GATES ACOUSTIC SERVICES

USCGC HEALY (WAGB-20)

ACOUSTIC TRIAL RESULTS

Tim Gates – tim@gatesacoustics.com
Marisa Yearta – marisa@gatesacoustics.com
AUGUST 2014
INTRODUCTION

Gates Acoustic Services was tasked by SCRIPPS Institute of Oceanography to investigate and quantify acoustic issues associated with operation of the USCGC HEALY (WAGB-20). An at-sea investigation was accomplished during ship operations in deep water out of Nome, Alaska on August 13-24, 2014.

During the at sea test on HEALY, the primary goal was to determine ship acoustic and bubble sweepdown characteristics and to assess their potential impacts to sonar performance. The Kongsberg EM 122 sonar was the primary focus of this testing. Additional goals of this test were to determine propeller cavitation characteristics and to obtain a preliminary snapshot of acoustic noise generated while operating in various ice conditions.

The following objectives were accomplished for this testing:

1. The noise levels from the sonar transducers were measured using internal Built In Self Test (BIST) routines for the EM 122.

2. The controlling sources of sonar acoustic levels were investigated.

3. The noise levels of a reference hydrophone were measured at selected speeds and vessel conditions.

4. Propeller cavitation characteristics were assessed.

5. The presence of bubble sweepdown was assessed.

6. Various machinery items were measured for noise and vibration levels.

7. Data was acquired for a variety of ice conditions.

INSTRUMENTATION

In order to successfully accomplish the desired objectives, it was necessary to install a special suite of vibration sensors and monitoring equipment. Two
Accelerometers were installed in after steering above each propeller to monitor propeller performance and the inception of cavitation. The installed accelerometers were Wilcoxon 752 types with sensitivity of 100 millivolt per g. Additional data was acquired from 1 permanently installed hydrophone located near the sonar location. This hydrophone was a HAP 5050 model with a receive sensitivity of -171 dB per volt relative to one micro pascal. The data from these sensors was processed using a Krohn-Hite Amplifier and a Quattro Signal Analyzer to yield calibrated acoustic levels. Additional data was acquired using the BIST RX Noise Level routine inherent in the EM 122 sonar system.

Figure 1 presents the location of the reference hydrophone and the 2 propeller accelerometers.

**TEST CONDITIONS**

The following test conditions were evaluated during the underway operations on HEALY:

- Various vessels speeds were tested from dead in the water to 15 knots in 10 rpm increments.
- Eight different vessel headings were measured at a typical survey speed.
- Various machinery units were cycled on and off to assess their sonar acoustic contributions.
- Various speeds were evaluated while operating in thin/pancake ice, thicker ridges and small floating pockets of multi-year ice.

Sea conditions for this trial were varied with Knudsen Sea States observed between 1 to 3 with winds up to 25 knots. The water depth during acoustic data acquisition ranged between 3000 and 4000 meters.

The following table provides vessel speed and shaft rpm for a given vessel thrust setting:

<table>
<thead>
<tr>
<th>Shaft RPM</th>
<th>Speed (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>1.7</td>
</tr>
<tr>
<td>40</td>
<td>3.6</td>
</tr>
<tr>
<td>50</td>
<td>4.6</td>
</tr>
<tr>
<td>60</td>
<td>5.4</td>
</tr>
<tr>
<td>70</td>
<td>6.4</td>
</tr>
<tr>
<td>80</td>
<td>7.6</td>
</tr>
<tr>
<td>90</td>
<td>8.6</td>
</tr>
</tbody>
</table>
DATA RESULTS

Baseline Bathymetric Sonar Acoustic Evaluation

Data was acquired from the BIST RX NOISE LEVEL routine inherent to the EM 122 sonar system. This data represents the background acoustic signature the sonar must operate in. This routine samples data at 12 kHz for each of the 64 hydrophone staves resident in the receive array for the EM 122 sonar system.

Figure 2 presents the average BIST levels of the EM 122 data as a function of vessel speed. Each point in this figure represents an average of the 64 receive array hydrophones sampled 20 times. This data indicates there is relatively little speed dependence noted in EM 122 data. The decibel levels noted in this figure range from the mid to high 60’s, which is considered unusually high for a typical quiet sonar installation. Figure 3 presents a speed series presentation of EM 122 data. This data shows the acoustic profile across the receive array for each vessel speed. As vessel speed is increased, levels increase only slightly.

