Main Engine Power and Torque Requirements

On the MV Klitsa

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Authors
Bruce Cowper: LamaLo Technology Inc., Calgary, Alberta, Canada
Alex Kolomojcev: Consultant to LamaLo Technology Inc., Ottawa, Ontario, Canada
Bob Armor, Polar Design Sales, Vancouver, British Columbia, Canada
KS Ng: British Columbia Ferry Services, Vancouver, British Columbia, Canada
Andre Berthiaume: British Columbia Ferry Services, Victoria, British Columbia, Canada

Abstract:

British Columbia Ferry Services Inc. fleet has 36 vessels, representing a wide range of sizes, classes and operational profiles. A number of these vessels are over 25 years old, and have more than 120,000 hours of service on the propulsion machinery. To reduce the cost of operations and extend service life, some propulsion systems are being upgraded. This includes replacing the main engines with modern more fuel efficient engines, and the propellers to better match the engine and ship performance requirements. Each vessel has a unique operational profile that can be very demanding on the propulsion machinery. Docking manoeuvres are conducted up to 80 times a day. To assist in defining ship specific main engine power and torque requirements, propulsion shaft torque and power measurements with existing propulsion machinery were obtained and assessed. The MV Klitsa was the first of the vessels to be assessed in this manner and the propulsion system upgraded accordingly. Main engines and propellers were selected, and were replaced in the spring of 2002. The after conversion performance was reported to be exceptional, with an increase of 1.5 knots in speed with no vibrations. Prior to the propulsion upgrade one or two scheduled crossings would be canceled each day. After the upgrade the vessel was reported to easily complete all its schedule crossings.

MV Klitsa

Introduction

British Columbia Ferry Services Inc. operates 35 vessels providing service to 48 ports of call on 25 routes throughout coastal British Columbia. Vessel particulars and operational profiles vary considerably, depending upon the service route and requirements. Several of the vessels are more than 25 years old, with over 120,000 hours of service on the main propulsion engines. Although relatively old, the results from independent surveys determined that some vessels are fit for service for another 20 years. Due to the savings realized by increased fuel efficiency and reduced maintenance costs over the extended life of these vessels, the propulsion systems are being upgraded. This includes installing more fuel-efficient main engines and propellers to better match the engine and ship performance requirements. To assist in defining ship specific power and torque requirements, propulsion shaft torque and power measurements with existing propulsion machinery are obtained and assessed. The results of this work on the MV Klitsa are presented in this paper.

Vessel and Propulsion System Description

The MV Klitsa is a 47-m long double ended passenger/car ferry that was built in 1972 in Vancouver. The vessel has a capacity of 26 cars and 195 passengers and crew, with a displacement of 352 tons. The MV Klitsa operates from Chemainus on Vancouver Island to Thetis Island and Kuper Island (, British Columbia. During some periods it also operates between Albion and Fort Langley, British Columbia. The propulsion system consists of two Steerable Right Angle Drive Units (SRAD Units) located on the starboard aft and port forward ends of the vessel. The original propulsion system consisted of Detroit Diesel-Allison 8V 92N diesel engines, each with a shaft power rating of 305 BHP driving a SRAD unit at 1800 RPM. The engines were installed in 1978 and had about 100,000 hours of service. The SRAD Units have a double reduction right-angle gearing arrangement, with a three bladed nozzled propeller. The operating shaft speed ranges from about 600 to 1850 RPM. The Cardan shaft is about 1 m long, with universal joints on each end and a spline in the middle. A schematic of the shaftline is shown in Figure 1. Photo 1 shows the shafting on the vessel.

