REDUCING KITCHEN APPLIANCE NOISE

BY

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Submitted to the Department of Electrical Engineering on May 23, 1956 in partial fulfillment of the requirements for the degree of Bachelor of Science.

ABSTRACT

SPL measurements, in octave bands, were made on five appliances in each of two single family dwellings. The appliances measured: dishwasher, clothes washer, clothes drier, garbage disposall, and vacuum cleaner. From the data obtained, the band power level for the appliances was calculated.

The power level of the dishwasher was used to design a quieter model. After three attempts, an enclosure for the dishwasher was designed to meet a speech interference level criterion of 30. The result was a sealed enclosure lined with Ultracoustic and made of 0.1 inch steel plate.

The power level of the other appliances was plotted for use in a future sound problem of kitchen appliances.

Thesis Advisor Dr. Leo L. Beranek

TABLE OF CONTENTS

FIGURES

REDUCING KITCHEN APPLIANCE NOISE

INTRODUCTION

For many years man has been disturbed by noise. He has been harassed with noise from factories, neighbors, and transportation vehicles, including jets which have been the greatest and most recent problem. Also among noise problems is the one which we live with every day--noise in our homes. The literature shows that no study has been made on noise in single-family dwellings although studies in the acoustical properties of apartment houses have been conducted in England and Holland since World War II. However, the results of these studies do not apply to the single-family dwellings predominant in the United States because of the differences in building details and basic differences in single and multiple-type dwellings.

The study of noise in a single-family dwelling which is needed has been divided into four parts. They are:

1. Transmission of sound through typical walls in homes and studies of means for reducing sound transmission through them.

2. Transmission of sound through doors of various types and of means for reducing sound transmission through them.

3. Studies of noise from kitchen appliances and means for reducing the noise in kitchens using commercially available materials without major redesign of the appliances.

4. Studies of noise in plumbing in typical single-family houses and means for reducing the noise by use of commercially available materials.

Each part is the subject of a Senior thesis and each is carried out independently of the rest.

My part has been to study and reduce the noise of kitchen appliances, but I found no simple means of reducing the noise except by redesigning the enclosure of the appliance.

OBTAINING AND EVALUATING DATA

The data for this study was obtained from two single-family dwellings--Professor Beranek's in Winchester and Mr. Pietrasanta's in Newton. Each house has the following appliances: dishwasher, garbage disposall, home laundry, clothes drier, and vacuum cleaner.[1] (I went a little out of the kitchen in some cases.) The data needed was the PWL[2] of the appliance. SPL equals approximately IL[2], therefore the intensity at a certain distance from the source can be found. Since the sound source radiates energy spherically, the sound power can be found by multiplying the sound intensity by the area of the spherical surface, not obstructed by walls, floors, etc. The PWL can be obtained from the power by the formula:

$$PWL = 10 \log \frac{W}{10-13}$$

1. Model numbers and years given in appendix, page 7. Rough sketches of each appliance given in appendix, Figures 14 to 21.

2. Definitions given in appendix.

In order to use the above process, the SPL was measured in the "far field", but not in the reverberant field. That is, the microphone was placed close enough to the appliance so that the effects of the room were not recorded. However, the microphone was not placed close enough to be in the "near field" or where the distance to the microphone is small compared with a wave length. Strictly speaking, of course, the microphone would have to be moved at each different frequency measurement, but approximations were made and the microphone was usually placed 20"-40" from the center of the source.

PROBLEMS IN OBTAINING DATA

One of the problems encountered was the short duration of the noise produced by the garbage disposal. The tape recorder was used to solve this. The sound was simply recorded and later analyzed with an OBA.[1] The calculation of the area that the source radiated into also presented a problem. Even though it was not too critical, (an error of a factor of 2 only caused a 3 decibel error in the PWL) I felt that it should be as accurate as possible. After trying integration formulas, formulas for spherical triangles, etc., I finally solved this problem by buying a 5" ball for 79 cents. Using ruler and compass, I laid out the areas on the ball and actually measured them.

1. Octave Band Analyzer --(See appendix--Equipment Used).

The background noise level which sometimes presents a problem, was at least 10 decibels below the measured noise level of the appliances. This would cause an error of only .5 decibel. (If the meter was read this close, we were doing well.) The directivity effects of the appliance were slight according to measurements. That is, the SPL was about the same for all orientations of the microphone provided the distance from the microphone to the center of the source was kept constant. Therefore, these small effects were ignored and the microphone was kept in one position for all the measurements of an appliance.

<u>EXAMINATION OF SOUND POWER LEVELS</u>[1]

For the most part, the PWL lies between 70-90 decibels re 10^{-13} in most of the appliances. Also, most of the levels went down at the high frequencies.

<u>Clothes Drier</u>: The two driers have about the same sound characteristics. The Westinghouse has lower overall PWL, but it decreases more slowly with frequency than that of the Norge drier. At the high frequency bands the Norge drier has a lower PWL than the Westinghouse. I don't feel there is any particular explanation for this

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1. The graphs of PWL versus frequency are given in Figures 1-10.

2. See Figures 1 and 2.

except I noted that the Norge drier had a great deal of vibration at the low frequencies which might account for its high PWL in these bands. Other than this, the only difference is that of the type of components and constructions used in each case. However, none of these could be singled out and defined as the cause for the increased noise in certain bands without much more analysis of the appliances than I had time for.

Clothes Washers: The two clothes washers, the Norge and the Bendix,[1] differ mostly in the high frequencies; the older model Bendix lies about 7 decibels above the newer Norge. The noise of the running water (Filling operations) lies mostly in the high frequency bands but was overshadowed by mechanical vibrations at low frequency. The PWL's of the other bands seem to lie fairly close together with occasional peaks such as the 1200-2400 cycles per second band of the Norge washer's rinse cycle, and the 150-300 cycles per second band of the Bendix washer's spin dry cycle. The Norge clothes washer has a greater difference of PWL between the high and low frequencies than the older model Bendix. The high power level in the low frequencies of the Norge washer was again, like the Norge drier, due to the great vibration.

Vacuum Cleaners: The vacuum cleaners,[2] both of the same type, had a peak of PWL in the 300-600 band. This

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1. See Figures 3 and 4.

2. See Figures 5 and 6.

peak is about 11 decibels higher in the older Lewyt vacuum cleaner. The General Electric cleaner has a more gradual change in PWL with each frequency band while the Lewyt increases by 22 decibels from the 75-150 band to the 150-300 band and decreases by 17 decibels from the 600-1200 band to the 1200-2400 band.

Garbage Disposalls: The disposall units[1] had power levels which disappointed me. That is, they were lower than I expected corresponding them with the PWL of the other appliances. I felt that the garbage disposall was "the noisiest thing in the kitchen." However, according to the graphs, the PWL is less than that produced by a clothes washer. The high frequency noise in the disposall units is due to the water splashing in the sink. In the disposall at Mr. Pietrasanta's house, the 1200-2400 band had a peculiar perodic sound which varied by about 10 decibels as shown on the graph. I don't know exactly how to explain it except possibly it was a resonance of the disposall. Also, there was a sharp dip in the 75-150 band of 10 decibels which I can't explain. It might be noted that the overall PWL for both is about the same, although the Hotpoint is ten years newer than the General Electric Disposall.

Automatic Dishwashers: Lastly, let us consider the dishwasher.[2] The newer Hotpoint has a PWL which

1. See Figures 7 and 8.

2. See Figures 9 and 10.

drops off about 7-10 decibels per octave. After the 1200-2400 cycles per second band. The General Electric dishwasher stays nearly constant at 80 decibels after the 150-300 cycles per second band. The peak in the PWL for the Hotpoint in the 150-300 band is due to the rattling of the dishwasher door.

DESIGN OF QUIET DISHWASHER

In noise control problems, three things must be considered. They are:

1. Source--power
2. Transmission environment -- loss
3. Receiver--criterion

In the kitchen appliance problem the source is a dishwasher. The size of the kitchen and its absorbing qualities will determine the loss due to environment. The receiver is a human being who wants to communicate abstract noise interferences.

Source: The dishwasher power levels have all been plotted in figures 9 and 10.

Kitchen Absorption: The average modern kitchen may be assumed to be about 12 feet by 15 feet by 8 feet. It has a linoleum or tile floor and a plaster ceiling and the walls are covered with about 60% wood panelling and 40% plaster. Using the values of absorption coefficients from Beranek's ACOUSTICS (Page 300) I tabulated the values of (See Table I) by band. Since the lowest and highest frequency were missing, I kept the same values that were listed for the adjoining frequency.

TABLE I

Freq. cps	Corres. Band	α_{pc}	α_{pw}	α_{lf}	α_{wp}
	20-75	0.04	0.02	0.04	0.3
125	75-150	0.04	0.02	0.04	0.3
250	150-300	0.05	0.02	0.03	0.25
500	300-600	0.06	0.02	0.04	0.2
1000	600-1200	0.08	0.03	0.04	0.17
2000	1200-2400	0.04	0.04	0.03	0.15
4000	2400-4800	0.06	0.04	0.02	0.1
	4800-10,000	0.06	0.04	0.02	0.1

KEY: Plaster Ceiling--pc
Plaster Wall--pw
Linoleum Floor--lf
Wood Panelling--wp

TABLE II

Freq. cps	Corres. Band	$\bar{\alpha}_K$	R_K ft.^{2}	HP TL	GE TL
	20-75	0.12	108	12	15
125	75-150	0.12	108	12	17
250	150-300	0.10	88	20	19
500	300-600	0.092	80	28	30
1000	600-1200	0.089	77	32	35
2000	1200-2400	0.074	63	38	39
4000	2400-4800	0.060	51	29	40
	4800-10,000	0.060	51	24	40

KEY: Hotpoint--HP
General Electric--GE

Receiver Criterion: Since man's tastes and ideals change from time to time, it would be senseless to use a criterion based on an "ideal" sound level. Also, this sound level would be impossible to obtain since everybody's opinion differs as to the definition of an "ideal" sound level.

So I decided to use the maximum sound level which would not interfere with normal speech. Using the table and curves on Page 427 and 428 of Beranek's ACOUSTICS, I determined the curve of this sound level vs frequency. The result is shown in Figure 11.

FIRST ATTEMPT AT DESIGN

First I used the formula for sound pressure level in a room with a source of given power level.

$$SPL_k = PWL_d - 10 \log_{10} \left(\frac{R_k}{4}\right)$$

I reasoned that if the PWL of the dishwasher was decreased by SPL_k less SPL_c then:

$$SPL_k = SPL_c$$

Therefore since

$$TL = PWL_1 - PWL_2 \text{ [1]}$$

the transmission loss necessary for the walls of the dishwasher would be the difference of the SPL_k and SPL_c. This TL was plotted in Figure 12. Using mass law and critical frequency techniques[1] the weight of the required material was too high to be considered a solution.

SECOND ATTEMPT AT DESIGN

Looking at the problem a little differently, I treated the appliance like a small room and covered the inside of its "walls" with Ultracoustic, a high sound absorbing material. A three-inch thickness of Ultracoustic has the absorption coefficients given in Table III.

1. See definitions in Appendix.

TABLE III

Freq. cps	Corres. Band	α_d	R_d ft.[2]	HP TL	GE TL
	20-75	0.2	6.6	10	13
125	75-150	0.43	19.9	15	20
250	150-300	0.91	267	16	10
500	300-600	0.99	2620	18	10
1000	600-1200	0.98	1310	15	18
2000	1200-2400	0.95	502	25	26
4000	2400-4800	0.93	351	17	28
	4800-10,000	0.93	351	12	28

KEY: Hotpoint--HP
General Electric--GE

As in the case of the kitchen, the room constant R_d is calculated from α_d and S_d. Now, using the formula[1]

$$TL = PWL_d + 10 \log_{10} (S_w/R_d) - SPL_c + 10 \log_{10}\left(\frac{1}{S_w} + \frac{4}{R_2}\right)$$

TL is calculated and then tabulated in Table III for each of the dishwashers. TL is also plotted vs. octave bands in Figure 13. A line is drawn on this figure which has a slope of 5 db/octave and touches the required TL curve at the 75-150 band. This means that 20 db TL is needed at 105 cps (mean frequency of band). Using the graph in Reference 2[2], Figure 2.4, a value of wf is found[3] which equals 2500. At 105 cps, this corresponds to a 8.24 lb./ft.^{2} material. If aluminum is used, its thickness must be .59 inches. However, the critical frequency will lower the TL curve obtained by mass law. This critical frequency was

1. See Appendix

2. See Bibliography

3. See Definitions in Appendix.

calculated to be 850 cps. The mass law curve with the "dip" due to critical frequency is shown in Figure 13. The dip in the curve just misses the required TL. Therefore 0.59 inch-thick aluminum would work, but it does not seem too practical because of its large thickness.

THIRD ATTEMPT AT DESIGN

Using the required values of TL calculated for the second attempt, I decided to sacrifice a little TL at low frequencies. I drew the line for mass law shown on Figure 13 which is 5 db below the previous attempt. This TL is still good enough for the newer dishwasher and so, a design around this TL should be adequate since we can assume that manufacturers are using quieter components in the new models. This new line corresponds to a material of 4.12 lb./ft.^{2}. Using steel instead of aluminum, the thickness would be about 0.1 inch. The critical frequency is 4850 cps for steel of this thickness. However, since the steel is 0.1 inch, a damping material such as "automotive felt" equal in thickness to the steel can be attached to the steel and rid the TL curve of its dip at critical frequency.

