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Characterizing Operational Performance of Rotary Subwoofer Loudspeaker

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Sensors and Electron Devices Directorate, ARL

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14. ABSTRACT

The US Army Research Laboratory (ARL) is currently investigating using high-speed video cameras to measure vibrations of objects excited by soundwaves. A commercial rotary subwoofer speaker is one of the sources used to generate low-frequency soundwaves. Laboratory testing was performed on the speaker to understand the tradeoffs between the rotation rate of the fan blades and the amplitude of the articulation of the fan blades to maximum the amplitude on the resulting acoustic pressure waves.

15. SUBJECT TERMS

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Contents

List of Figures

List of Tables

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1. Introduction

The US Army Research Laboratory (ARL) is currently investigating using high-speed video cameras to measure vibrations of objects excited by low-frequency sound waves. To support this effort, data were collected by ARL's Acoustics and Electromagnetic Sensing Branch to characterize the performance of a rotary subwoofer speaker. This speaker will be used in field tests to vibrate objects in ARL's Building 406, such as windows. This commercial technology can be used to generate infrasound signals using a relatively small speaker.

2. Field Experiment

In early July 2017, ARL conducted a test to characterize the operational performance of a rotary subwoofer speaker. Building 406 is a single-story, concrete building that has 7 major rooms and Plexiglas windows. The building space contains several small offices and machine rooms that consist of lab benches and large machinery primarily used for developing ARL hardware. The test equipment was set up in the hallway that connects all of the rooms in the building. The rotary subwoofer was stationed in the doorway of a back room, while the other devices were set up on a stationary cart relatively close to the subwoofer. The speaker was attached to a piece of plywood with a circular hole for the fan blade that was mounted into the door opening using clamps and screws. The plywood created a barrier between the intake and exhaust of the fan. The amplifier and waveform generator were approximately 2 ft away from the subwoofer, while the oscilloscope was located on a lab bench approximately 3 m away from the speaker. The oscilloscope measured the peak-to-peak voltage produced by the output of the amplifier driving the microphone. Table 1 shows the list of equipment used during the measurements.

Table 1 Rotary subwoofer speaker and supporting technology

Device	Specifications
Eminent Technology Rotary Subwoofer TRW-17	Blade Number: 5 (300 rpm) Amplifier Requirement: 150 watts @ 8 ohms Impedance: 8 ohms 0 Hz : 0 Hz Frequency Response: 1 Hz : 30 Hz ±4 dB Suggested Crossover: 20 Hz @ 18 dB/octave Sensitivity: 94 dB 1 watt 1 meter @ 10 Hz Maximum Acoustic Output: >115 dB bet. 1 and 20 Hz (ET 2017)
Fuji Electric AF-300 MICRO-$AVER II Drive 1/4–5 Horsepower	Frequency Range: 0–400 Hz (0.2 to 15 Hz Start Frequency; 15 to 400 Hz Base Frequency) Rate Output Voltage: 3-Phase, 3-Wire, 80–240 VAC or 160–480 VAC Gain: Output frequency gain corresponding to the reference signal can be set from 0 to 250% (GEFD 1998)
Eminent Technology Rotary Woofer Controller Model BT42 by Marchand Electronics	Phase: 170 Damping: 12 dB Low Pass: 25 Hz Gain: 10
Agilent 54624A 4 Channel 100 MHz Oscilloscope	Channels: 4 Bandwidth: 100 MHz Maximum Sample Rate: 200 MSa/s Maximum Memory: 4 MB 2 MB of MegaZoom deep memory per channel Patented high-definition display Flexible triggering including I^2C, SPI, CAN, and USB
33220A Function / Arbitrary Waveform Generator, 20 MHz	Channels: 1 5 MHz pulse waveforms with variable rise/fall times Pulse, Ramp, Triangle, Noise, and DC waveforms 14-bit, 50 MSa/s, 64 K-point Arbitrary waveforms AM, FM, PM, FSK, and PWM modulation types 10 mVpp to 10 Vpp amplitude range

The first test used an oscilloscope to make 6 measurements of the subwoofer's peak-to-peak voltage by stepping the input frequency for each measurement and varying the fan speed. During this test the waveform generator outputted a constant voltage of 100 mV with the speaker's amplifier set to a gain of 5. The speaker's fan speed was stepped from 10 to 45 Hz in 5-Hz increments at a fixed frequency for each measurement. The measurements were stepped with a sinusoidal input frequency of 1 to 20 Hz in increments of powers of 2. The results indicated that the subwoofer's optimal fan speed is dependent on the input frequency used to modulate the blades. For lower frequencies below 8 Hz, an output fan speed of approximately 15 Hz should suffice for near maximum performance.