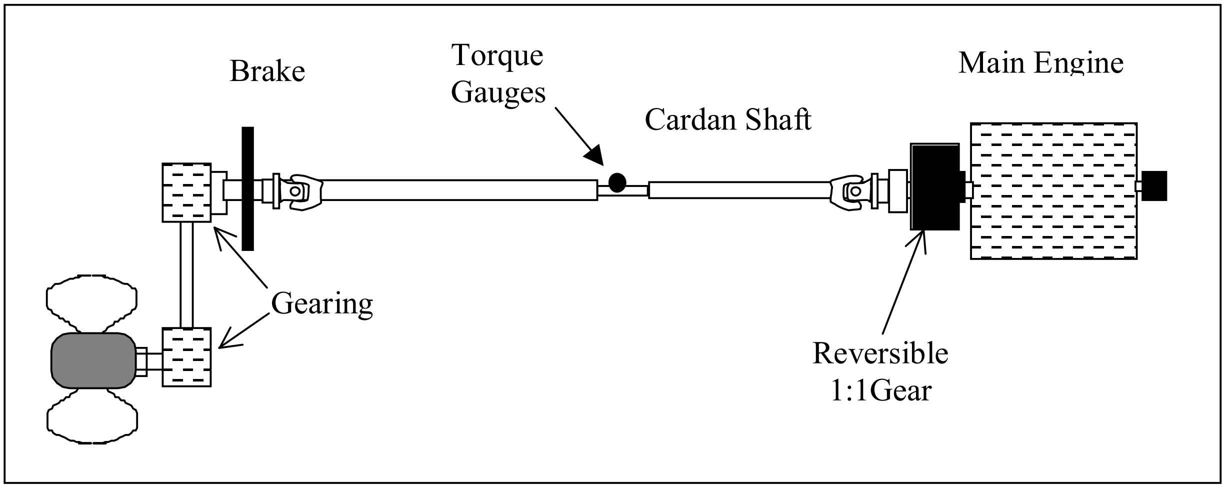


Figure 1 Schematic of Propulsion Shaftline for MV Klitsa

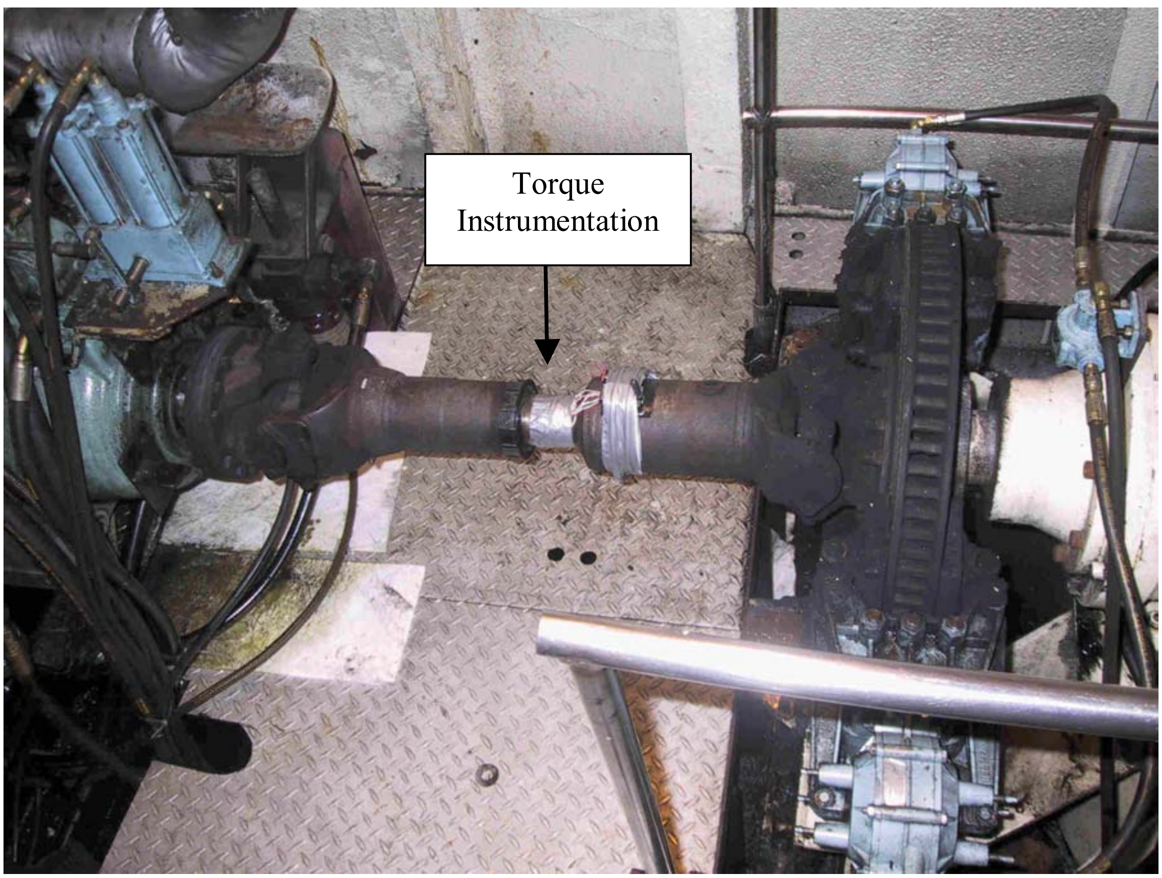


Photo 1 MV Klitsa Shafting

During the Albion-Fort Langley run the MV Klitsa is scheduled for about 80 dockings a day, and about 30 dockings when operating the Chemainus-Thetis Island - Kuper Island operation. Each time the vessel approaches the dock the SRADs are rotated up to 180 degrees to slow the vessel down and manoeuvre into the dock. In case of a steering failure the vessel speed is reduced by reversing the rotation of the propeller. Under some operations the shafts are de-clutched and clutched-in at each docking.

Instrumentation Description

Shaft torque was measured using strain gauges. The strain gauge signals were transmitted to a stationary receiver using a digital telemetry system. The strain gauges were mounted on near the centre of the cardan shaft, aft of the spline. The analog shaft torque signal was digitized at rates from 500 to 2000 readings/sec. for periods of 60 to 240 seconds. The digital data was stored and analyzed on a lap-top computer. The shaft and ship speed were noted from displays provided by on-board indicators on the bridge. The estimated measurement error was as follows:

- Torque: ±5%
- Ship Speed: < 0.2 knots
- Shaft RPM: ±1%
- Shaft Power: ±6%
- Resolution of Peak Magnitude of Torsional Vibration: 97%

Test Plan and Conditions

Propulsion shaft torque (mean and dynamic) measurements were obtained during dedicated tests on October 25, 2001 in the Fraser River near the Albion dock. Measurements were taken throughout the operational profile, including transit, docking, accelerations, and turning. A crash stop and speed power tests were also performed. The weather condition was calm as shown in Photo 2. The current was estimated to be less than 0.2 knots. The barometric pressure was 101.7 kPa. Since there were no vehicles on board the vessel during the dedicated testing, water bags were filled on the main deck as shown in Photo 3. The vessel draft was 7'6" Fwd and 7'2" Aft. The water depth was reported to be greater than 15 m, which was more than 5 times the draft, and suitable for testing. The instrumented propulsion shaftline was aft when transiting downstream.

