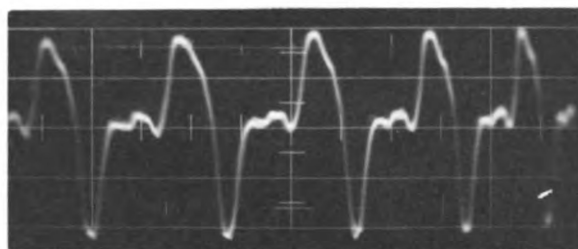
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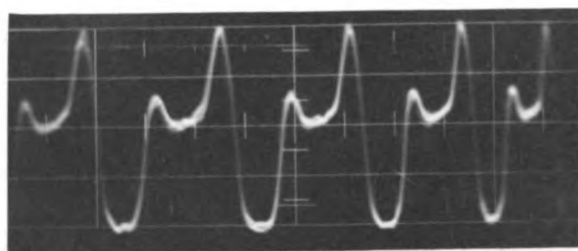
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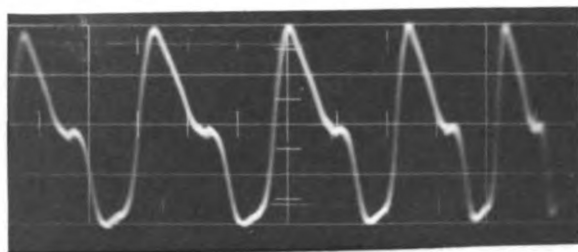
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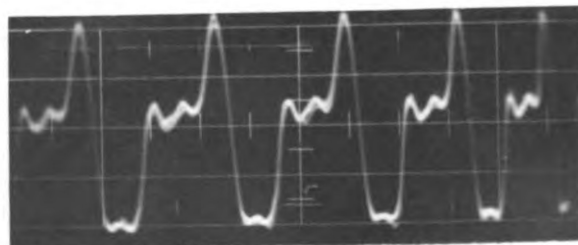
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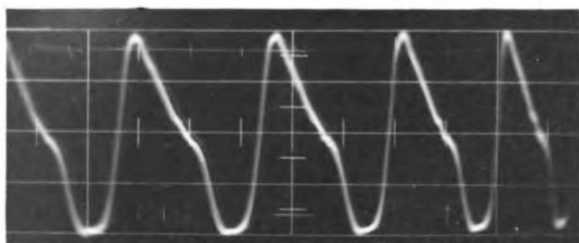
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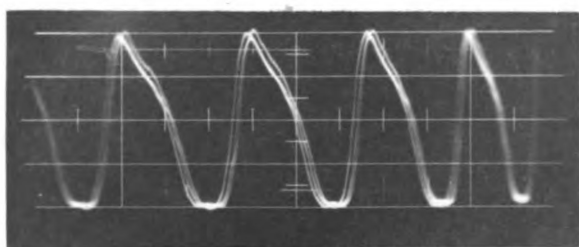
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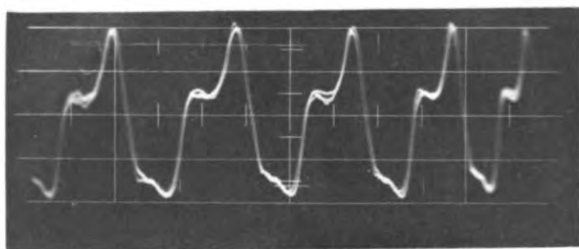
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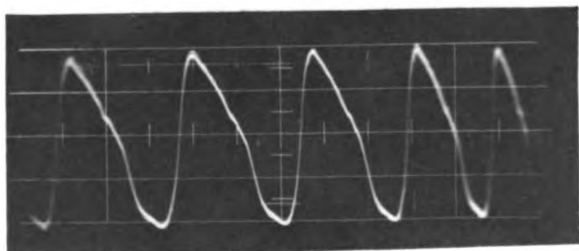