Since the levels of the EM 122 were considered to be extremely high, even at dead-in-the-water conditions, an investigation was performed to determine what was the cause of the elevated levels. It was determined that machinery noise was controlling the acoustic background levels of the sonar. Many different machinery items were evaluated and specific data from these items will be documented in the Machinery Diagnostic section contained later in this report. During the specific machinery testing, it was determined that two systems were creating the bulk of the excessive noise. The largest noise offender in the sonar acoustic signature was the Boiler Feed Pumps. When these pumps were secured, up to 8 dB reductions were noted in sonar data. Unfortunately, it is only possible to secure these pumps for short periods of time. The other significant noise offender was the potable water system. This system has 2 pumps that operate in an "on demand" mode, and typically cycled on for about 15 seconds every few minutes. When this pump was operating, it produced acoustic levels similar to those observed from the Boiler Feed Pumps. To document the residual acoustic levels in the absence of these two noise sources, a special, modified speed series was conducted with both of these items secured. Figures 4 through 7 present this data collected at 40, 60, 80 and 100 rpm, respectively, compared to data at the same speed with the units operating. Significant reductions are noted in these figures at all tested speeds, while in the
"quiet" condition. Figure 8 presents this data in a speed versus level comparison to further document the reductions. The approximate levels when these noisy units were secured, was around 60 dB in EM 122 data and it was determined these quieter levels were controlled by machinery noise and not related to propulsion. The majority of the remaining noise was associated with main engine operations. Each of the four engines on HEALY contributed similar acoustic levels to the EM 122 background noise when operated. This "quiet" level of 60 dB is still not considered to be good, but should be adequate for HEALY to accomplish adequate mapping in the typical water depths in which she operates.

   Snapshots of sonar performance were collected to document the impact these two noise sources have on the mapping capability of the EM 122. Figure 9 presents a baseline quiet condition, with both the boiler feed and potable water systems secured. Figure 10 presents the sonar waterfall display while the boiler feed pumps are operating. It is easy to note the data drop outs that occur when this noisy pump is operating. Figure 11 presents the sonar waterfall display during a potable water pump transient event. The significant dropouts caused by the noise from the pump are noted for its operational duration.

**Hydrophone Evaluation**

   Data was also acquired during the speed runs on HEALY from the reference hydrophone. This data was acquired in two frequency bands from 0 to 20 kHz and from 0 to 80 kHz. This data is presented in figures 12 and 13 for each frequency range, respectively. This data is included for completeness and additional data from this sensor will be presented in the Machinery Diagnostic section. One note regarding this data is when Main Seawater Pump 2 was energized, significant increases in acoustic and electrical noise was present. The unusual shaped curves noted at a few speeds in these figures are associated with that pumps operation.

**Propeller Cavitation**

   Cavitation measurements were made on both the port and starboard fixed pitch propellers of HEALY. The measurements were made using an accelerometer mounted on the hull plating located just above each propeller. Cavitation performance was evaluated by monitoring the 0 to 2 kHz, 0 to 10 kHz and 0 to 20 kHz band levels of these sensors as speed was slowly increased during straight line course operations.

   Figures 14, 15 and 16 present speed series data from the port propeller at all tested speeds for frequency ranges of 0 to 2 kHz, 0 to 10kHz and 0 to 20 kHz, respectively. Figures 17, 18 and 19 present similar data for the starboard propeller. The presence of propeller cavitation can be seen in the data on these figures for vessel speeds above 50/60 rpm.
Figure 20 presents a speed versus level comparison of the port and starboard propellers at a representative frequency of 12 kHz. As seen on this figure, the propellers are quite similar in noise level at all tested vessel speeds above a few knots. This figure also indicates that propeller cavitation incepted at vessel speeds around 6 knots (50/60 rpm). While this cavitation inception point is not considered good, the propellers were not considered a factor in sonar performance due to machinery noise levels.