Photo 2 Conditions During Testing

Photo 3 Water Bags on Deck

Data Analysis Technique

The data from each test was plotted in the time domain. The mean torque levels were computed for each of the constant shaft speed tests. The dynamic torques were determined by close examination of the time domain data plots. A digital low pass digital filter algorithm was applied to some data to isolate torsional vibration frequencies of interest. Fourier Transforms of the time domain data were also computed to verify / determine dominant frequencies of vibration.

Power Requirements

The rated shaft power for the main engine is 305 HP at 1800 RPM. The maximum engine speed was set to 1850 RPM. This could be achieved since the power absorbed by the propeller was less than the rated engine power. Figure 2 presents the measured shaft power over the speed range of the engine. The performance data published for the main engine is also presented in this figure. Figure 3 illustrates the propeller demand curve and the manufacturer's rated power curve for the main engine. Figure 4 illustrates the ship speed power curve. The results indicate the following:

(i) The existing propellers do not match the engine performance. The power absorbed by the propeller at 1800 RPM is 80% of the rated power. Running at 1850 RPM the power absorbed is about 90% of the rated power.

(ii) The maximum shaft speed was in the range of 1850 to 1900 RPM for a maximum speed of 9 knots. The maximum shaft speed was higher than the rated engine speed of 1800 RPM. This could be achieved since the power absorbed by the propeller was less than the rated engine power.

(iii) At full ahead, the average power was 272 HP at an average shaft speed of 1,850 RPM, for a ship speed of 8.9 knots.

(iv) A shaft power of 333 HP at about 2000 RPM is required to increase the ship speed from the existing full ahead speed of 9 knots to the specified service speed of 10 knots.