The second data set made 6 measurements with the oscilloscope as the input voltage on the waveform generator and gain on the amplifier were varied. For each test run, the input frequency signal generated by the waveform generator was set to a constant value between 1 to 16 Hz, while the fan speed for each test run was set to the previously determined optimal values between 15 to 40 Hz. The results indicate that to generate a 101-dB signal, the waveform generator should output a voltage of 500 mV and the speaker's amplifier be set to a gain of 1. Users can expect to see a 3–5 dB gain as compared to alternate suboptimal configurations.

The pressure signals generated by the rotary subwoofer speaker were collected using a B&K 4193 microphone, UC 0211 infrasound adaptor, and a 2669 Preamp that was connected to an oscilloscope. An amplifier and waveform generator (AT 2005) were used to generate signals outputted by the speaker. The speaker's fan speed was operated between 10 to 45 Hz, while the amplifier's gain was set between 1 and 5. In addition, the input frequency and input voltage were stepped between 1 and 20 Hz, and 100 and 500 mV, respectively. Table 1 lists the rotary subwoofer speaker and its supporting technology, including necessary power supplies. These devices are listed by name and model specifications. Photos of the device models used during the experiment are in Figs 1–5. Pressure waves generated by the subwoofer caused objects to vibrate throughout the building. The AF-300 drive supported the rotary subwoofer and controlled many factors, including the speaker's fan speed. The rotary woofer controller was used as the subwoofer's amplifier and controlled the level of gain fed into the speaker. The waveform generator set the frequency and power outputted by the speaker.

This experiment consisted of 2 data collects. One set of tests aimed at stepping the input frequency and varying the speaker's fan speed simultaneously. This data set included a total of 6 tests, each with 6–7 trial runs. During these test runs, the gain and input voltage were set to a constant value of 5 and 100 mV, respectively during these data collects. During the second data collect, the input voltage and gain were varied, while the fan speed and input frequency, measured in hertz, were given constant values for each of the data collect's 6 tests. Each test had approximately 9 data runs in this section of the experiment. The data for these tests can be found in Tables 2 and 3 of this report. Approximately 10 s of data were taken during each test run.

Fig. 1 Eminent Technology rotary subwoofer TRW-17

Fig. 2 Fuji Electric AF-300 MICRO-$AVER II Drive

Fig. 3 Eminent Technology Rotary Woofer Controller Model BT42 by Marchand Electronics

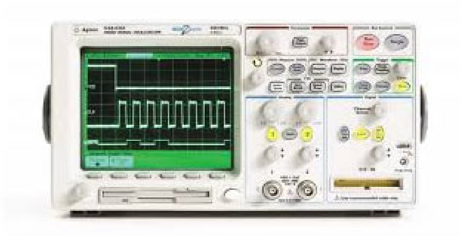

Fig. 4 Agilent 54624A 4-Channel 100 MHz Oscilloscope

Fig. 5 33220A Function/Arbitrary Waveform Generator, 20 MHz

Images of the experimental setup are shown below in Figs. 6–8. Figure 6 shows the positioning of the rotary subwoofer in relation to the waveform generator and speaker's amplifier. The speaker is mounted to a wooden door, which was designed and created by ARL's machine shop. Figure 7 is a close-up image of the rotary subwoofer speaker, with the speaker's 5-blade fan and AF-300 drive device clearly visible. The speaker was placed on top of a square piece of cardboard to level it against the wooden door. Figure 8 displays a lab room in Building 406 with lab benches. During this experiment the oscilloscope was stationed on a bench in this room, as seen in Fig. 8.

Fig. 6 Setup of rotary subwoofer attached to a wooden door, with the waveform generator and amplifier in plain view (top shelf of cart)

Fig. 7 Rotary subwoofer speaker mounted to wooden door

Fig. 8 Building 406 lab room; oscilloscope stationed on lab bench (on left)

3. Data Collection

In this report various parameters were tested and modified to determine the optimal performance of the rotary subwoofer. These parameters include the input frequency, input voltage, gain, and fan speed of the speaker. Data were collected inside Building 406 with an oscilloscope. The subwoofer caused objects throughout the building, such as boxes and tools on the lab benches, to display vibrational motion. Tables 2 and 3 contain the measurements recorded by the oscilloscope, amplifier, waveform generator, and rotary subwoofer during each test run.