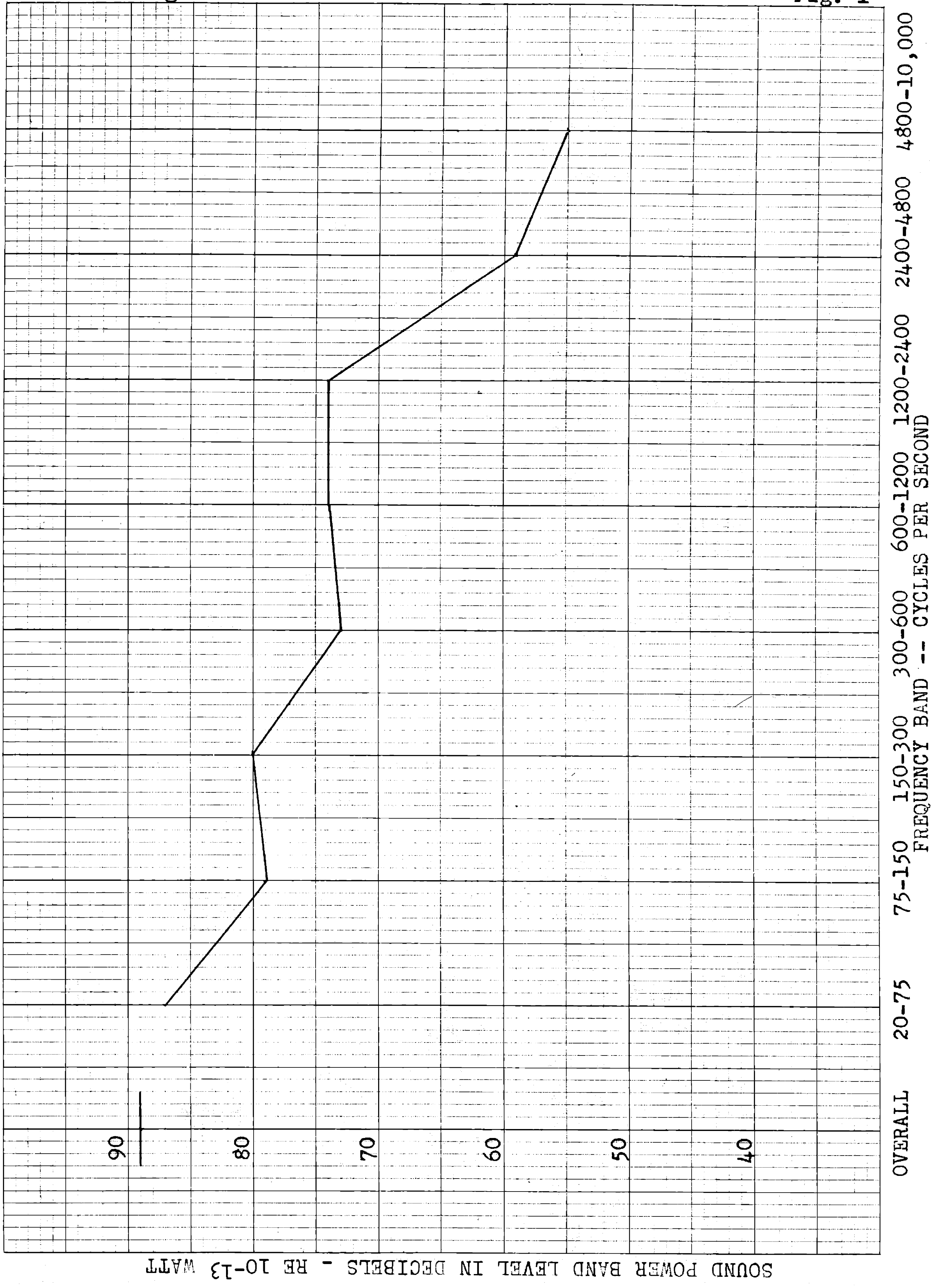
ANOTHER PROBLEM IN DESIGN

Since the unit would be completely sealed, using the above method, I felt that ventilation for the motor was necessary. However, upon looking at the present day dish washers I decided that (1) since the motor is not called upon to do a great deal of work and (2) since the entire cycle is not too long that no special ventilation is required.

If it is required, the motor could be ventilated separately for it does not add much to the noise level of the appliance.