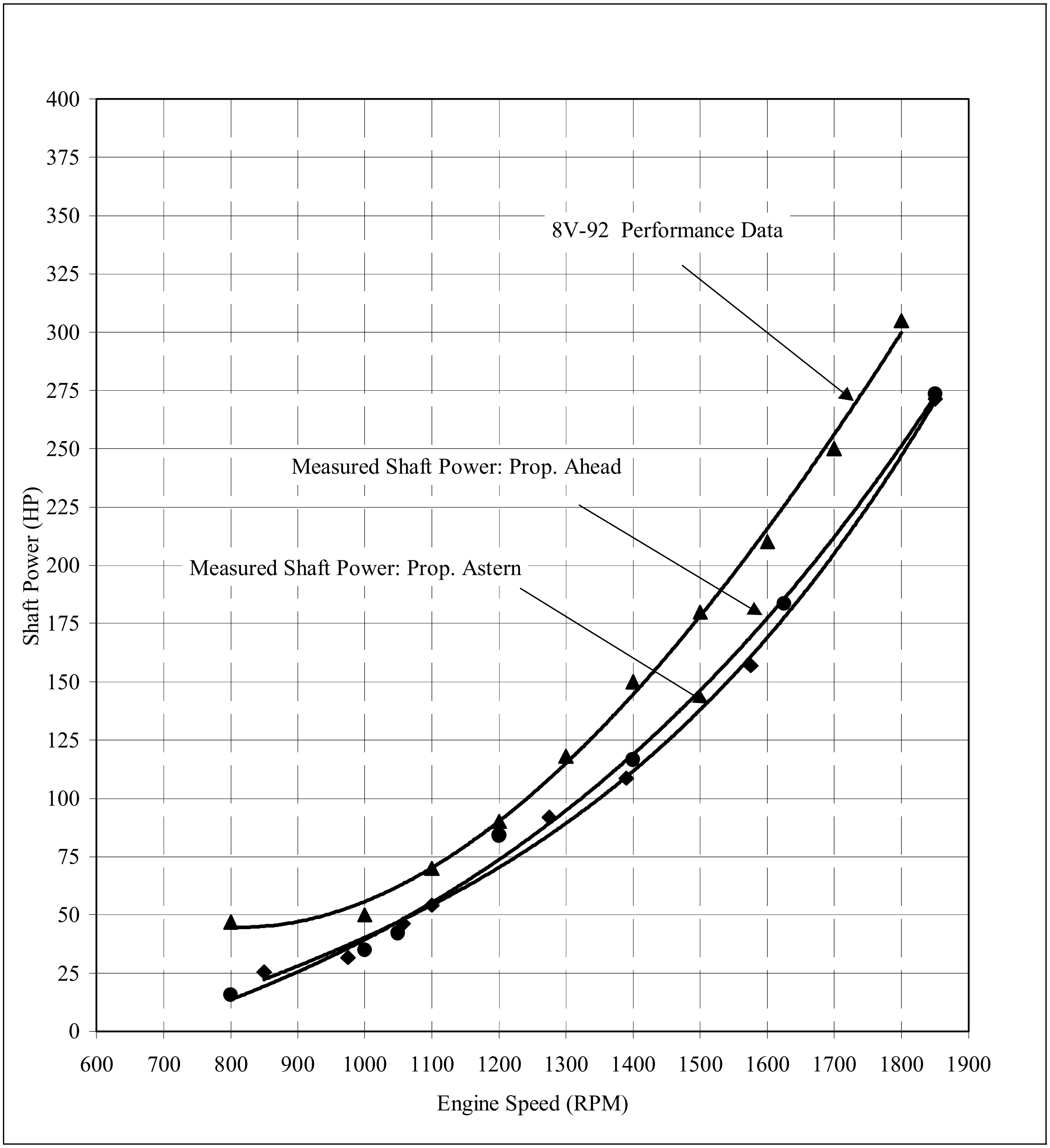


Figure 2 Propeller Demand Curve