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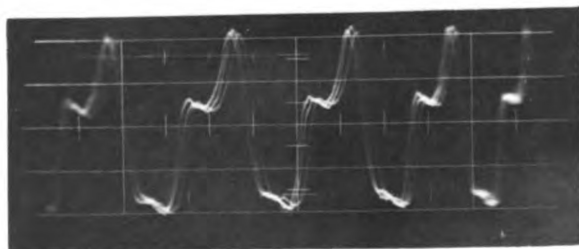
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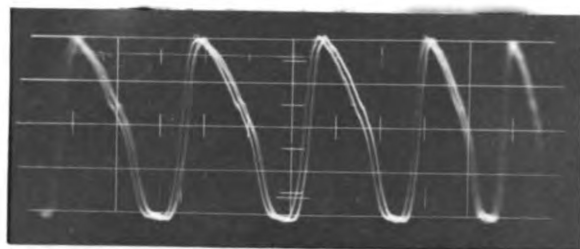
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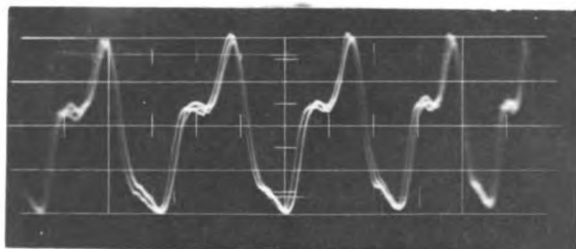
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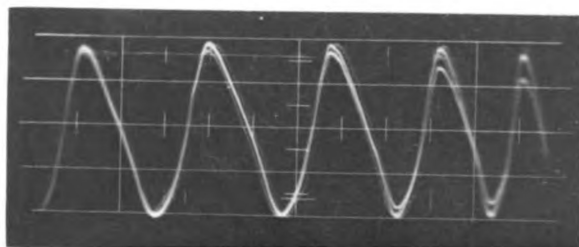
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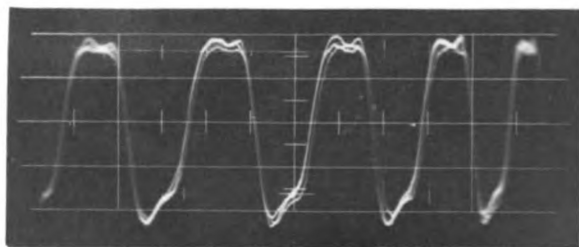
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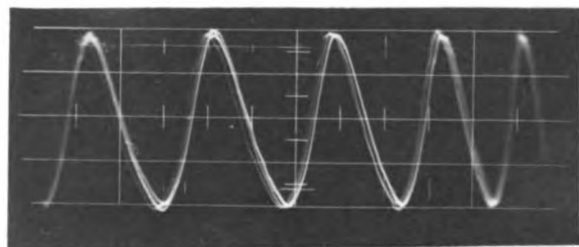
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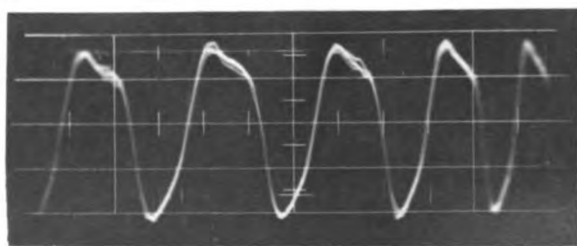
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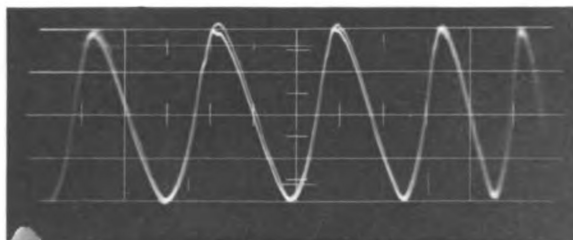