**Bubble Sweepdown**

An assessment was conducted to assess the presence and impact of bubbles associated with bubble sweepdown along the vessel hull. During the at-sea period, infrequent bubble transients were detected on HEALY at vessel speeds above 4-5 knots. The bubble transients were believed to be associated with bubbles passing near the sonar receive arrays, on the outer edges. Typically bubbles are detected aurally when they are near the sonar arrays. The bubble evaluation consisted of eight different ship headings with respect to the prevailing sea conditions while operating at a constant speed of 80 rpm. Sea conditions for this evaluation were moderate (sea state 2/3). Figure 21 presents average EM 122 BIST data collected at these eight vessel headings. Very little difference is noted at each heading and it is believed this is in part due to the high noise associated with vessel machinery masking the bubble sweepdown noise. Figure 22 presents a snapshot of the EM 122 waterfall display at 80 rpm. The rough outer edges of this figure document some bubble sweepdown degradations to sonar performance. It is believed that in typical arctic conditions however, bubble sweepdown will not be a major sonar deficiency to HEALY operations.

**Machinery Diagnostics**

During the acoustic evaluation onboard HEALY several machinery items were evaluated.

The most significant machinery offender was determined to be the Boiler Feed Pumps. Pump 1 and Pump 2 had similar impacts to the acoustic background of the EM 122 sonar. Figure 23 presents data from the EM 122 BIST routine for this pump operating and secured. Figures 24 and 25 present data taken from the reference hydrophone at a range of 0 to 20 kHz, for Boiler Feed Pumps 1 and 2, respectively. Figure 26 presents data collected directly on the base of these pumps with a portable accelerometer. It should be noted these pumps are hard mounted directly to the ship’s hull structure. Significant reductions in vibration noise transmitted to the hull would be realized if these pumps were sound isolated.
The second significant machinery offender was the potable water pump system. Both potable water pumps had similar levels and when operated, cause noticeable impacts to EM 122 sonar performance. Figures 27 and 28 present EM 122 BIST data from these two pumps. Figure 29 presents data from the reference hydrophone while potable water pump 2 was running. It should be noted, this pump is always operated in an "on demand" mode, and turns on when water pressure drops below a certain level. Since it isn't always operational, it is not considered as significant as the boiler feed system.

During the speed series evaluation, an unusual noise was detected in reference hydrophone data around 90 rpm. It was determined that a second diesel engine had been turned on at that time, to accommodate the additional power requirements. Further diagnostics indicated the diesel that was energized was operated in conjunction with main seawater pump 2. Upon isolating this pump from other noise sources, it was determined this pump caused unusual acoustic and electrical interference with the reference hydrophone as well as increases to the EM 122 BIST noise levels. Figure 30 presents the EM 122 BIST data for this pump. Figure 31 presents data from the reference hydrophone when main seawater pump 2 is operational. It is recommended that when quiet conditions are desired, this pump not be operated.

The ships doppler speed log caused high levels of acoustic interference in the reference hydrophone. The test results of this system on versus off is presented in Figure 32. As seen in the data on the figure, there are significant level increases in acoustic data when the doppler speed log is operational. It was determined this system did not impact EM 122 levels.

Figures 33 to 35 present data taken from the rudder hydraulic pump units for three different frequency ranges in the port propeller accelerometer. Figures 36 to 38 present similar data for the starboard propeller accelerometer. Very little difference between these units was noted. This data is presented because these units were considered to be exceptionally noisy. It was determined that rudder HPU noise did not impact EM 122 acoustic levels however.

**ICE OPERATIONS**

During the at-sea test on HEALY, a significant amount of data was collected in ice operations. The main purpose of collecting this data was to document how much noise HEALY created in the arctic environment while breaking and transiting through various ice conditions. The ice conditions present during this test were sparse however. Data was collected during pancake ice conditions, and then during smashing and ramming mini ice floes and small ridges. Despite these conditions, the noise created during ice operations was spectacularly loud. The bulk of this data was collected for a separate project that will be presented in another report combined with recently conducted radiated noise testing. As an example, Figures
39 and 40 present ice impact data from the port and starboard propellers, respectively. For this example, up to 25 dB increases were noted in propeller noise. Figure 41 presents EM 122 BIST data during the transit through the pancake ice. The acoustic levels of the sonar were over 80, which is considered above the failure threshold for this system.