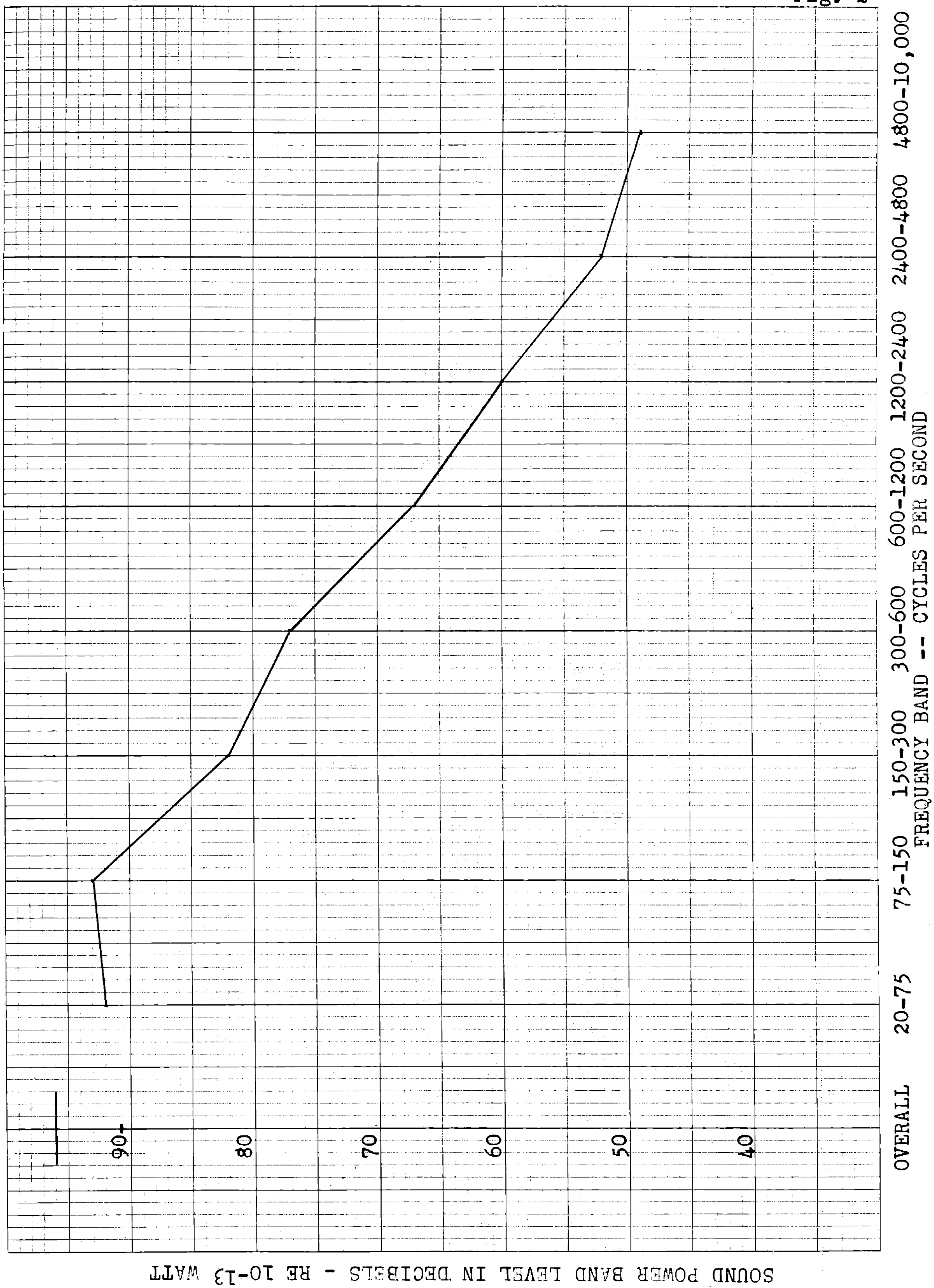
Westinghouse Clothes Drier

Fig. 1



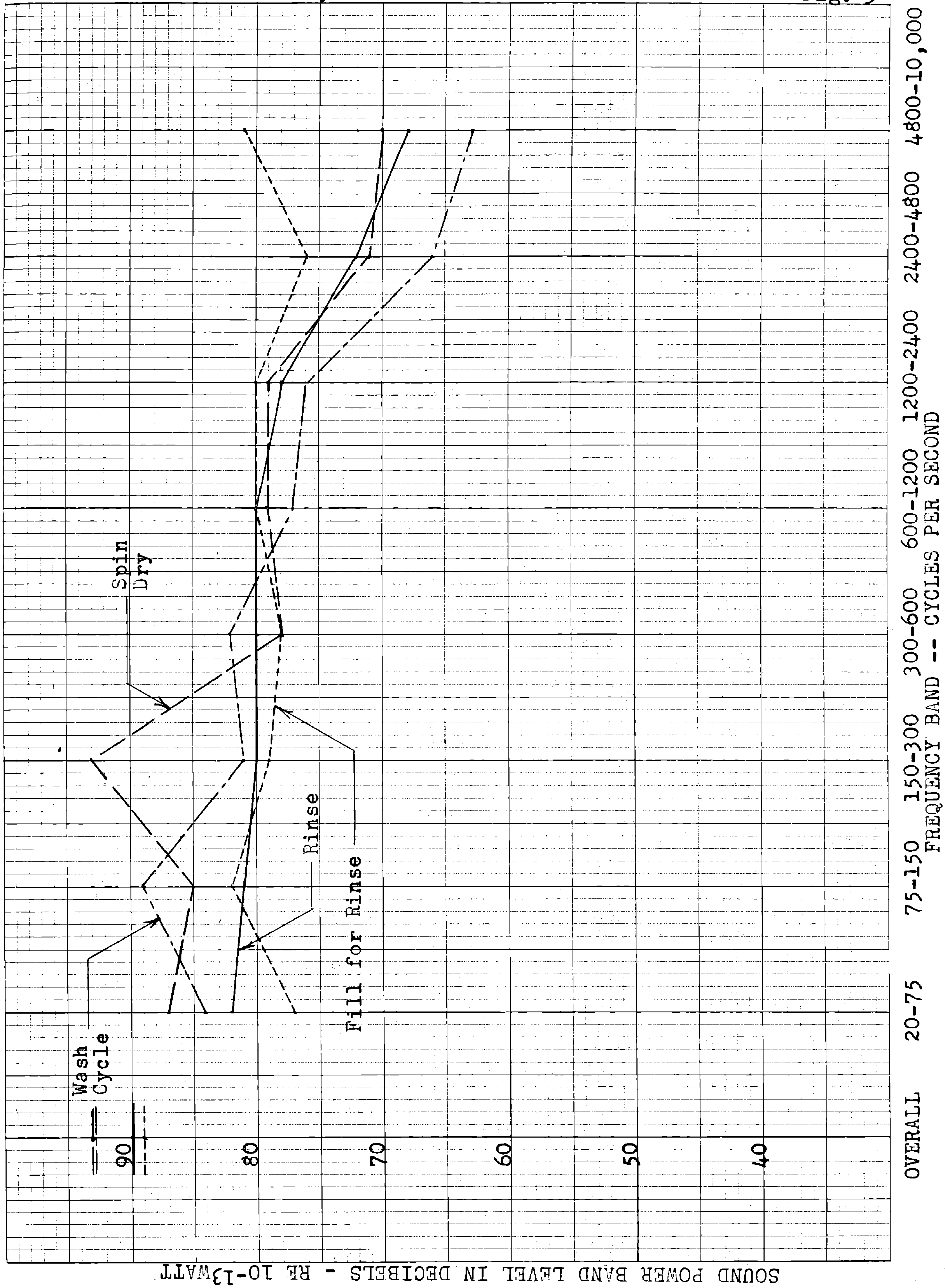
Norge Drier

Fig. 2



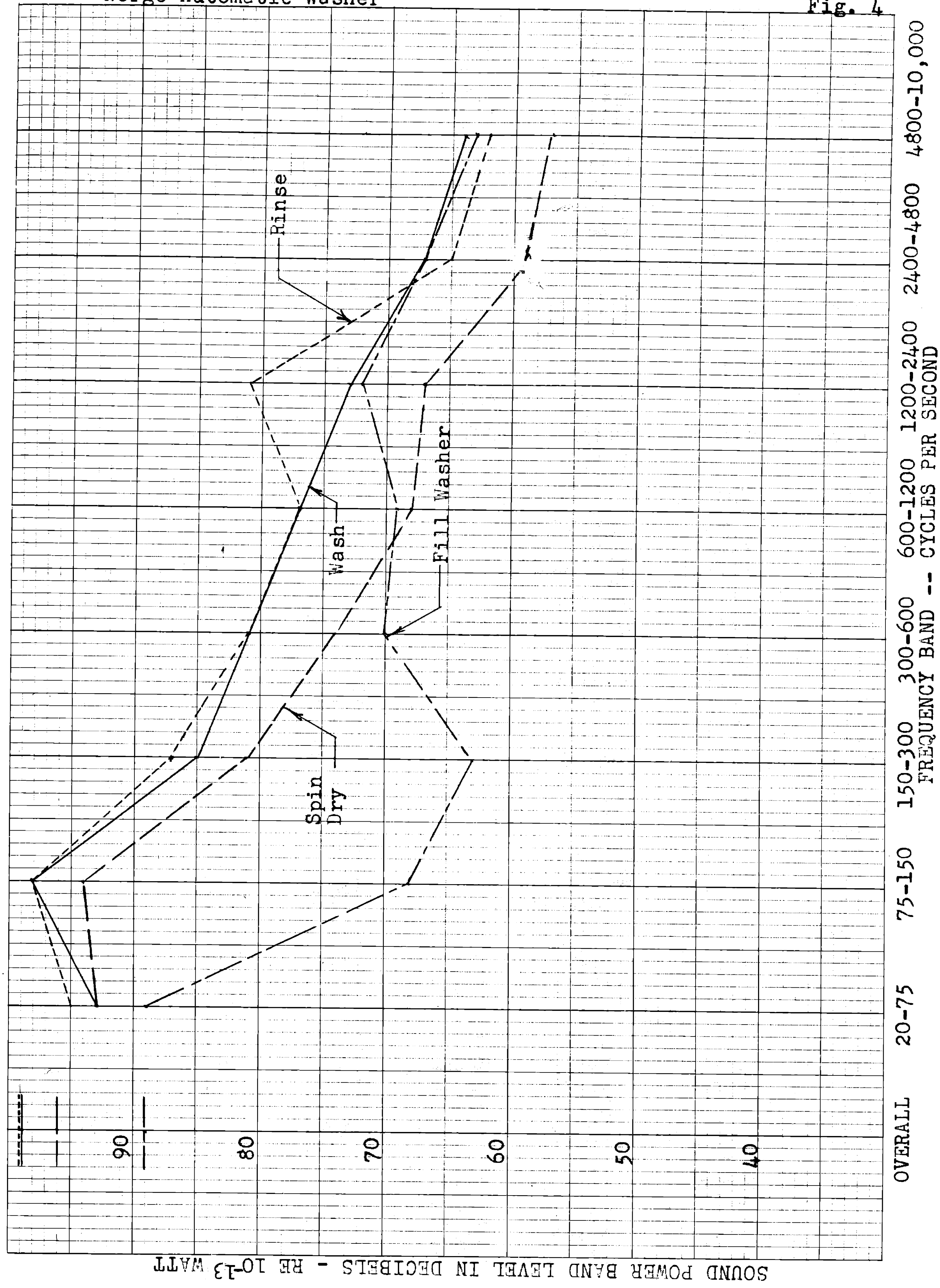
Bendix Home Laundry

Fig. 3



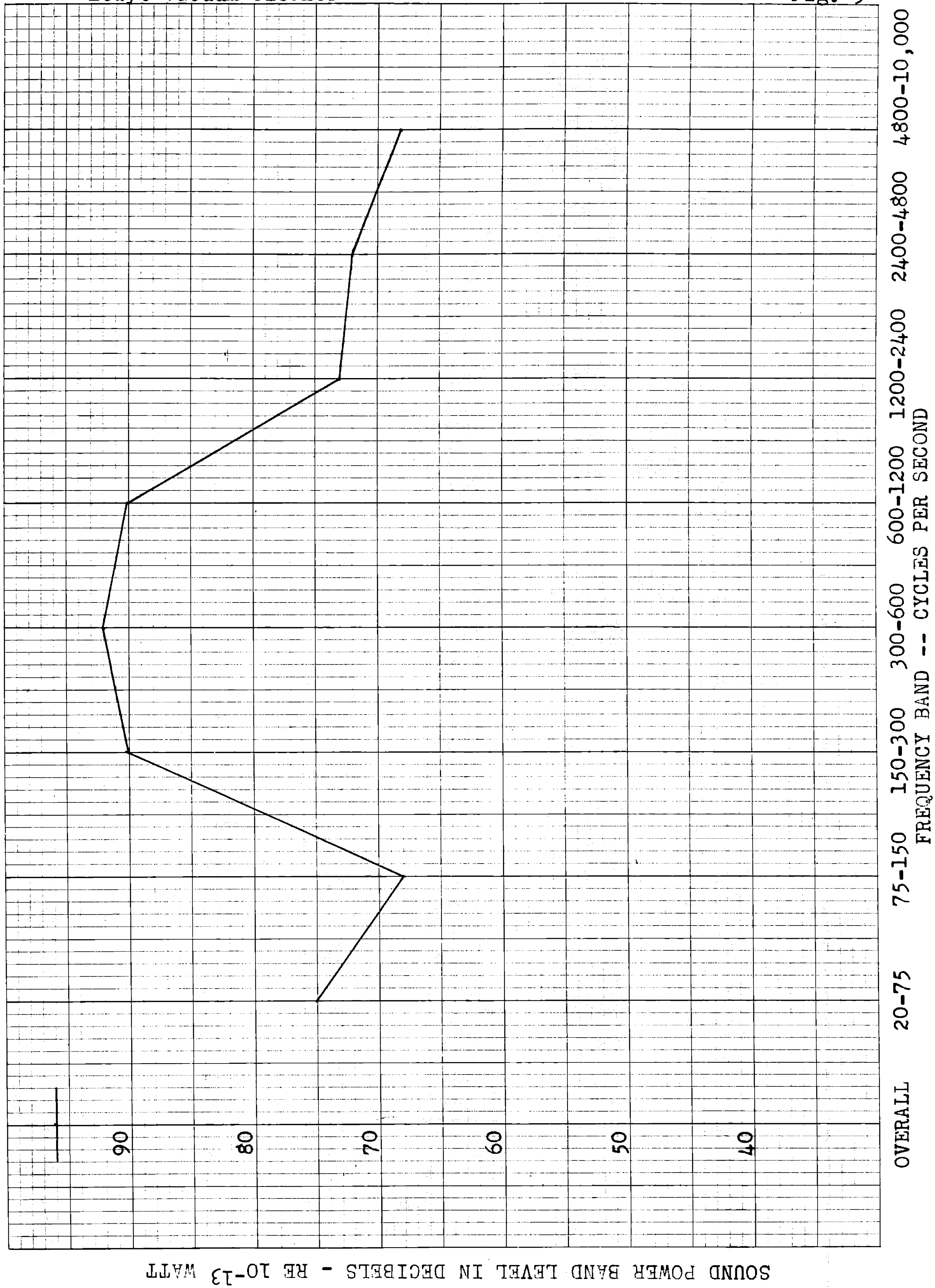
Norge Automatic Washer

Fig. 4



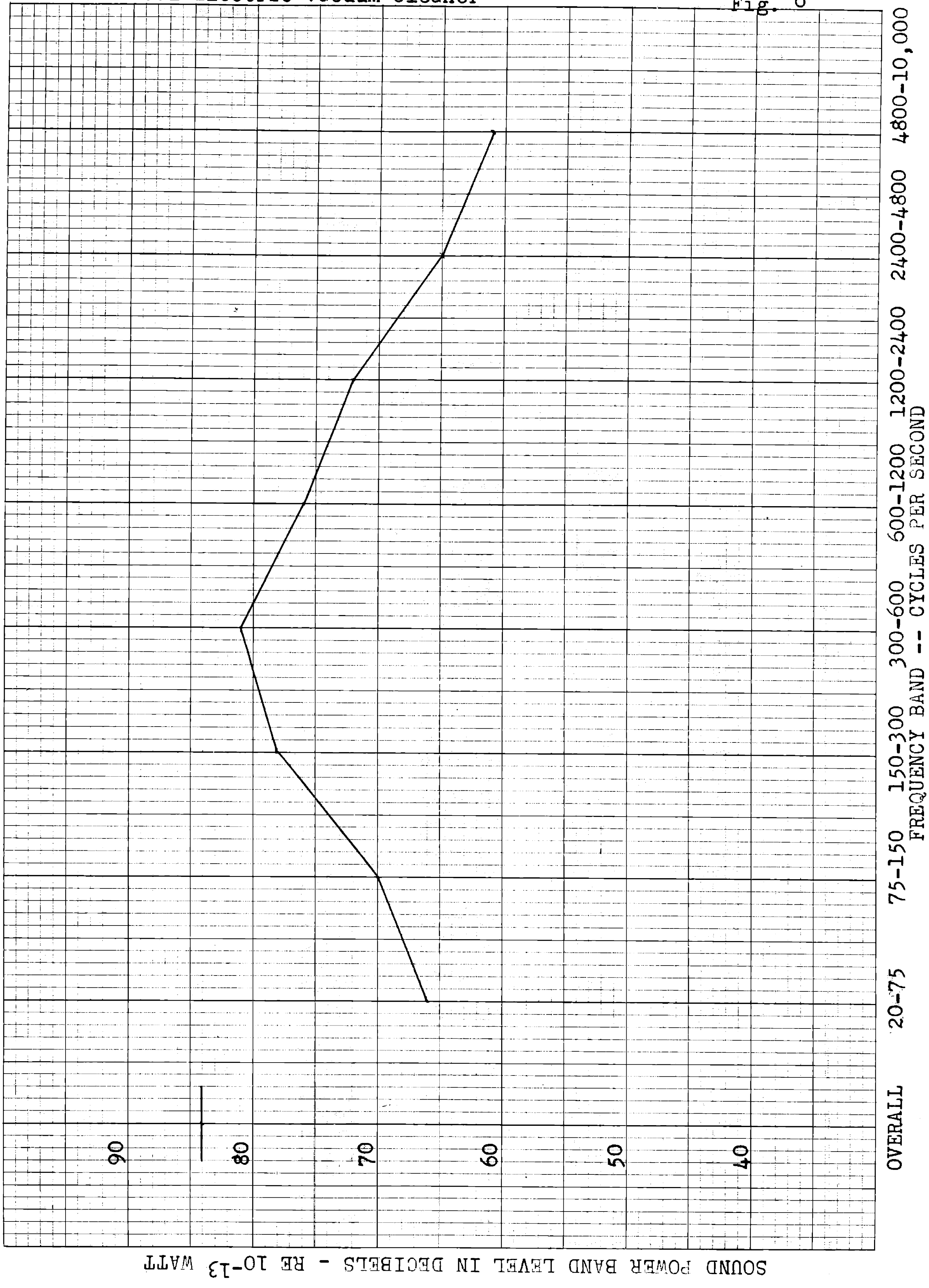
Lewyt Vacuum Cleaner

Fig. 5



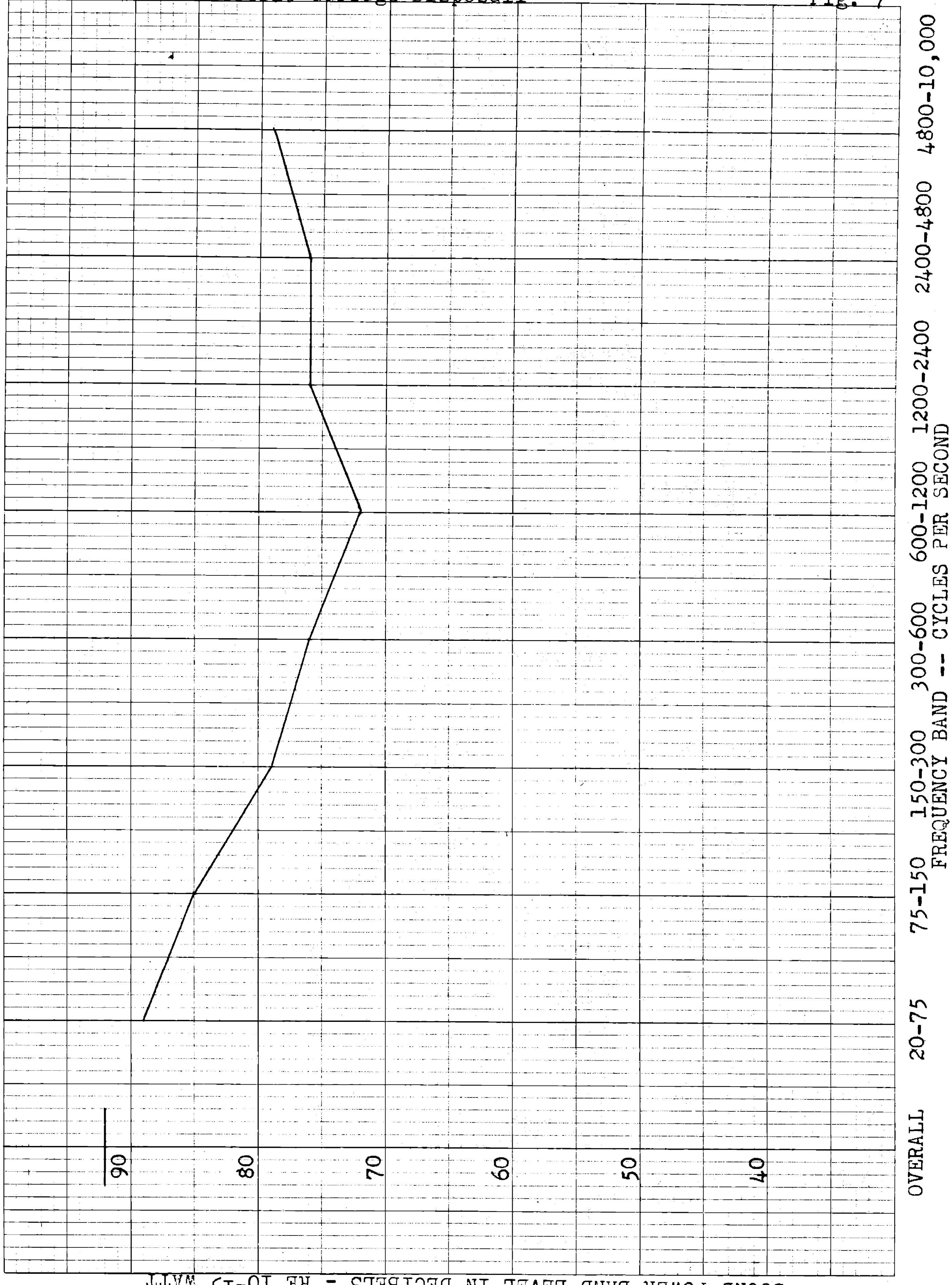
General Electric Vacuum Cleaner