Table 2 shows the results of the first experiment. The table lists each test run number and its corresponding input frequency, fan speed, input voltage, gain, and resulting peak-to-peak voltage of the microphone output during each trial. The experiment consisted of 6 tests in which the waveform generator's input frequency was stepped while the subwoofer's fan speed was varied. For example, the first row of the data table refers to the first trial run of the first test in Experiment 1, also known as the "Test 1.1.1" data collect. Each test run is labeled by the following naming convention: Experiment#.Test#.Trial#. During this trial, the waveform generator produced a sinusoidal input frequency signal at 1 Hz and an input voltage of 100 mV. The speaker's fan speed was set to 10 Hz, while the speaker's amplifier was set to a gain of 5. The oscilloscope measured the microphone's peak-to-peak voltage of 237 mV, which converts to 95 dB. The rest of the test data can be interpreted in a similar manner. The data includes measurements of the rotary subwoofer operating at input frequencies ranging from 1–20 Hz and fan speeds varying from 10 to 45 Hz. After analyzing the data in Table 2, it can be concluded that the rotary subwoofer generates maximum power at 20 Hz.

Table 2 Experiment 1 data—stepping the input frequency and varying the subwoofer's fan speed

Test Runs	Input Frequency (Hz)	Fan Speed (Hz)	Input Voltage (mV)	Gain	Pk-to-Pk Voltage (mV)
1.1.1	1	10	100	5	237
1.1.2	1	15	100	5	260
1.1.3	1	20	100	5	255
1.1.4	1	25	100	5	230
1.1.5	1	30	100	5	205
1.1.6	1	35	100	5	190
1.1.7	1	40	100	5	180
1.2.1	2	10	100	5	350
1.2.2	2	15	100	5	400
1.2.3	2	20	100	5	370

Table 2 Experiment 1 data—stepping the input frequency and varying the subwoofer's fan speed (continued)

Test Runs	Input Frequency (Hz)	Fan Speed (Hz)	Input Voltage (mV)	Gain	Pk-to-Pk Voltage (mV)
1.2.4	2	25	100	5	330
1.2.5	2	30	100	5	300
1.2.6	2	35	100	5	270
1.2.7	2	40	100	5	240
1.3.1	4	10	100	5	285
1.3.2	4	15	100	5	350
1.3.3	4	20	100	5	335
1.3.4	4	25	100	5	330
1.3.5	4	30	100	5	300
1.3.6	4	35	100	5	280
1.3.7	4	40	100	5	265
1.4.1	8	10	100	5	460
1.4.2	8	15	100	5	825
1.4.3	8	20	100	5	1050
1.4.4	8	25	100	5	99
1.4.5	8	30	100	5	860
1.4.6	8	35	100	5	750
1.4.7	8	40	100	5	660
1.5.1	16	10	100	5	80
1.5.2	16	15	100	5	110
1.5.3	16	20	100	5	150
1.5.4	16	25	100	5	220
1.5.5	16	30	100	5	325
1.5.6	16	35	100	5	450
1.5.7	16	40	100	5	490
1.5.8	16	45	100	5	410
1.6.1	20	10	100	5	85
1.6.2	20	15	100	5	100
1.6.3	20	20	100	5	130
1.6.4	20	25	100	5	175
1.6.5	20	30	100	5	240
1.6.6	20	35	100	5	325
1.6.7	20	40	100	5	450
1.6.8	20	45	100	5	560

The results of Experiment 2 are documented in Table 3. The table specifies the test run number, input frequency, fan speed, input voltage, gain, and resulting peak-to-peak voltage value recorded during each test run. This data collect also consists of 6 tests. During this experiment the input voltage and gain varied. For example, the first second of the Table 2 refers to the second trial run of the first test in Experiment

2, which can be referenced as the "Test 2.1.2" data collect. During this trial, the waveform generator produced a sinusoidal input frequency signal at 1 Hz and an input voltage of 150 mV. The speaker's fan speed was set to 15 Hz, while the speaker's amplifier gain was set to 3 1/3. The data includes measurements of the rotary subwoofer operating at input voltages ranging from 100–500 mV and gain values varying from 1 to 5. After analyzing the data in Table 3, it is concluded that the rotary subwoofer operates at its maximum performance around an input voltage of 500 mV (101 dB) and a gain of 1.