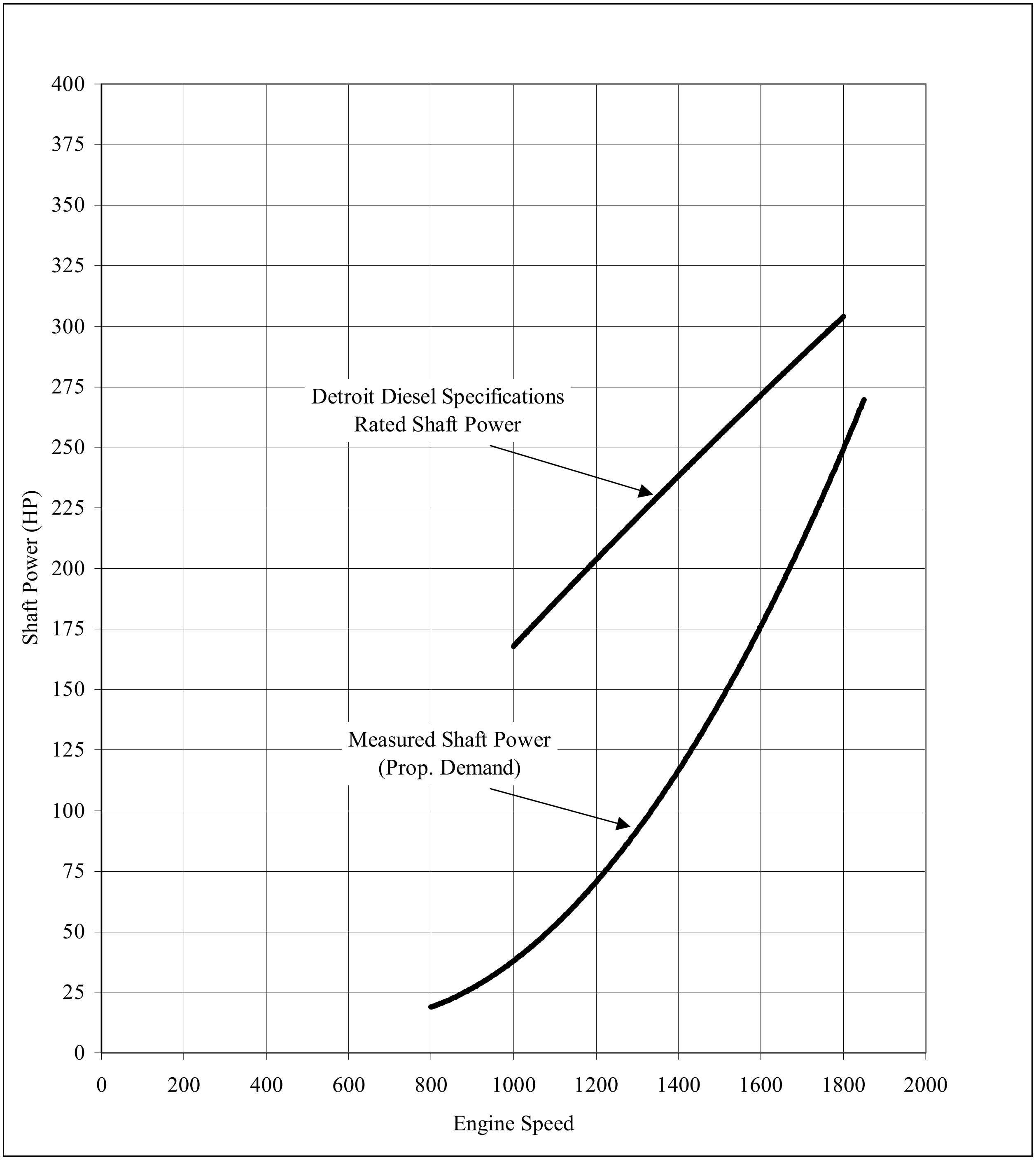


Figure 3 Engine Specification and Propeller Curve