Fig. 6



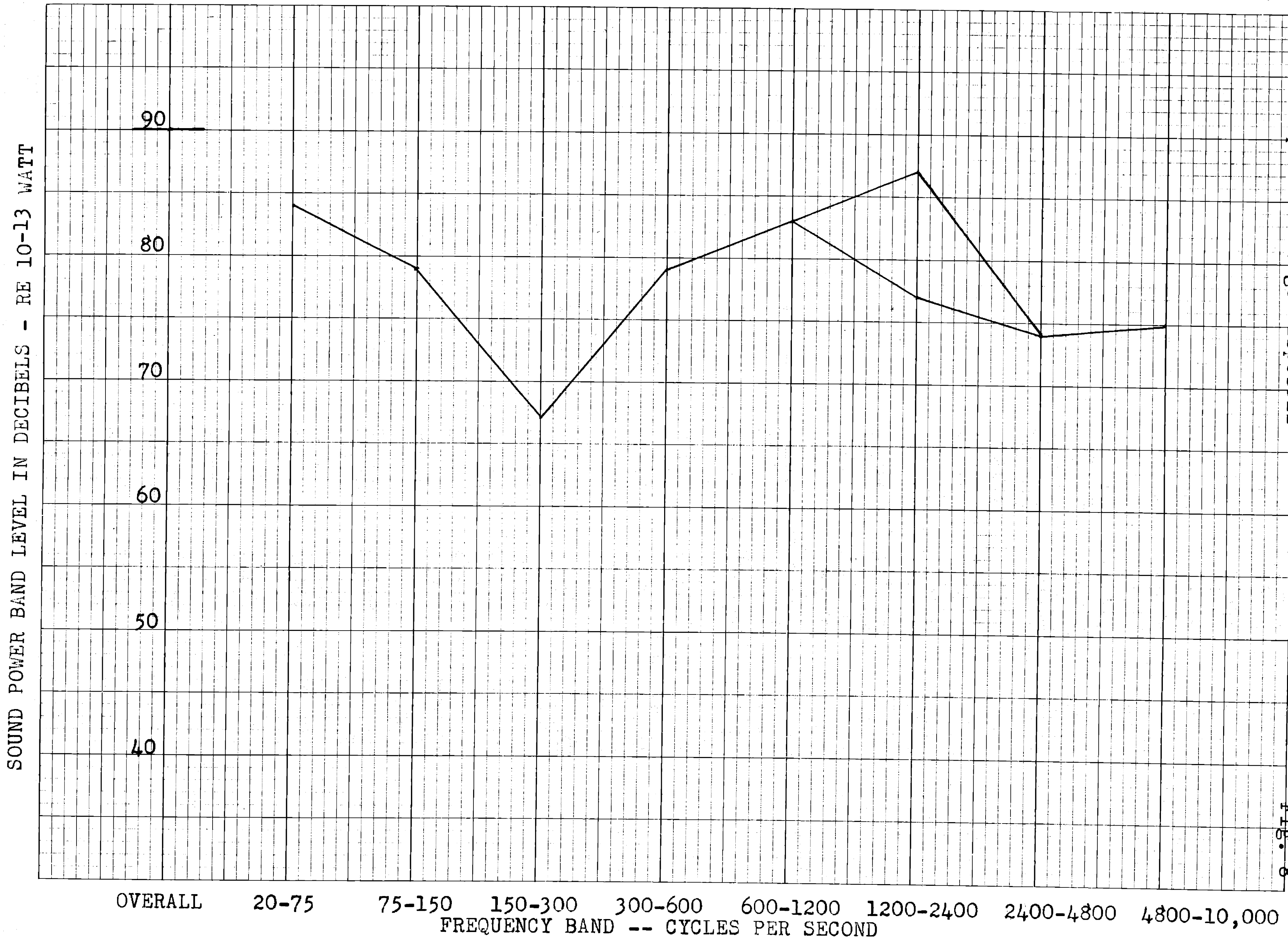
General Electric Garbage Disposall

Fig. 7



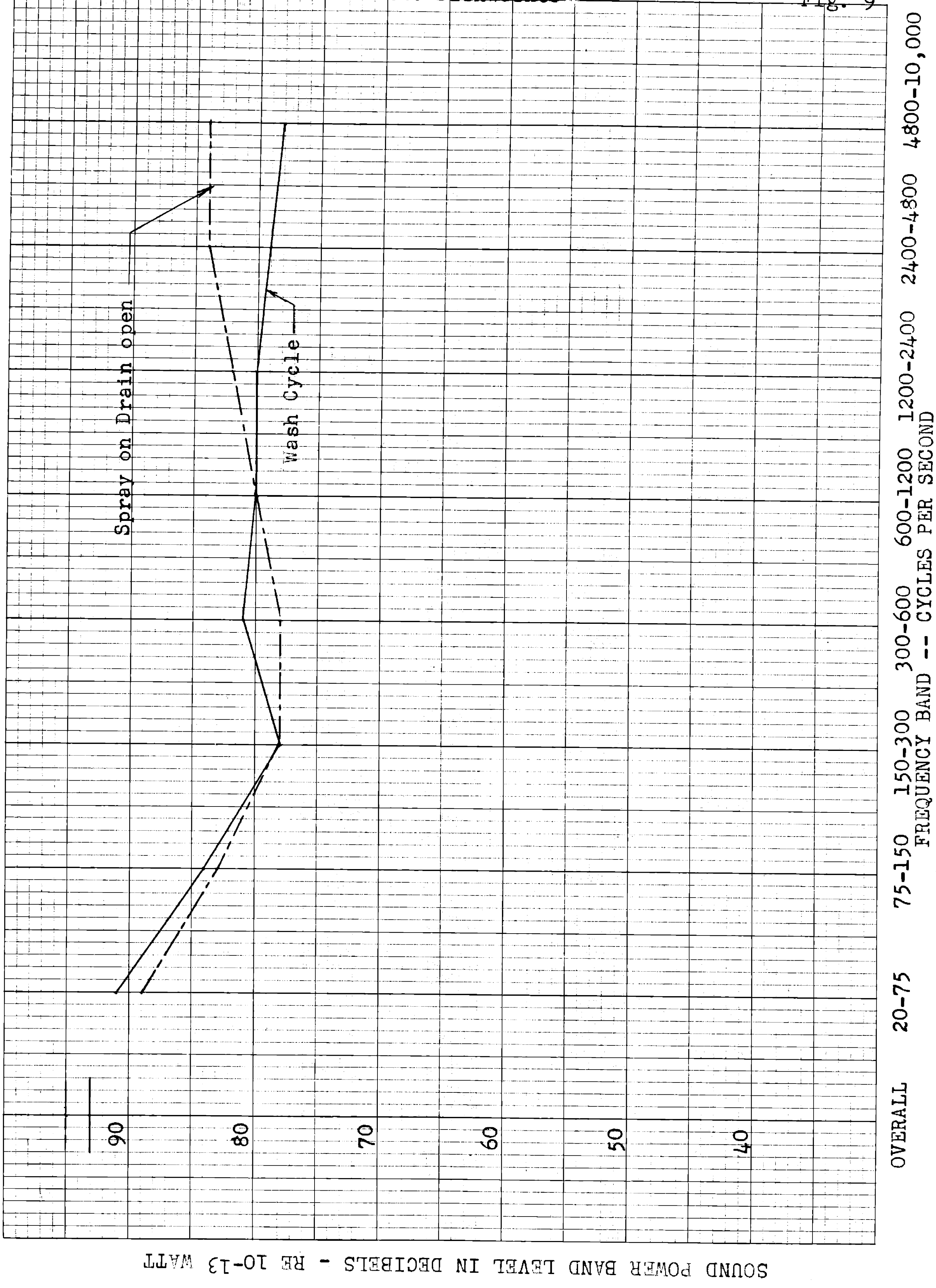
Hotpoint Garbage Disposall

Fig. 8



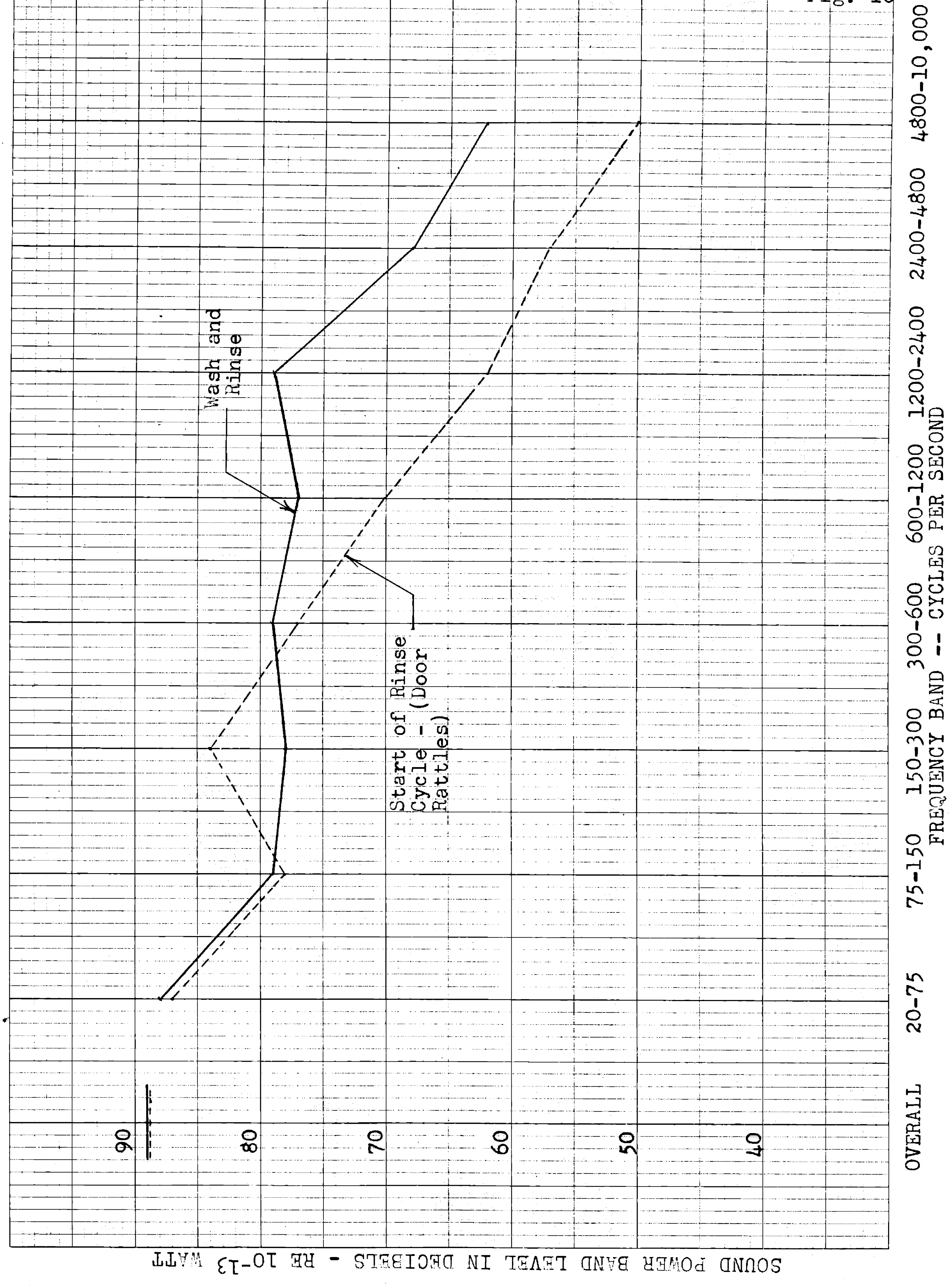
General Electric Automatic Dishwasher

Fig. 9



Hotpoint Automatic Dishwasher

Fig. 10



Speech Communication criteria SC-30

Fig. 11

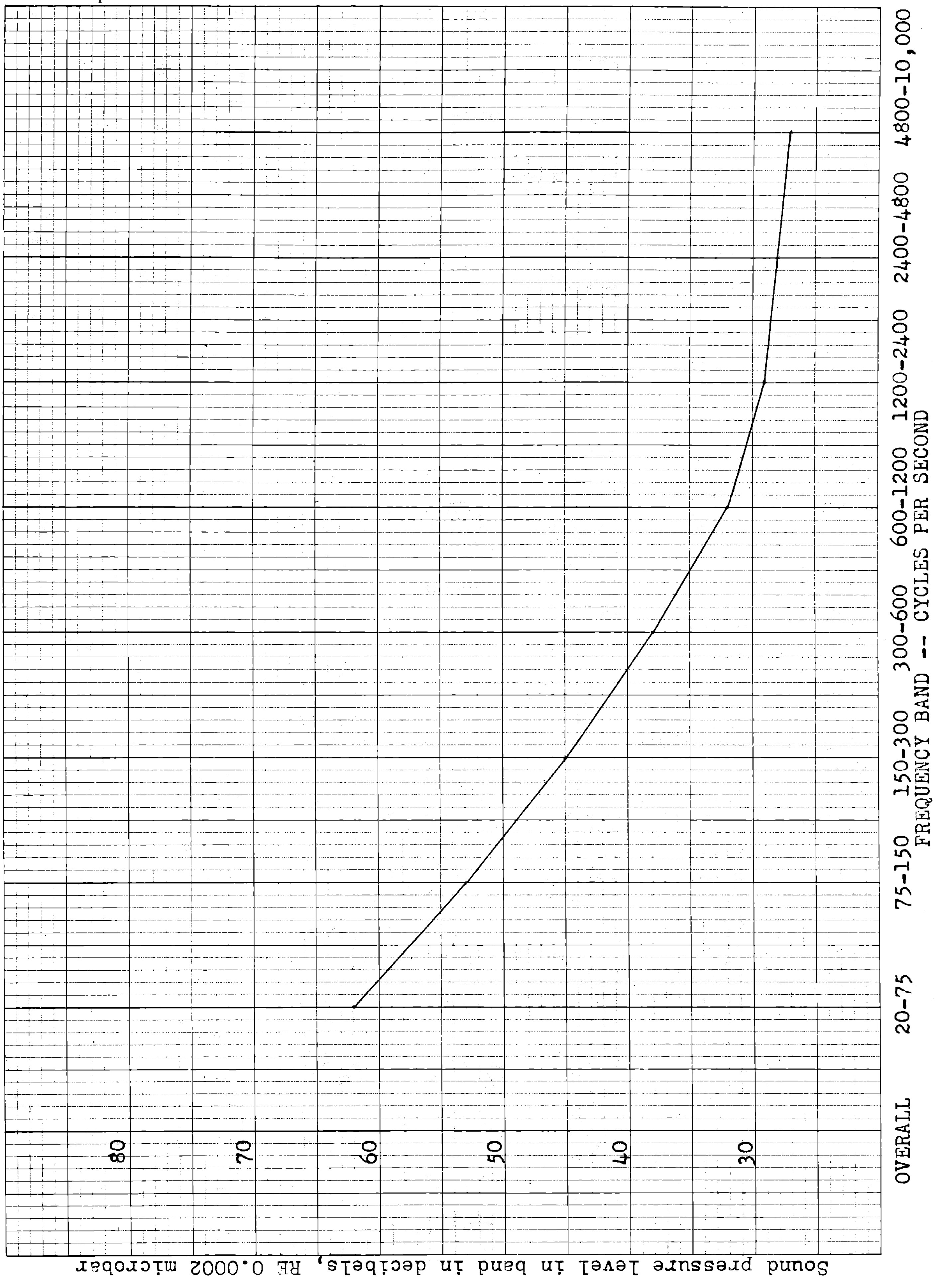
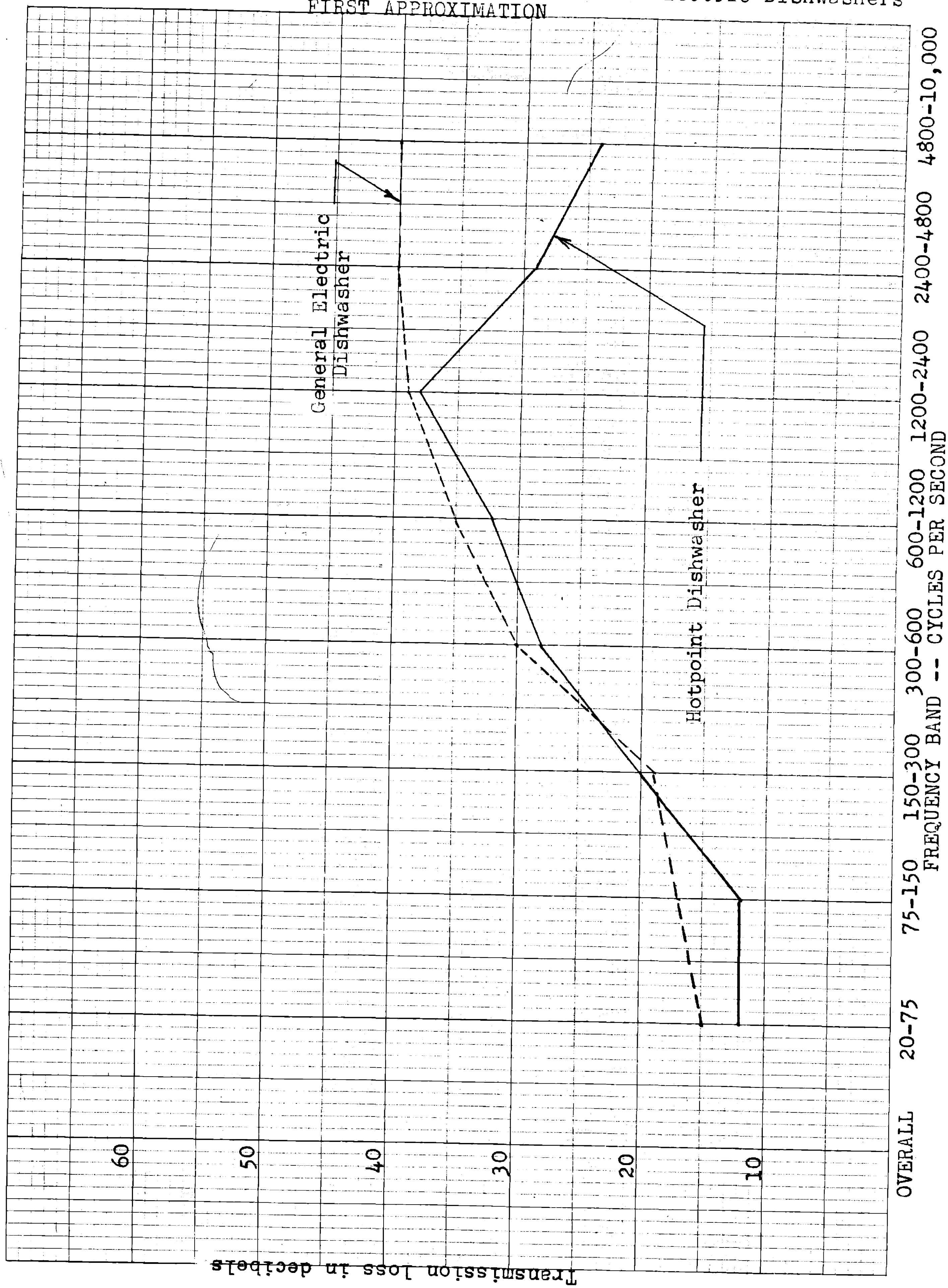