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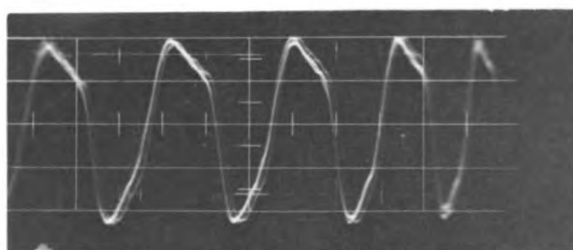
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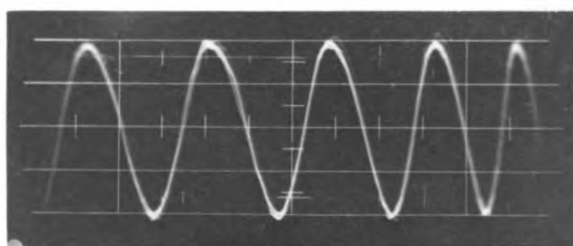
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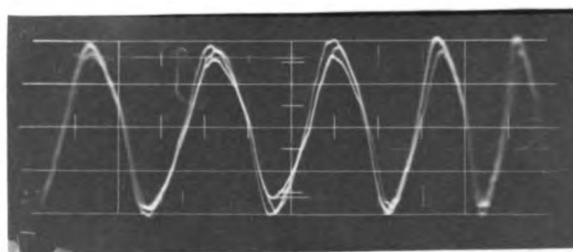
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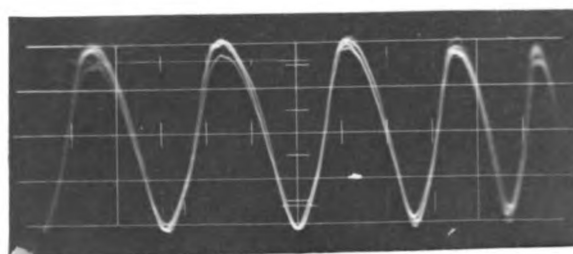
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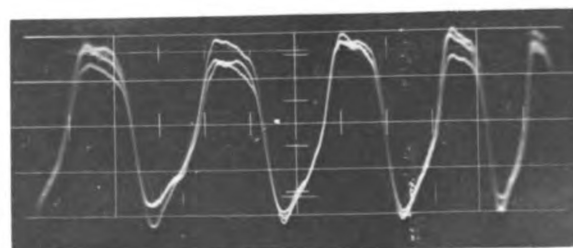
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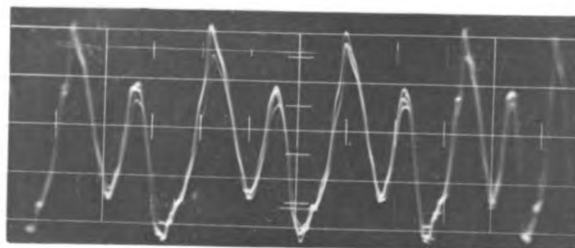
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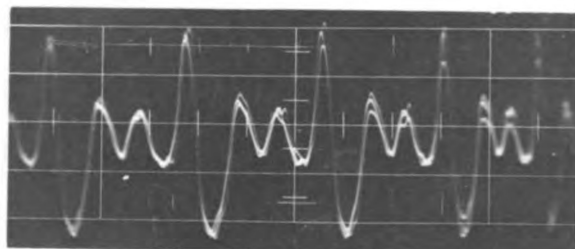