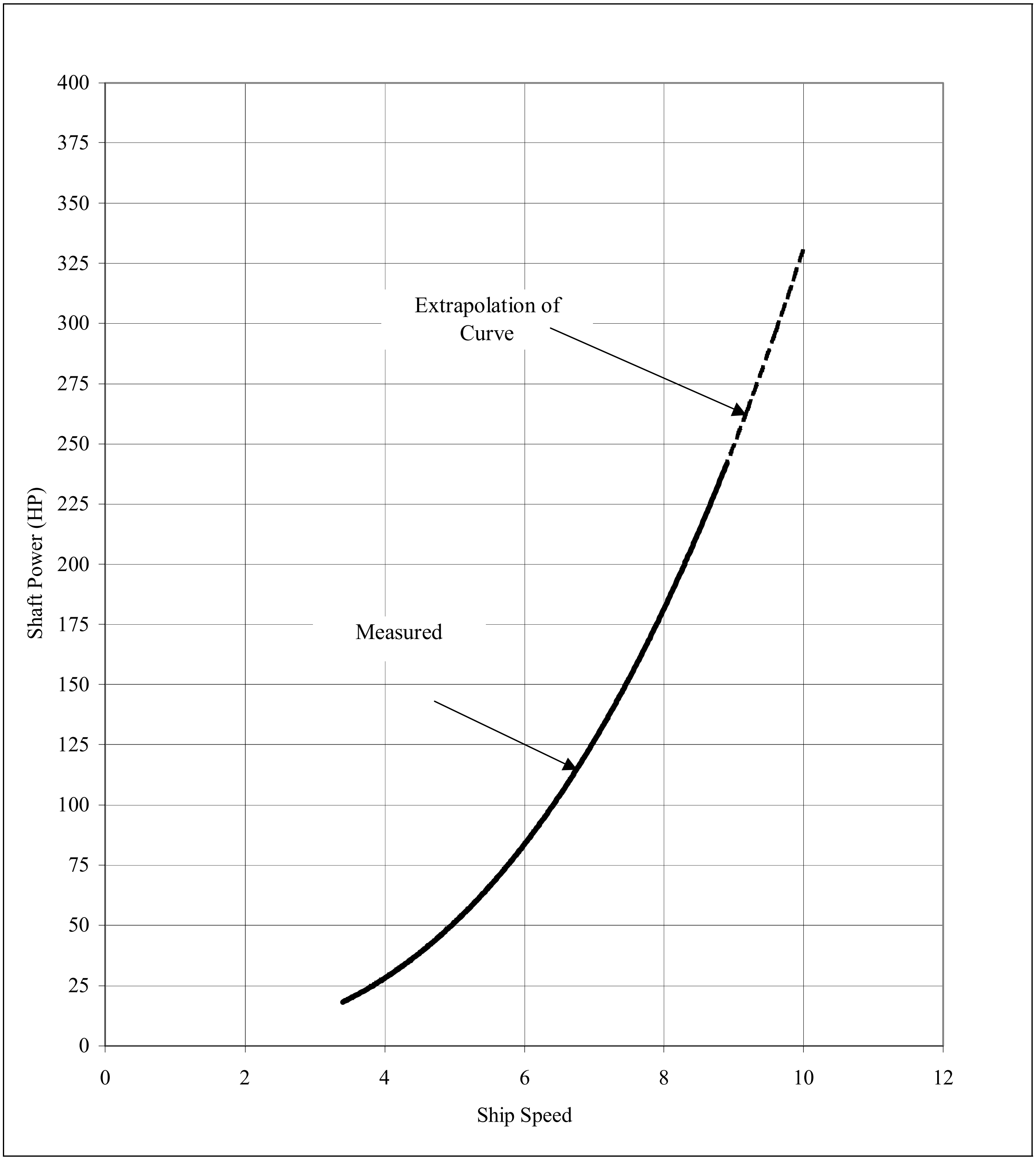
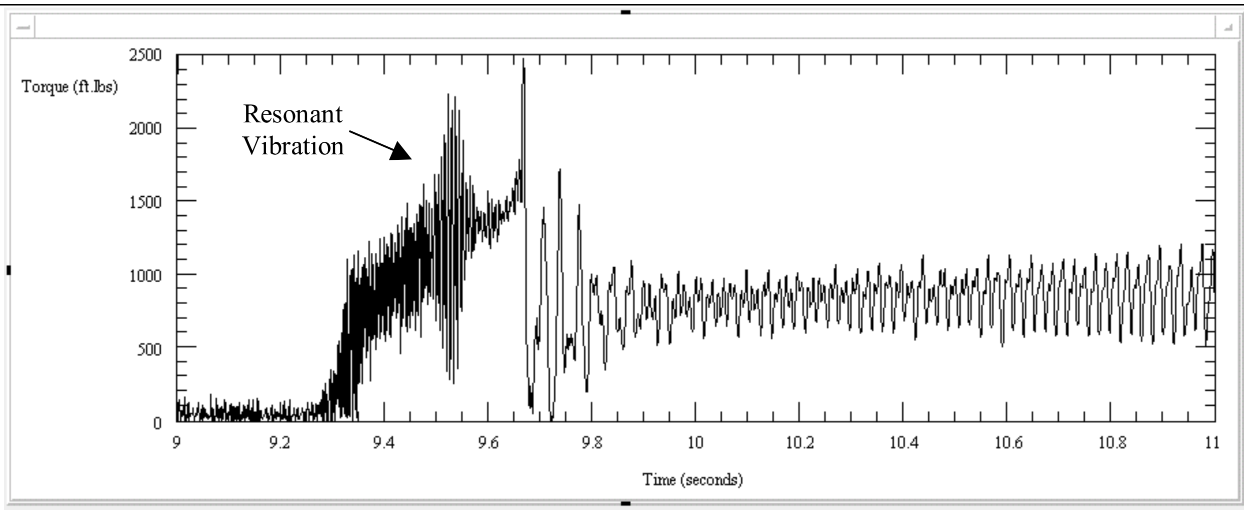