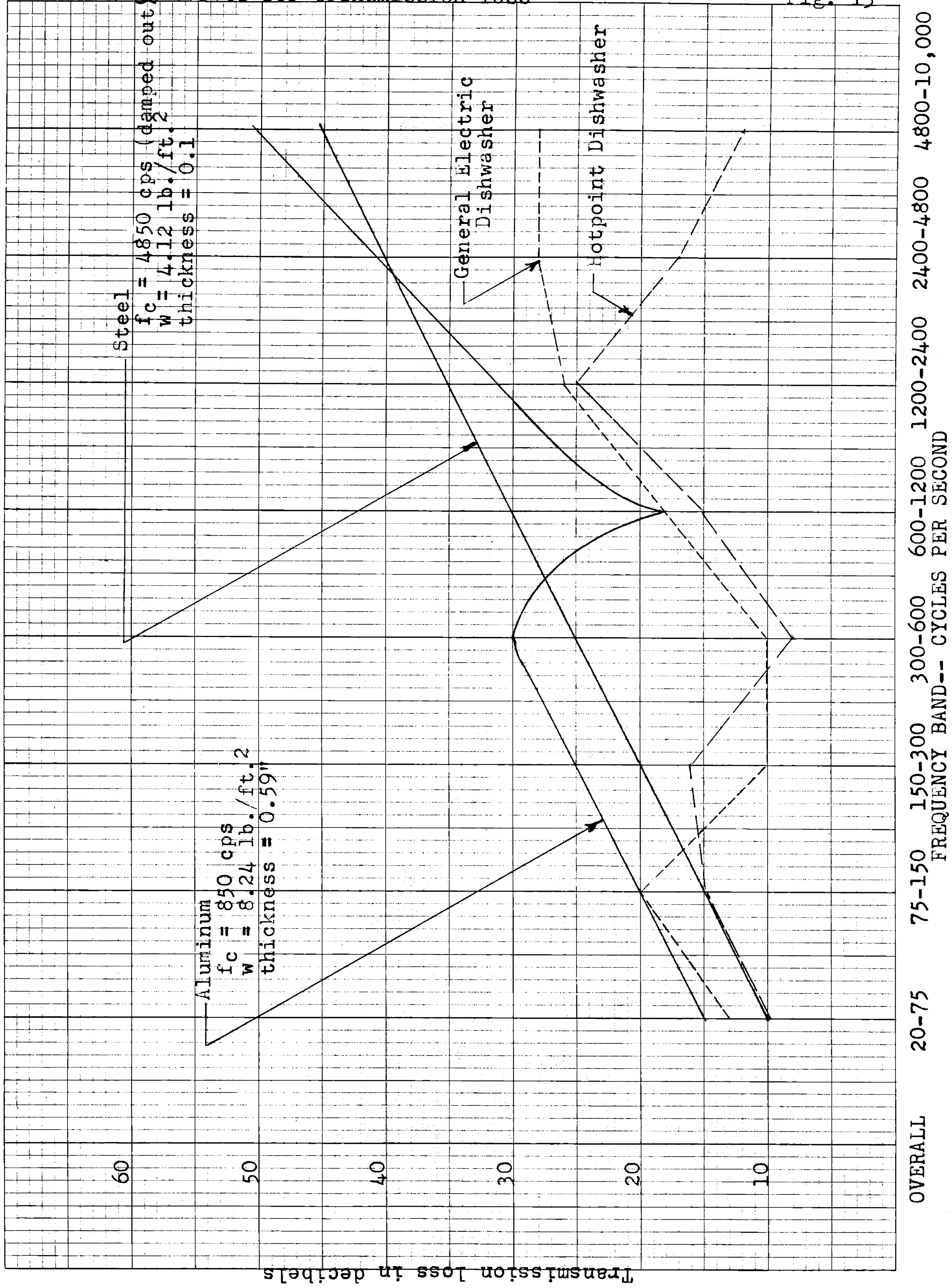
Figure 12

TL curves of enclosure for Hotpoint and General Electric Dishwashers

FIRST APPROXIMATION



Design curves for transmission loss Fig. 13



Figures 14-21

Scale--3/64 inch = 1 inch

--Symbol for microphone

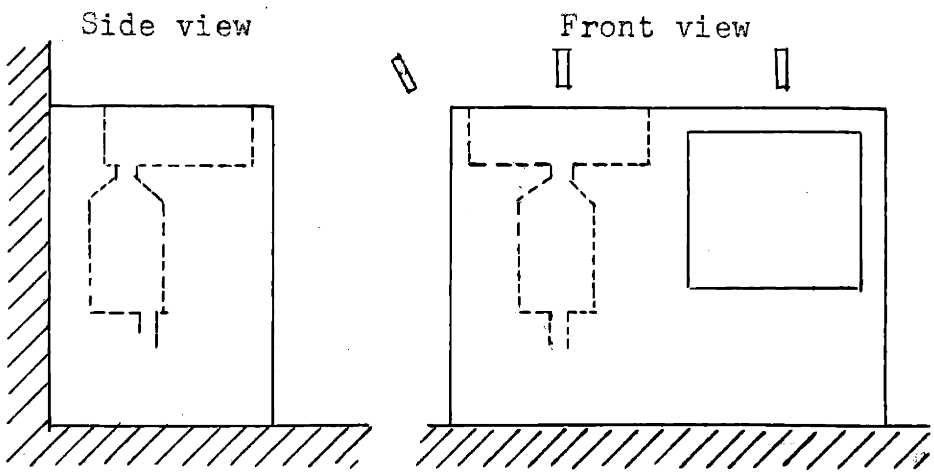


Figure 14 - Hotpoint Disposall and Dishwasher

A for dishwasher = 3.54 $meters^2$

A for disposall = 3.54 $meters^2$

(A--See Figure 22)