The authors would like to especially thank the crew of the HEALY for going above and beyond with their support to acquire the ice data that was collected during this at-sea period. In spite of limited ice conditions, we were able to create our own ice operations by conducting special and unusual maneuvers to simulate thicker and more plentiful ice. Additionally, the support of the Engineering department was exceptional during machinery diagnostic and troubleshooting evolutions.

CONCLUSIONS

- Sonar background noise levels were considered high for a typical research vessel due to machinery noise
- The Boiler Feed Pumps were determined to be the most significant machinery noise source on HEALY
- The Potable Water Pumps, when operating, caused sonar degradations
- Main Seawater Pump 2 created acoustic and electronic noise interference that impacted sonar and hydrophone levels
- In the absence of boiler feed and potable water pumps, sonar levels were controlled by machinery associated with main engine operations
- Propeller cavitation was determined to incept around 6 knots, but was not a sonar degradation
- Bubble sweepdown was not a major contributor to sonar operations
- The ships doppler speed log produces significant acoustic interference at high frequencies
- Ice data was collected and will be presented in another report

RECOMMENDATIONS

A few recommendations are provided with this report as follows:

- Sound isolate the boiler feed pumps
- Following any sound isolation of the boiler feed pumps, if additional quieting is desired, sound isolate the potable water system
- Do not operate Main Seawater Pump 2 when quiet conditions are desired
FIGURE 3

HYDROPHONE STAVE NUMBER

140 RPM
130 RPM
120 RPM
110 RPM
100 RPM
90 RPM
80 RPM
70 RPM
60 RPM
50 RPM
40 RPM
30 RPM
20 RPM
10 RPM
0 RPM

SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)

16 AUGUST 2014

SPEED SERIES

EM 122 RX NOISE LEVEL

USCG HEALY (WAGB-20)
HYDROPHONE STAVE NUMBER

SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)

16 AUGUST 2014
40 RPM VS 40 RPM QUIET LINE UP
EM 122 RX NOISE LEVEL
USCG HEALY (WAGB-20)
FIGURE 5

HYDROPHONE STAVE NUMBER

60 RPM - QUIET (NO BOILER FEED)

60 RPM

SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)

16 AUGUST 2014

60 RPM VS 60 RPM QUIET LINE UP

EM 122 RX NOISE LEVEL

USCG HEALY (WAGB-20)
FIGURE 6

HYDROPHONE STAVE NUMBER

SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)

16 AUGUST 2014
80 RPM VS 80 RPM QUIET LINE UP
EM 122 RX NOISE LEVEL
USCGC HEALY (WAGB-20)
FIGURE 7

SPECTRUM LEVEL (dB re 1 μPa at 12 kHz)

0 10 20 30 40 50 60 70 80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63

HYDROPHONE STAVE NUMBER

100 RPM

100 RPM - QUIET (NO BOILER FEED)

USCGC HEALY (WAGB-20)

EM 122 RX NOISE LEVEL

100 RPM VS 100 RPM QUIET LINE UP

16 AUGUST 2014
17 AUGUST 2014
SPEED VS 12 KHZ LEVEL - NORMAL VS QUIET LINE UP
EM 122 RX NOISE LEVEL
USCG HEALY (WAGB-20)
FIGURE 10

August 2014
000 RPM – Boiler Feed 1
EM 122
USCGC HEALY (WAGB 20)
16 August 2014
Speed Series
Reference Hydrophone
USCG HEALY (WAGB-20)
FIGURE 14

14 AUGUST 2014

USCGC HEALY (WAGB 20)

PORT PROPELLER

SPEED SERIES (0-2 KHz)

VIBRATION LEVEL (dB re 1 µg)
14 AUGUST 2014
SPEED SERIES (0-20 KHz)
PORT PROPELLER
USCGC HEALY (WAGB 20)
USCGC HEALY (WAGB 20)

STARBOARD PROPELLER

14 AUGUST 2014

SPEED SERIES (0-2 KHZ)

VIBRATION LEVEL (dB re 1 µg)
FIGURE 18

USCGC HEALY (WAGB 20)
STARBOARD PROPELLER
SPEED SERIES (0-10 kHz)
14 AUGUST 2014

VIBRATION LEVEL (dB re 1 µg)

FREQUENCY (Hz)