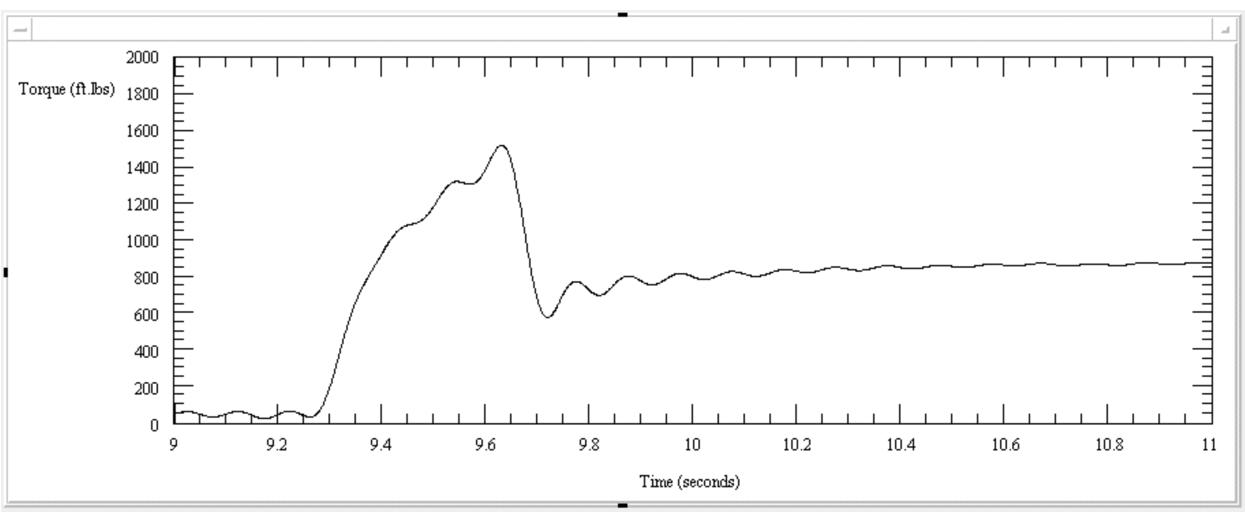
Figure 4 Ship Speed Vs Shaft Power

Figures 5 shows a time domain plot of the shaft torque during and acceleration test (0 to Full Ahead). The top plot is unfiltered (1000 readings/sec) and the bottom plot is the result after a 10 Hz low pass digital filter is applied. The results indicate the following:

(i) There is a dynamic torque on the shaft prior to reaching full speed of over 150% of rated torque. The torque "spikes" to 2400 ft-lb. (unfiltered), or over 200% of the rated torque.
(ii) The propeller absorbs the maximum power output of the engine prior to reaching full ship speed.
(iii) There is a resonant shaft vibration resulting in a vibratory torque of 1000 ft-lb.



Unfiltered



10 Hz Low Pass Digital Filter

Figure 5 Shaft Torque: Acceleration Test Propeller Astern

Torque Requirements

The specified "peak" torque for each engine is 1,038 ft-lb. at 1800 RPM. The allowable vibratory torsional stress on shaft is estimated to be in the range of 3,000psi (21 MPa) at 1800 RPM, which corresponds to a shaft torque of 767 ft-lb (900 Nm), or less than the mean torque at any speed, whichever is less.