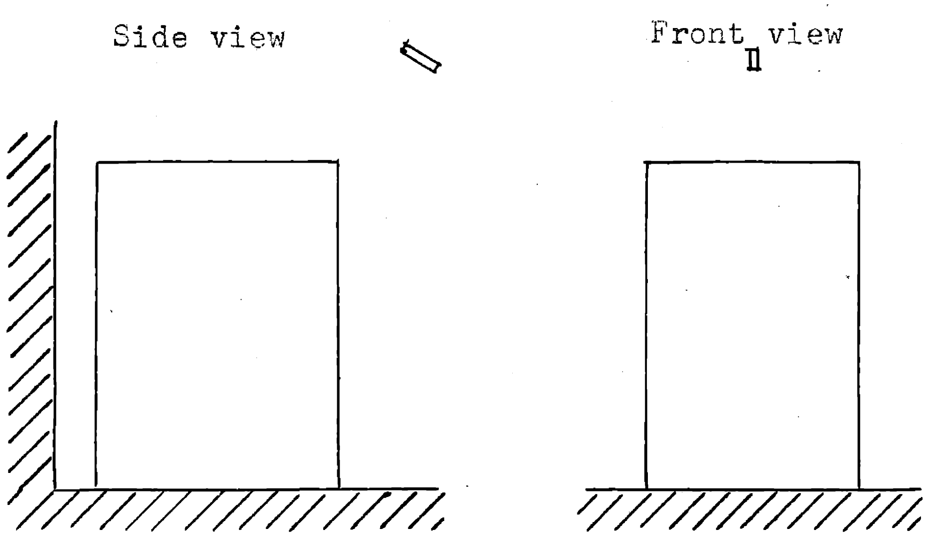


Figure 15 - Norge Automatic Washer

A for washer = 8.67 $meters^2$

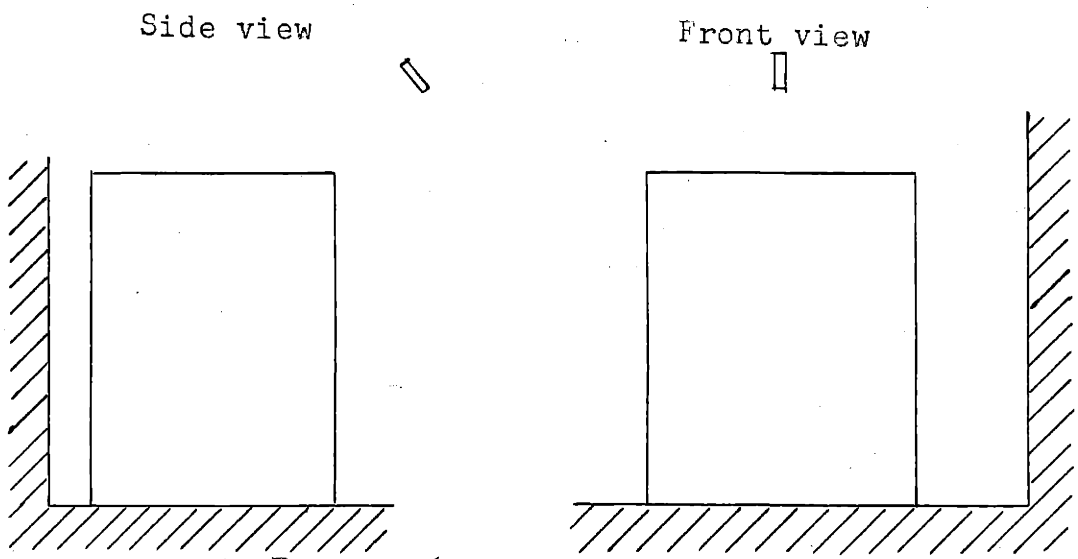


Figure 16 - Norge Drier

A for drier = 7.09 meters^2

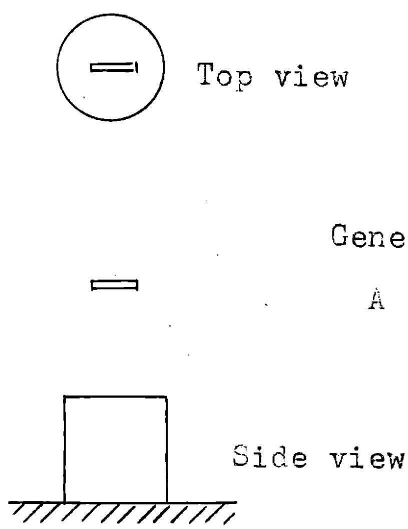


Figure 17

General Electric Vacuum Cleaner

A for cleaner = 1.75 meters^2

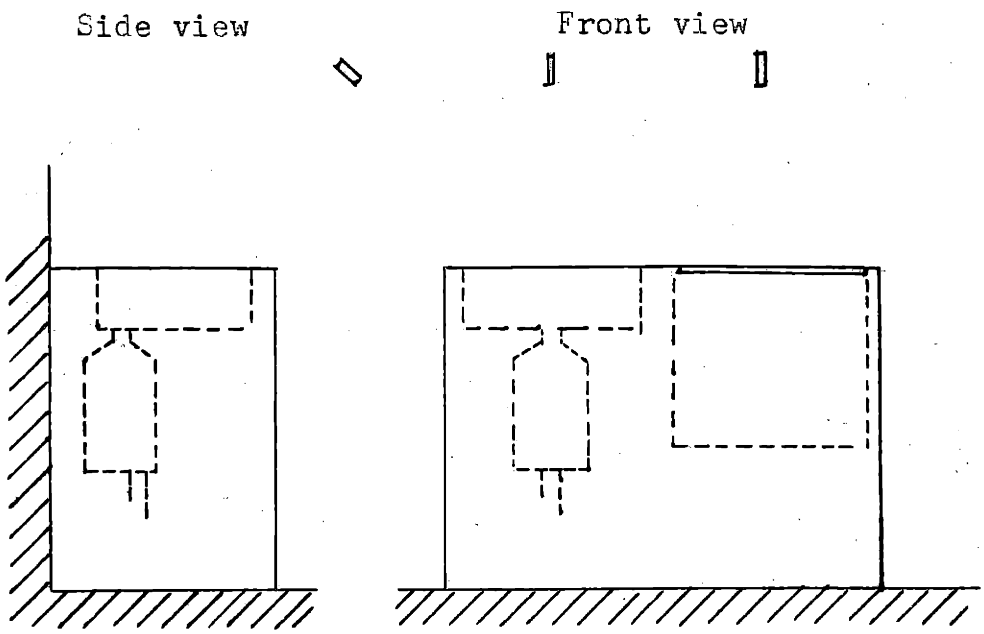


Figure 18 - General Electric Disposall and Dishwasher

A for dishwasher = 6.06 $meters^2$

A for disposall = 6.06 $meters^2$

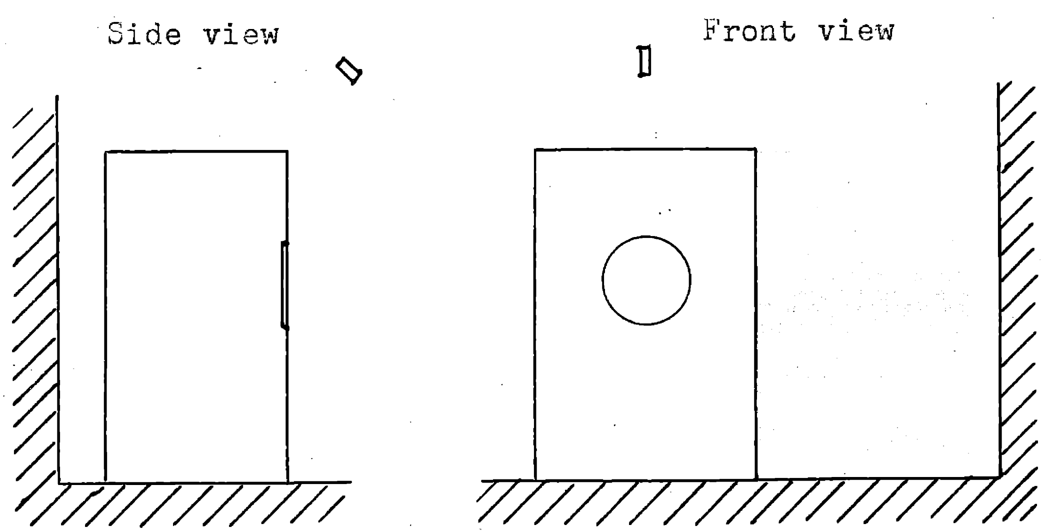


Figure 19 - Bendix Home Laundry

A for washer = 4.3

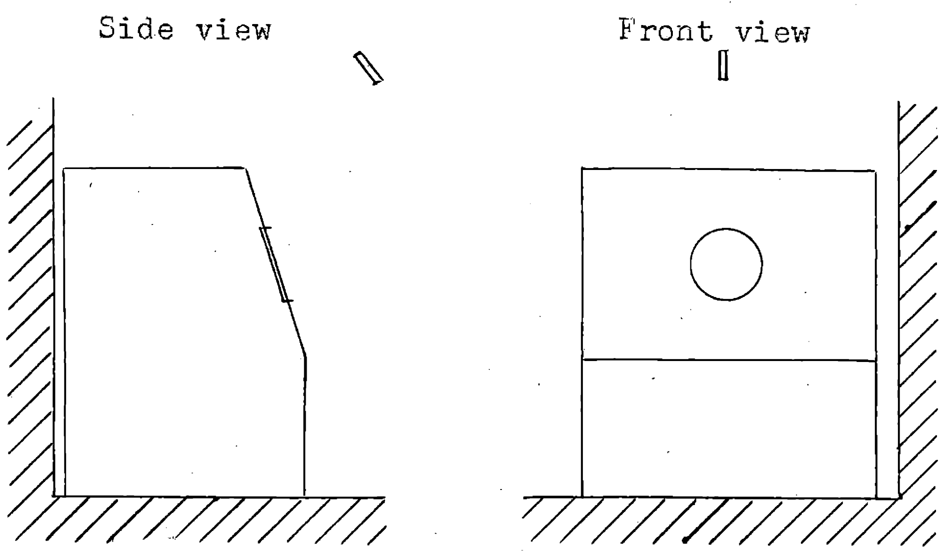


Figure 20 - Westinghouse Clothes Drier

A for drier = 3.8 meters^2

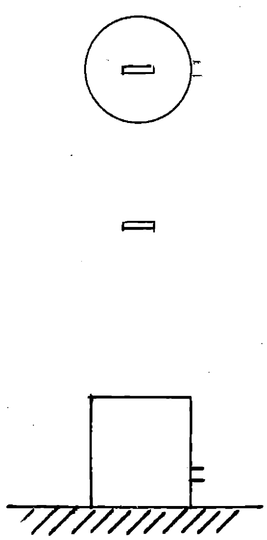


Figure 21 - Lewyt Vacuum Cleaner

A for cleaner = 4.6 meters^2

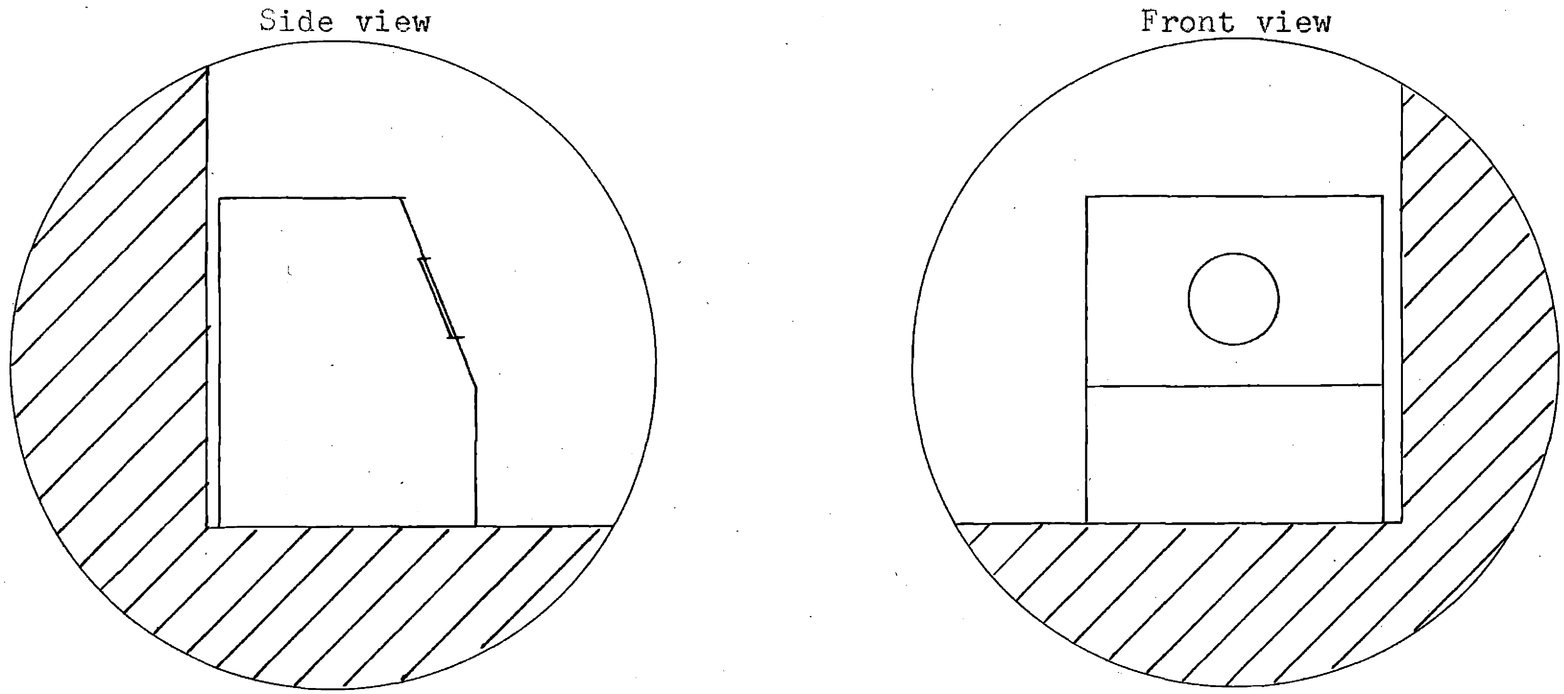


Figure 22 - Definition of A using Westinghouse Drier as an example.