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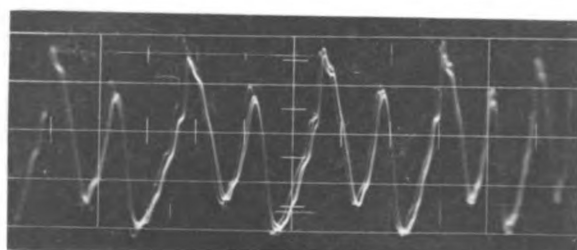
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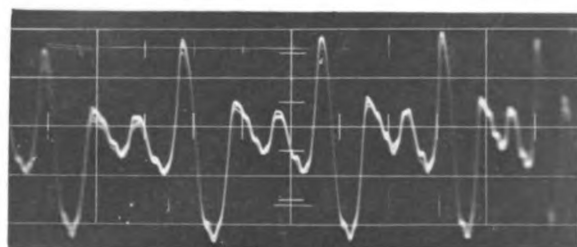
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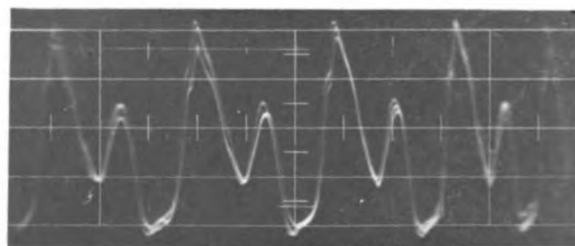
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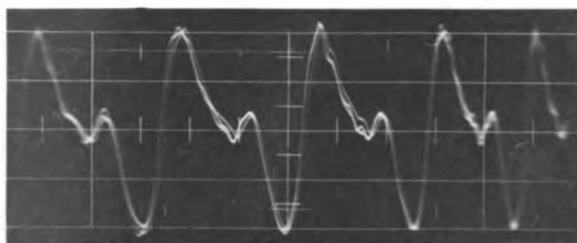
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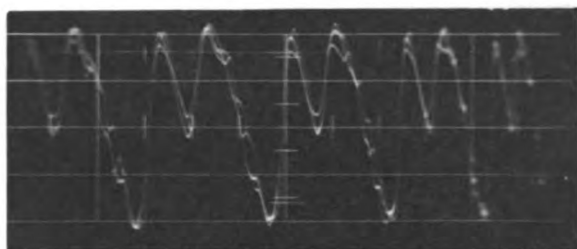
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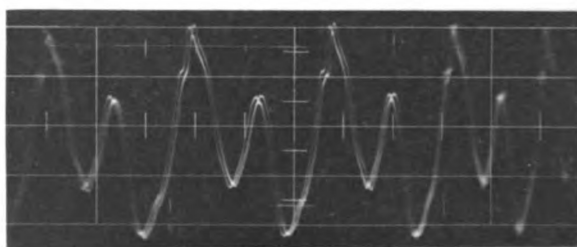
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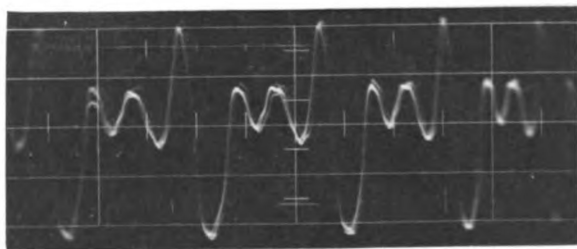
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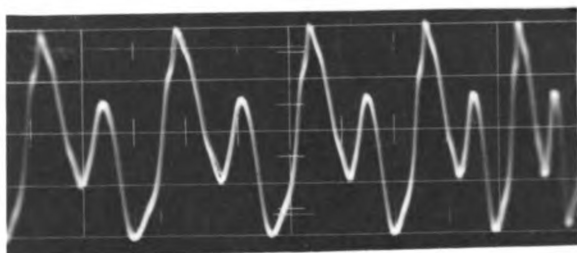