0 10 20 30 40 50 60 70 80 90

0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

140 RPM
130 RPM
120 RPM
110 RPM
100 RPM
90 RPM
80 RPM
70 RPM
60 RPM
50 RPM
40 RPM
30 RPM
0 RPM
14 AUGUST 2014
Speed Series (0-20 kHz)
STARBOARD PROPELLER
USCGC HEALY (WAGB 20)
FIGURE 20

14 AUGUST 2014
SPEED VERSUS 12 KHz LEVEL
PORT VERSUS STARBOARD PROPELLER
USCGC HEALY (WAGB 20)
16 AUGUST 2014
HEADING VERSUS SEA STATE - 80 RPM
EM 122 RX NOISE LEVEL
USCG HEALY (WAGB 20)
August 2014
80 RPM
EM 122
USCGC HEALY (WAGB 20)
16 August 2014

Boiler Feed Pump 1 Running

EM 122 RX Noise Level

USCGC Healy (WAGB 20)
FIGURE 24

USCGC HEALY (WAGB 20)
REFERENCE HYDROPHONE
MACHINERY SERIES 0 - 20 KHZ
17 AUGUST 2014

SPECTRUM LEVEL (dB re 1 µPa)

0 20 40 60 80 100 120 140

0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000

BASELINE
BOILER AND BOILER FEED PUMP 1 RUNNING
USCGC HEALY (WAGB-20)

BOILER FEED PUMP 2 - ON VS OFF

REFERENCE HYDROPHONE
17 AUGUST 2014
17 August 2014
ACCELEROMETER
BOILER FEED PUMP 2 - ON VS OFF
USCG HEALY (WAGB-20)
Figure 28

16 August 2014
Portable Water Pump 2 Running
EM 122 RX Noise Level
USCGC Healy (WAGB 20)
SPECTRUM LEVEL (dB re 1 µPa)

FREQUENCY (Hz)

00000 20000 40000 60000 80000 100000 120000 140000 160000 180000 200000

BASELINE

PORTABLE WATER PUMP 2 RUNNING

17 AUGUST 2014
MACHINERY SERIES 0 - 20 KHz
REFERENCE HYDROPHONE
USCG HEALY (WAGB 20)
FIGURE 30

HYDROPHONE STAVE NUMBER

16 AUGUST 2014
MAIN SEAWATER 2 RUNNING
EM 122 RX NOISE LEVEL
USCG HEALY (WAGB 20)

SPECTRUM LEVEL (dB re 1 pPa at 12 kHz)

0 10 20 30 40 50 60 70 80

0 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
17 August 2014
Machinery Series 0 - 20 kHz
Reference Hydrophone
USCGC HEALY (WAGB 20)
17 August 2014
Reference Hydrophone
Doppler Speed Log - On Vs Off
USCGC HEALY (WAGB-20)
17 August 2014
Rudder HPU Pumps - 000 RPM - 0-2 KHz
Port Propeller
USCGC Healy (WAGB 20)
FIGURE 34

17 AUGUST 2014
Rudder HPU Pumps - 000 Rpm - 0-2 KHz
Starboard Propeller
USCGC HEALY (WAGB 20)
FIGURE 35

17 AUGUST 2014
Rudder HPU pumps - 000 RPM - 0-10 KHz
Port Propeller
USCGC HEALY (WAGB 20)
17 August 2014
Rudder HPU Pumps - 000 RPM - 0-10 kHz
Starboard Propeller
USCGC Healy (WAGB 20)
FIGURE 37

17 AUGUST 2014
Rudder HPU Pumps - 000 RPM - 0-20 kHz
Port Propeller
USCGC HEALY (WAGB 20)
17 AUGUST 2014
Rudder HPU Pumps - 000 RPM - 0-20 KHz
Starboard Propeller
USCGC HEALY (WAGB 20)
17 AUGUST 2014
THROUGH ICE VS OPEN WATER - 80 RPM
PORT PROPELLER
USCGC HEALY (WAGB 20)
17 August 2014
Through ice vs open water - 80 RPM
Starboard propeller
USCGC Healy (WAGB 20)
FIGURE 4.1

HYDROPHONE STAVE NUMBER

SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)

17 AUGUST 2014
80 RPM - OPEN WATER VS THROUGH ICE
EM 122 RX NOISE LEVEL
USCG HEALY (WAGB-20)