Radius of sphere equals distance from center of source to microphone.

A = Unshaded area of shpere

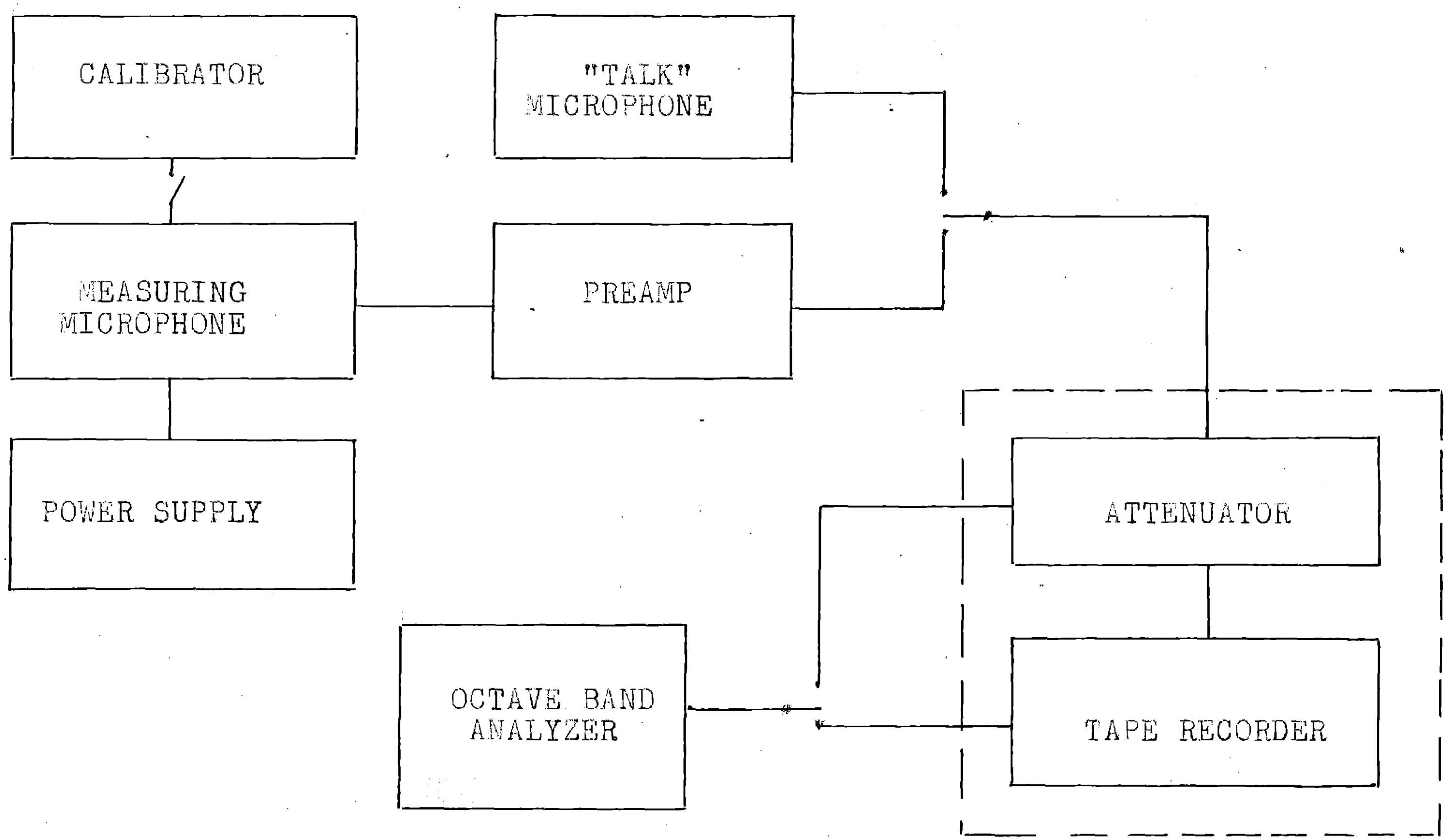


Figure 23 - Block diagram of measuring equipment.

In Tables 4 and 5:

Intensity = $a + 10^{-b}$
Power = $a + 10^{-b}$

Units for Sound Intensity = watts/meter^2

Units for Sound Power = watts/meter^2

TABLE 4

INTENSITIES

Frequency Band cps	Norge Automatic Washer							
	Fill		Wash		Rinse		Spin Dry	
	a	b	a	b	a	b	a	b
OVERALL	1.00	5	1.00	4	1.00	4	5.01	5
20-75	1.00	5	3.98	5	2.51	5	2.51	5
75-150	7.94	8	7.94	5	7.94	5	3.16	5
150-300	2.51	8	6.31	6	3.98	6	1.59	6
300-600	1.26	7	1.59	6	1.59	6	3.16	7
600-1200	1.00	7	6.31	7	6.31	7	7.94	8
1200-2400	2.00	7	1.59	7	2.51	7	6,31	8
2400-4800	6.31	8	3.98	8	6.31	8	1.00	8
4800-10,000	2.51	8	2.00	8	3.16	8	6.31	9

Frequency Band cps	Hotpoint Dishwasher							
	Wash		Rinse		Average		Start of Rinse, door rattles	
	a	b	a	b	a	b	a	b
OVERALL	2.51	5	2.51	5	2.51	5	2.00	5
20-75	2.00	5	1.26	5	1.63	5	1.26	5
75-150	2.00	6	2.00	6	2.00	6	1.59	6
150-300	1.59	6	2.00	6	1.80	6	7.94	6
300-600	2.51	6	2.00	6	2.26	6	1.26	6
600-1200	1.26	6	1.26	6	1.26	6	3.16	7
1200-2400	2.00	7	2.51	7	2.26	7	5.01	8
2400-4800	1.59	7	1.59	7	1.59	7	1.26	7
4800-10,000	5.01	8	5.01	8	5.01	8	3.16	9

Frequency Band cps	Norge Drier		Hotpoint Disposall		GE Vacuum Cleaner		Lewyt Vacuum Cleaner	
	a	b	a	b	a	b	a	b
OVERALL	5.01	5	3.16	5	1.59	5	7.94	5
20-75	2.00	5	7.94	6	2.51	7	6.31	7
75-150	2.51	5	2.51	6	6.31	7	1.26	7
150-300	2.00	6	1.59	6	3.98	6	1.96	5
300-600	6.31	7	2.00	6	7.94	6	3.16	5
600-1200	6.31	8	6.31	6	2.51	6	2.51	5
1200-2400	1.00	8	1.59	5,6	1.00	6	3.98	7
2400-4800	2.00	9	7.94	7	2.00	7	3.16	7
4800-10,000	1.26	9	1.00	6	7.94	8	1.59	7

TABLE 4 (con't)

INTENSITIES

Frequency Band cps	General Electric Automatic Dishwasher Wash$_1$		Wash$_2$		Wash$_3$		Average	
	a	b	a	b	a	b	a	b
OVERALL	3.16	5	3.16	5	3.98	5	3.43	5
20-75	1.59	5	1.59	5	3.16	5	2.11	5
75-150	3.98	6	2.51	6	5.01	6	3.83	6
150-300	1.26	6	7.94	7	7.94	7	9.49	7
300-600	2.00	6	2.00	6	2.00	6	2.00	6
600-1200	1.59	6	2.00	6	1.26	6	1.62	6
1200-2400	2.00	6	2.00	6	1.26	6	1.75	6
2400-4800	1.59	6	1.26	6	7.94	7	1.21	6
4800-10,000	1.59	6	1.00	6	6.31	7	1.07	6

Frequency Band cps	Dishwasher Spray on		General Electric Disposall 1st run		2nd run		Average	
	a	b	a	b	a	b	a	b
OVERALL	5.01	5	3.16	5	2.51	5	2.84	5
20-75	1.26	5	1.59	5	7.94	6	1.19	5
75-150	3.16	6	5.01	6	5.01	6	5.01	6
150-300	1.00	6	1.26	6	1.59	6	1.43	6
300-600	1.00	6	7.94	7	5.01	7	6.48	7
600-1200	1.59	6	3.16	7	1.59	7	2.38	7
1200-2400	2.51	6	7.94	7	5.01	7	6.98	7
2400-4800	3.98	6	7.94	7	5.01	7	6.98	7
4800-10,000	3.98	6	1.26	6	1.59	6	1.43	6

Frequency Band cps	We'house Drier		Bendix Home Laundry Fill$_1$		Fill$_2$		Average	
	a	b	a	b	a	b	a	b
OVERALL	2.00	5	2.51	5	1.59	5	2.05	5
20-75	1.26	5	1.26	6	1.26	6	1.26	6
75-150	2.00	6	3.16	6	3.98	6	3.57	6
150-300	2.51	6	1.59	6	2.51	6	2.05	6
300-600	5.01	7	1.59	6	1.59	6	1.59	6
600-1200	6.31	7	2.51	6	2.00	6	2.25	6
1200-2400	6.31	8	2.51	6	2.00	6	2.25	6
2400-4800	2.00	8	1.26	6	6.31	7	9.50	7
4800-10,000	7.94	9	3.98	6	2.00	6	2.99	6

TABLE 4 (con't)

INTENSITIES

Frequency Band cps	Bendix Home Laundry Wash$_1$		Wash$_2$		Average		Rinse	
	a	b	a	b	a	b	a	b
OVERALL	2.00	5	6.31	5	4.15	5	2.51	5
20-75	5.01	6	6.31	6	5.66	6	3.98	6
75-150	6.31	6	3.16	5	1.90	5	3.16	6
150-300	1.59	6	3.98	6	2.79	6	2.51	6
300-600	3.16	6	3.98	6	3.57	6	2.51	6
600-1200	1.00	6	1.59	6	1.30	6	2.51	6
1200-2400	1.00	6	7.94	7	8.97	7	1.59	6
2400-4800	1.26	7	7.94	8	1.03	7	3.98	7
4800-10,000	3.98	8	6.31	8	5.15	8	1.59	7

Frequency Band cps	Bendix Home Laundry Spin Dry$_1$		Spin Dry$_2$		Spin Dry$_3$		Average	
	a	b	a	b	a	b	a	b
OVERALL	3.98	5	3.98	5	5.01	5	4.32	5
20-75	1.59	5	1.26	5	1.00	5	1.28	5
75-150	6.31	6	6.31	6	7.94	6	6.85	6
150-300	5.01	6	3.98	6	3.98	6	4.32	6
300-600	1.59	6	1.26	6	1.26	6	1.37	6
600-1200	1.59	6	1.59	6	2.00	6	1.73	6
1200-2400	2.00	6	1.59	6	2.00	6	1.86	6
2400-4800	1.59	6	1.26	6	1.59	6	1.48	6
4800-10,000	2.51	7			2.51	7	2.51	7

TABLE 5

SOUND POWERS

Frequency Band cps	Norge Automatic Washer Fill a	Fill b	Wash a	Wash b	Rinse a	Rinse b	Spin Dry a	Spin Dry b
OVERALL	8.67	5	8.67	4	8.67	4	4.34	4
20-75	8.67	5	3.45	4	2.18	4	2.18	4
75-150	6.88	7	6.88	4	6.88	4	2.74	4
150-300	2.18	7	5.47	5	3.45	5	1.38	5
300-600	1.09	6	1.38	5	1.38	5	2.74	6
600-1200	8.67	7	5.47	6	5.47	6	6.88	7
1200-2400	1.73	6	1.38	5	2.18	6	5.47	7
2400-4800	5.47	7	3.45	7	5.47	7	8.67	8
4800-10,000	2.18	7	1.73	7	2.74	7	5.47	8