Table 3 Experiment 2 data—varying the input voltage and gain

Test Runs	Input Frequency (Hz)	Fan Speed (Hz)	Input Voltage (mV)	Gain	Pk-to-Pk Voltage (mV)
2.1.1	1	15	100	5	260
2.1.2	1	15	150	3.33	263
2.1.3	1	15	200	2.5	275
2.1.4	1	15	250	2	275
2.1.5	1	15	300	1.67	270
2.1.6	1	15	350	1.42	290
2.1.7	1	15	400	1.2	305
2.1.8	1	15	450	1.11	325
2.1.9	1	15	500	1	320
2.2.1	2	15	100	5	410
2.2.2	2	15	150	3.33	. . .
2.2.3	2	15	200	2.5	. . .
2.2.4	2	15	250	2	500
2.2.5	2	15	300	1.67	. . .
2.2.6	2	15	350	1.42	. . .
2.2.7	2	15	400	1.2	. . .
2.2.8	2	15	450	1.11	. . .
2.2.9	2	15	500	1	580
2.3.1	4	15	100	5	355
2.3.2	4	15	150	3.33	. . .
2.3.3	4	15	200	2.5	. . .
2.3.4	4	15	250	2	425
2.3.5	4	15	300	1.67	. . .
2.3.6	4	15	350	1.42	. . .
2.3.7	4	15	400	1.2	. . .
2.3.8	4	15	450	1.11	. . .
2.3.9	4	15	500	1	485
2.4.1	8	20	100	5	1045
2.4.2	8	20	150	3.33	. . .
2.4.3	8	20	200	2.5	. . .
2.4.4	8	20	250	2	1380

Table 3 Experiment 2 data—varying the input voltage and gain (continued)

Test Runs	Input Frequency (Hz)	Fan Speed (Hz)	Input Voltage (mV)	Gain	Pk-to-Pk Voltage (mV)
2.4.5	8	20	300	1.67	. . .
2.4.6	8	20	350	1.42	. . .
2.4.7	8	20	400	1.2	. . .
2.4.8	8	20	450	1.11	. . .
2.4.9	8	20	500	1	1640
2.5.1	12	30	100	5	475
2.5.2	12	30	150	3.33	. . .
2.5.3	12	30	200	2.5	. . .
2.5.4	12	30	250	2	600
2.5.5	12	30	300	1.67	. . .
2.5.6	12	30	350	1.42	. . .
2.5.7	12	30	400	1.2	. . .
2.5.8	12	30	450	1.11	. . .
2.5.9	12	30	500	1	760
2.6.1	16	40	100	5	450
2.6.2	16	40	150	3.33	. . .
2.6.3	16	40	200	2.5	. . .
2.6.4	16	40	250	2	635
2.6.5	16	40	300	1.67	. . .
2.6.6	16	40	350	1.42	. . .
2.6.7	16	40	400	1.2	. . .
2.6.8	16	40	450	1.11	. . .
2.6.9	16	40	500	1	780

4. Data Analysis

4.1 Experiment 1 Data Results

Figure 9 shows the results from Experiment 1, where the input frequency generated by the waveform generator and the speaker's fan speed were varied. As the speaker's voltage, frequency, and amplitude increase, the speaker begins to reach a threshold that represents the speaker's operational performance level. Past this threshold, the speaker can potentially be overloaded.

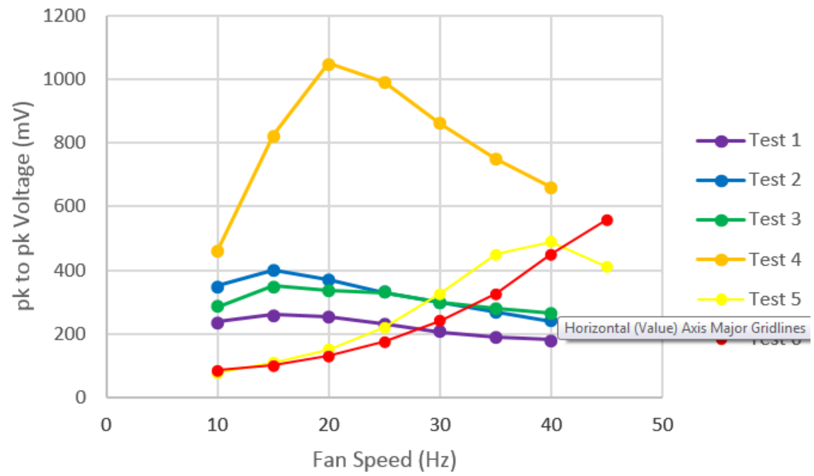

Fig. 9 Peak-to-peak voltage data as a result of stepping the input frequency and varying the fan speed

4.2 Experiment 2 Data Results

Figures 10 and 11 show the data collected from Experiment 2. Experiment 2 focuses on varying the input voltage from the waveform generator and changing the gain inputted by the speaker's amplifier. There are 6 sets of tests, each with 3 distinct data points. These points measure the speaker's input voltage in millivolts at 100, 250, and 500 mV. It can be concluded from this data that the rotary subwoofer should be driven at 500 mV or 101 dB to run at operational performance.