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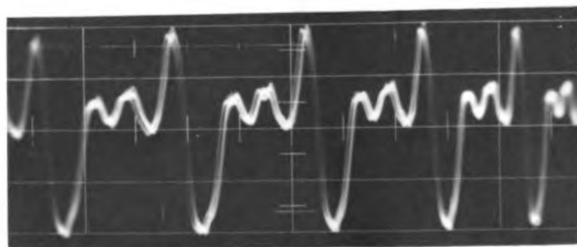
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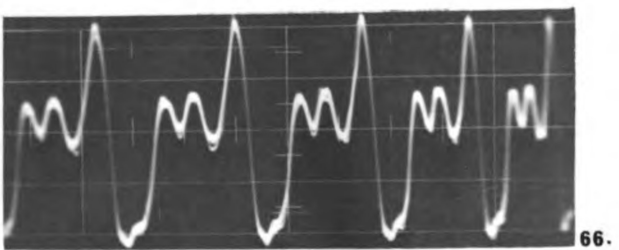
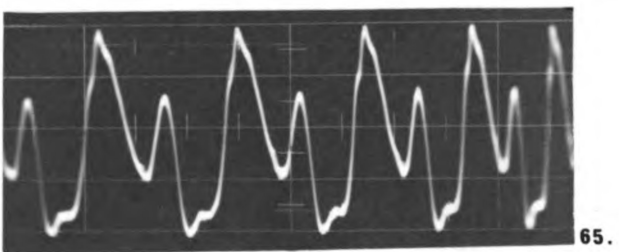
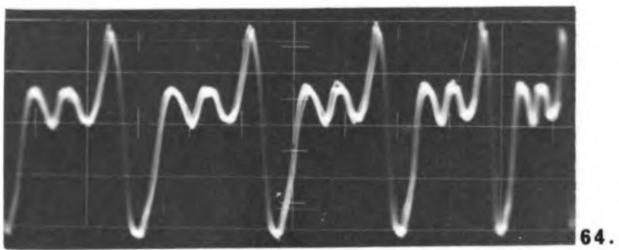
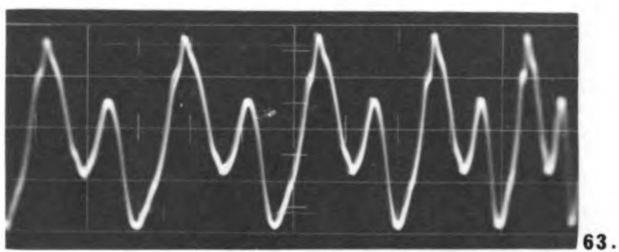
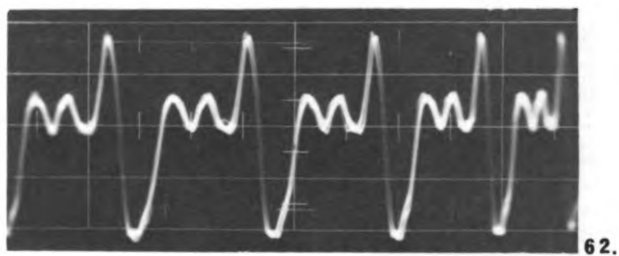
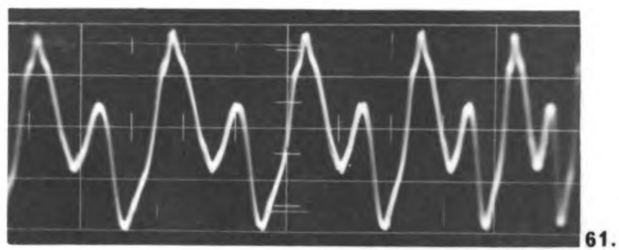
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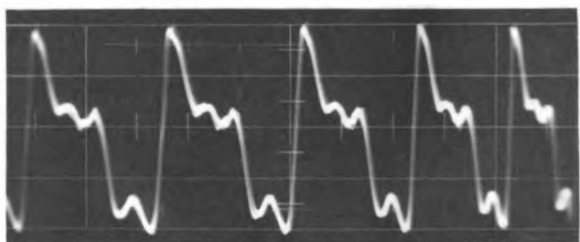


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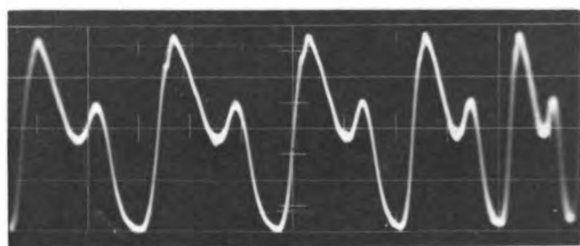




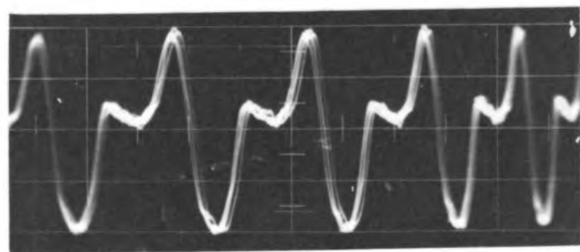
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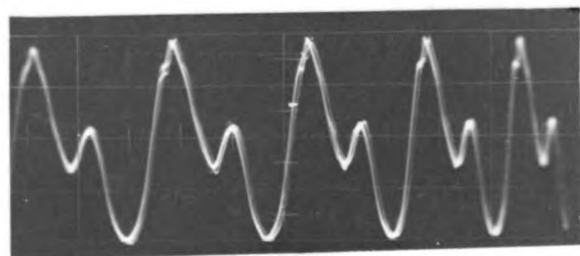