Frequency Band cps	Hotpoint Dishwasher Wash Rinse a	b	Start of Rinse, door rattles a	b	Norge Drier a	b	Hotpoint Disposall a	b
OVERALL	8.89	5	7.08	5	3.55	4	1.12	4
20-75	5.77	5	4.46	5	1.42	4	2.81	5
75-150	7.08	6	5.63	6	1.78	4	8.89	6
150-300	6.37	6	2.81	5	1.42	5	5.60	6
300-600	8.00	6	4.46	6	4.47	6	7.08	6
600-1200	4.46	6	1.12	6	4.47	7	2.23	5
1200-2400	8.00	6	1.77	7	9.07	8	5.60	5,6
2400-4800	5.63	7	4.46	8	1.42	8	2.81	6
4800-10,000	1.77	7	1.12	8	8.90	9	3.54	6

Frequency Band cps	GE Vacuum Cleaner a	b	GE Dishwasher Spray on a	b	Wash a	b	Lewyt Vacuum Cleaner a	b
OVERALL	2.78	5	3.04	4	2.07	4	3.65	4
20-75	4.39	7	7.64	5	1.28	4	2.90	6
75-150	1.10	6	1.91	5	2.32	5	5.80	7
150-300	6.97	6	6.06	6	5.75	6	9.02	5
300-600	1.39	5	6.06	6	1.21	5	1.45	4
600-1200	4.31	6	9.64	6	9.82	6	1.15	4
1200-2400	1.75	6	1.52	5	1.06	5	1.83	6
2400-4800	3.50	7	2.41	5	7.33	6	1.45	6
4800-10,000	1.39	7	2.41	5	6.48	6	7.31	7

TABLE 5 (con't)

SOUND POWERS

Frequency Band cps	Bendix Home Laundry Fill		Wash		Rinse		Spin Dry	
	a	b	a	b	a	b	a	b
OVERALL	8.81	5	1.78	4	1.08	4	1.86	4
20-75	5.42	6	2.43	5	1.71	5	5.50	5
75-150	1.54	5	8.17	5	1.36	5	2.95	5
150-300	8.82	6	1.20	5	1.08	5	1.86	4
300-600	6.84	6	1.54	5	1.08	5	5.89	6
600-1200	9.68	6	5.60	6	1.08	5	7.43	6
1200-2400	9.68	6	3.85	6	6.84	6	8.00	6
2400-4800	4.09	6	4.43	7	1.71	6	1.36	6
4800-10,000	1.29	5	2.21	7	6.84	7	1.08	6

Frequency Band cps	GE Disposall		We'house Drier	
	a	b	a	b
OVERALL	1.72	4	7.60	5
20-75	7.22	5	4.79	5
75-150	3.04	5	7.60	6
150-300	8.67	6	9.54	6
300-600	3.93	6	1.90	6
600-1200	1.44	6	2.40	6
1200-2400	3.93	6	2.40	6
2400-4800	3.93	6	7.60	8
4800-10,000	8.67	6	3.02	8

BIBLIOGRAPHY

AUTHOR: Dr. Leo L. Beranek (1)

TITLE: Acoustics (book)

PLACE OF PUBLICATION: United States of America

PUBLISHER: McGraw Hill Book Company

DATE: 1954

AUTHOR: Dr. Leo L. Beranek (2)

TITLE: Material and Structures for Noise Control (not published)

TYPE OF ARTICLE: A copyrighted report (1955)

AUTHOR: Dr. Leo L. Beranek (3)

TITLE: Acoustic Measurements (book)

PUBLISHER: John Wiley & Son, Inc.

DATE: 1949

AUTHOR: Robert F. Lambert, Department of Electrical Engineering, University of Minnesota (4)

TITLE: Design of Noise Enclosures

TYPE OF ARTICLE: A report

DATE: August 1955

APPENDIX

GENERAL NOMENCLATURE AND CONSTANTS[1]

p - rms value of the instantaneous sound pressure over a time interval at that point.
units - microbar = 0.1 newton/meter^2

u - rms value of instantaneous particle velocity
units - meters/second

P_o - static pressure; usually barametric pressure
units - newtons/meter^2
= 10^5 newtons/meter^2 (normal barametric pressure)

T - absolute temperature
degrees Kelvin
= 295° K (22° C) (normal room temperature)

ρ_o - ambient density of air
units- kilograms/meter^2

$$= 1.29 \frac{273}{T} \frac{P_o}{0.76}$$ = 1.18 kilograms/meter^2 (at normal pressure and temperature)

c - speed of sound in air
units - meters/second
= 331.4 + 0.607 θ meters/second
where θ = ambient temperature in degrees Centigrade
(valid for $-30 < \theta < 30$)
= 344.8 meters/second for 22° C.

$\rho_o c$ = characteristic impedance
units - mks rayls (using units of ρ_o and c above)
= 407 mks rayls (at 22°C and 10^{-5} newtons/meter^2)

I - intensity of sound
units - watts/meter^2

$$= \frac{p^2}{\rho_o c} \text{ watts/meter}^2$$

W - sound power
units - watts
In simple source radiating spherically
= IA where A is the area of surface of radiating sphere = πr^2

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1. Notation is consistant with Beranek's _Acoustics_

SPL - sound pressure level
units - decibels = db
$= 20 \log_{10} (p/p_{ref})$
where $p_{ref} = 0.0002$ microbar

usually written
SPL db re 0.0002 microbar

IL - sound intensity level
units - decibels
$= 10 \log_{10} (I/I_{ref})$
where $I_{ref} = 10^{-12}$ watts/meter^2
usually written
IL db re 10^{-12} watts/meter^2

$$IL = SPL + 10 \log_{10} ({p_{ref}}^2 / {}_o c I_{ref})$$
$$= SPL + 10 \log_{10} (400/ {}_o c)$$
but $\rho_o c = 407$ mks rayls
$$= SPL - 0.08 \approx SPL$$

PWL - sound power level
units - decibels
$= 10 \log_{10} (W/W_{ref})$
where $W_{ref} = 10^{-13}$ watts

usually written
PWL db re 10^{-13} watts

S - surface area
units - feet^2

- absorption coefficient
units - dimensionless

- average coefficient (of absorption)
units - dimensionless

$$= \frac{S_1\alpha_1 \quad S_2\alpha_2 \quad S_3\alpha_3 \quad \ldots\ldots\ldots \quad S_n\alpha_n}{S}$$

where α_1 is the absorption coefficient of area S_1 etc. and S is total area

R - room constant
units - feet^2
$= S\bar{\alpha}/1 - \bar{\alpha}$ feet^2

S_w - area of common wall in two rooms
units - feet^2

TL - difference of Power levels on opposite sides of wall
units-decibels

$$TL = 10 \log_{10} (W_1/W_2) = PWL_1 - PWL_2 \quad db$$

$$TL = PWL_1 + 10 \log_{10}(S_w/R_1) - SPL_2 + \log_{10}\left[\frac{1}{S_w} + \frac{4}{R_2}\right]$$

$$SPL = PWL + \log_{10} (4/R)$$

approx. when source is in the same room

w - weight per unit area of one inch thick material
units - pounds/feet^2

f_c - critical frequency in cycles per second
frequency at which dip in TL curve occurs

wf_c = 7000 pounds/feet^2 X cycles/second for aluminum
= 20,000 " " " " " " steel

SPECIFIC NOMENCLATURE

Subscript d - dishwasher
" k - kitchen
" c - criteria

CALCULATION OF SOUND POWER LEVELS FOR APPLIANCES

$SPL = IL$

$$I = 10^{-12} \log_{10}^{-1} (IL/10)$$

Using Westinghouse Drier as sample:

$$I = 10^{-12} \log_{10}^{-1} (73/10)$$

$$= 2 \times 10^{-5} \text{ watts/meter}^2$$

The intensities are tabulated on Table 4.

Finding area (A) sound source radiates into.[1]

1. Area is shown in Figure 22

Using a ball as a model, I measured the area (A) and found it to be:

$$A = 5850 \text{ inches}^2 = 3.8 \text{ meters}^2.$$

The areas are tabulated under the Figures.

From the values of A and I, the power of the source can be calculated by the formula:

$$W = A \times I = 3.8 \times 2 \times 10^{-5} = 7.6 \times 10^{-5} \text{ watts}$$

Also, the PWL can be calculated from:

$$PWL = 10 \log_{10} (W/10^{-13}) = 89 \text{ db}$$

The sound powers are tabulated on Table 5. Also the PWL's are plotted on Fig. 1-10.

CALCULATION OF ROOM CONSTANT OF KITCHEN

Area of linoleum floor	=	S_{lf}	=	180 feet^2
" " plaster ceiling	=	S_{pc}	=	180 feet^2
" " " walls	=	S_{pw}	=	173 feet^2
" " wood panel walls	=	S_{wp}	=	259 feet^2
Total area of kitchen	=	S_k	=	792 feet^2

$$\alpha_k = \frac{S_{lf}\alpha_{lf} \quad S_{pc}\alpha_{pc} \quad S_{pw}\alpha_{pw} \quad S_{wp}\alpha_{wp}}{S_k}$$

$$\alpha_k = 0.12$$

$$R_k = S_k\alpha_k/1 - \alpha_k = 108 \text{ Feet}^2$$

Both α_k and R_k are tabulated for each frequency band on Table II

DETERMINATION OF TL AND MATERIAL FOR DISHWASHER ENCLOSURE

$SPL_k = PWL_d + 10 \log_{10} (4/R_k)$

$= 88 - 14 = 74$ db re 0.0002 microbar

but $SPL_c = 62$ db re 0.0002 microbar

So PWL must be 12 db lower

or TL = 12 db

Values of TL are tabulated in Table II and plotted in Figure 12.

Using the "mass law" methods,[1] a line of 5 db/octave slope was drawn which just touched the required TL curve at 600-1200 band. This curve gave no allowance for critical frequency dip and so a different method was tried.

New Method: Treat the dishwasher like a small room.

Then-

$$R_d = S_d \alpha_d / 1 - \alpha_d$$

Since

$$S_d = 2(21 \times 36 + 21 \times 25 + 25 \times 36)/144$$
$$= 26.4 \text{ Feet}^2$$

and α_d is tabulated in Table III, then

$R_d = 6.6$ Feet^2 in lowest frequency band.

Other values of R_d are found in Table III.

1. See Reference 2.

Also,

$$S_w = (25 \times 36 + 21 \times 25)/144 = 8.3 \text{ feet}^2$$

Therefore

$$TL = PWL + 10 \log_{10} (S_w/R_d) - SPL_c + 10 \log_{10}\left[\frac{1}{S_w} + \frac{4}{R_k}\right]$$

$$= 88 + 1 - 62 - 7 = 10 \text{ db} \quad \text{(for Hotpoint)}$$

These values of TL are plotted on Figure 13 and tabulated in Table III

Using "mass law" and critical frequency approach, I drew a line with a slope of 5 db/octave which touched the required TL curve at the 75-150 band. I used the graph of Figure 2.4 in reference 2 to determine wf which corresponds to a 20 db TL at 105 cps (mean of band)

$$wf = 2400 \text{ lb./ft.}^2 \times \text{cps}$$

$$w = 8.24 \text{ lb./ft.}^2$$

Aluminum was tried which has a $wf_c = 7000$, (page 15 Reference 2). Therefore-

$$f_c = 7000/8.24 = 850 \text{ cps}$$

I put the dip which corresponds to this frequency on the graph of Figure 13. (Size of dip was obtained from Figure 2.5, Reference 2.) With

$$w = 8.24 \text{ lb./ft.}^2$$

and weight of aluminum equal to 14 pounds/foot^2 for a one inch thickness, then the thickness of aluminum required is

$$8.24/14 = .59 \text{ inches}$$

For a 5 db decrease in TL, then-

$$wf = 1250 \text{ lb./ft.}^2 \times \text{cps}$$

$$w = 4.12 \text{ lb./ft.}^2 \quad \text{(at 105 cps)}$$

Also

$$wf_c = 20{,}000 \qquad \text{for steel}$$

$$f_c = 4850 \text{ cps}$$

If the dip in TL at the critical frequency is damped out then since- weight of steel is 40 pounds/foot^2 the required thickness of steel is

$$4.12/40 = .1 \text{ inches}$$

APPLIANCES TESTED

Name	Model	Year
General Electric Automatic Dishwasher		1945
General Electric Disposall	FA2A16	1945
Lewyt Vacuum Cleaner	E65	1950
Bendix Home Laundry	K46	1944
Westinghouse Clothes Drier	D9	1955
Norge Automatic Washer	AW450	1955
Norge Drier	AE620	1955
Hotpoint Disposall	20MW9	1955
Hotpoint Automatic Dishwasher	50MCP18	1955
General Electric Vacuum Cleaner	C1	1955

EQUIPMENT USED

Name	Type
Tape Recorder	Ampex 600
Microphone, with preamp	Altec 21-BR 150
Power Supply - for Microphone	USAF 2151
Calibrator - for Microphone	BBN Acoustic Calibrator, 2 volts @ 400 cps = 130 db SPL re 0.0002 microbar #3086-3
Octave Band Analyzer	General Radio 1550 A
Microphone, with "push to talk switch"	Crystal Microphone