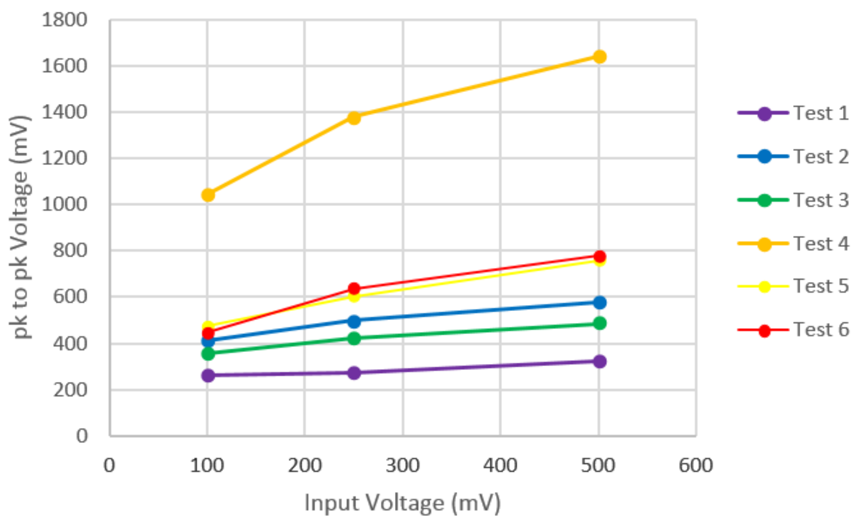

Fig. 10 Peak-to-peak voltage data as a result of varying the input voltage

Figure 11 shows the peak-to-peak voltage as a function of varying the gain. There are 6 sets of tests, each with 3 distinct data points. These points measure the speaker's input voltage in mV at 100, 250, and 500 mV. It can be concluded from this data that the rotary subwoofer should be driven at a gain of 1 at an input voltage of 500 mV to run at operational performance.

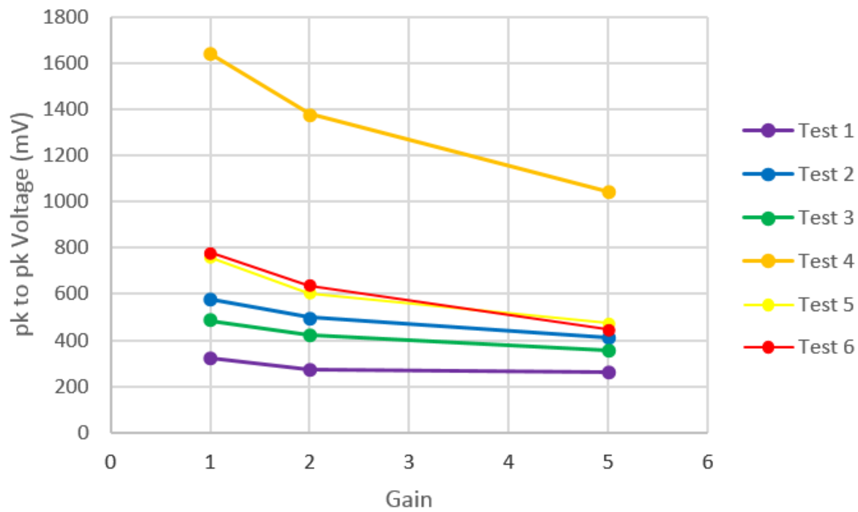

Fig. 11 Peak-to-peak voltage data as a result of varying the gain

5. Conclusion

ARL made measurements that were designed to determine the operational performance of a rotary subwoofer speaker. The team measured microphone signal levels on an oscilloscope that were generated by a low-frequency rotary subwoofer speaker. The team varied several parameters including the input frequency, input voltage, fan speed, and gain to access the performance. To obtain maximum output power, the rotary sub-woofer speaker should be driven by a 500 mV signal and at a fan speed of approximately 15 Hz.

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List of Symbols, Abbreviations, and Acronyms

AM	amplitude modulation
ARL	US Army Research Laboratory
DC	direct current
FM	frequency modulation
FSK	frequency shift keying
I^2C	inter-integrated circuit
PM	phase modulation
PWM	pulse width modulation
SPI	serial peripheral interface
USB	Universal Serial Bus
VAC	volts alternating current

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