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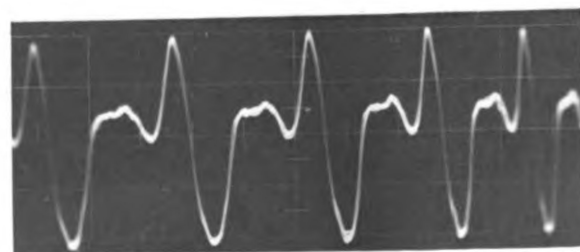
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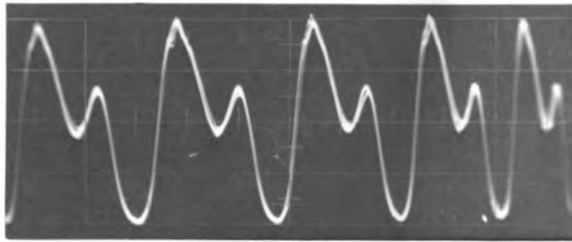
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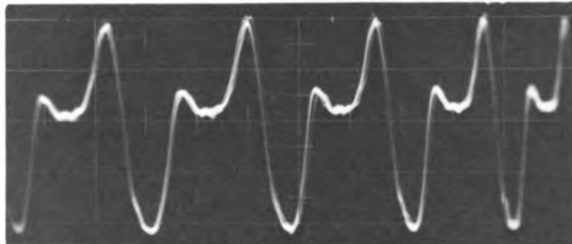
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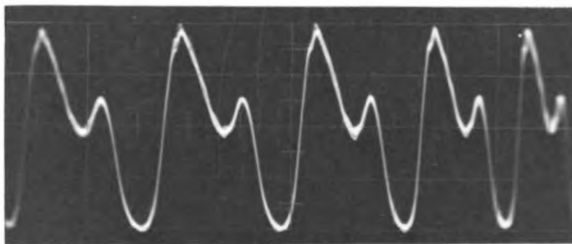
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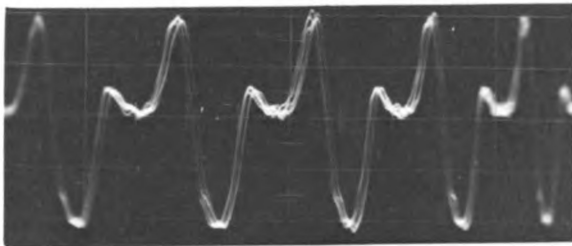
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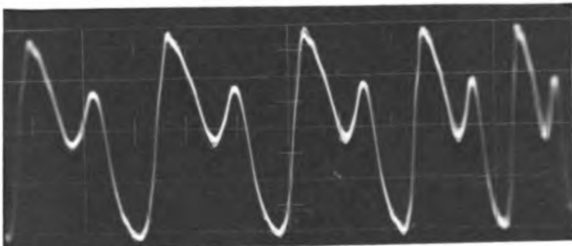
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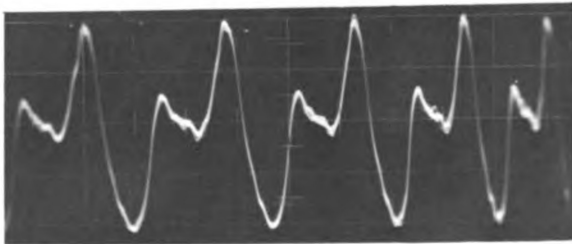
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76.



77.



78.