Clutch-In Torque

Figure 6 provides time domain plots when the clutch is engaged. The results indicate the following:

(i) The maximum torque requirement is 52% of full ahead and 39% of the maximum rating at 1800 RPM.
(ii) The maximum vibratory torque is 30% of the rated torque at full power.
(iii) The vibratory torque is characterized by a series of torque impulses applied at the blade rate (3 x shaft rate).

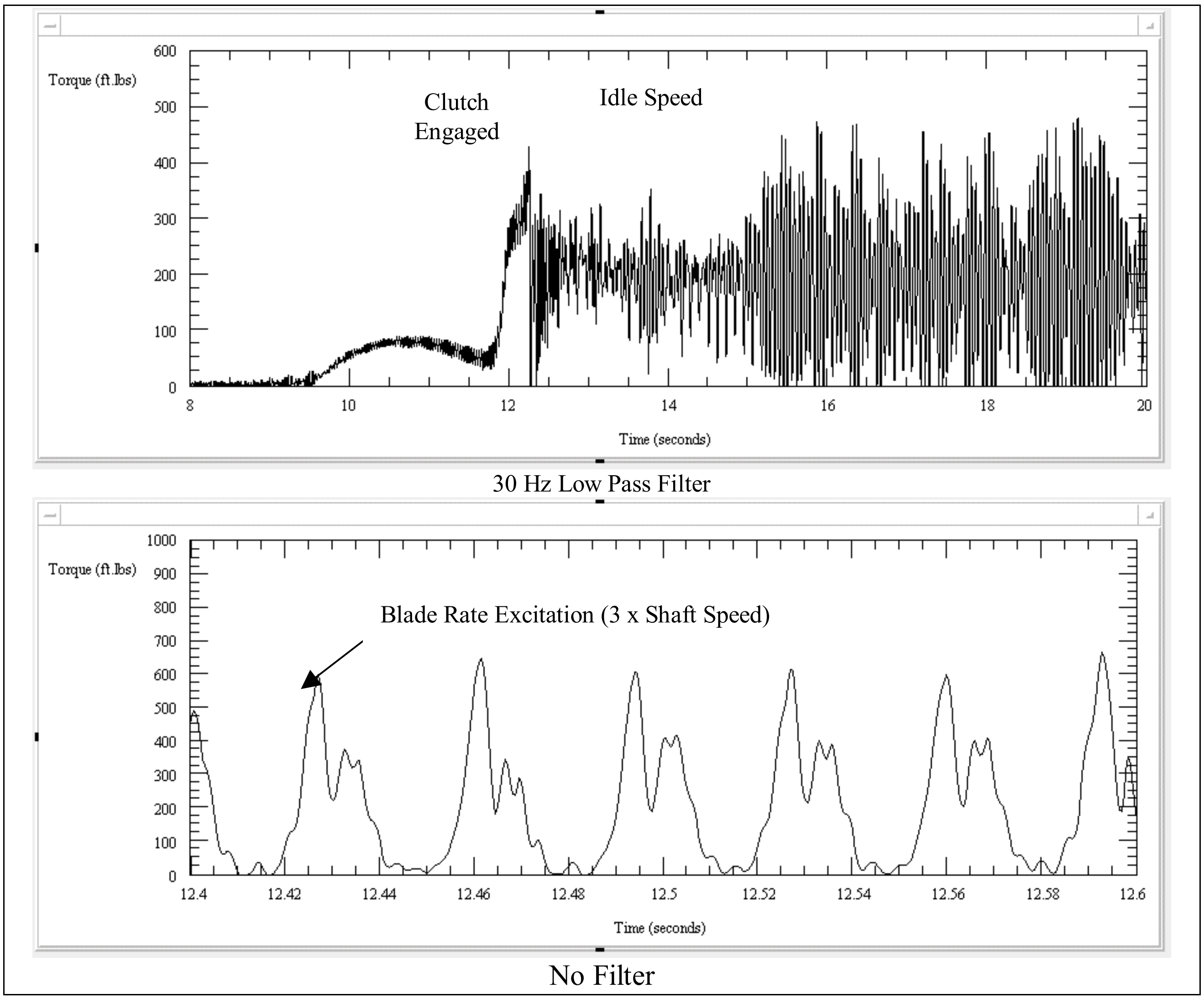
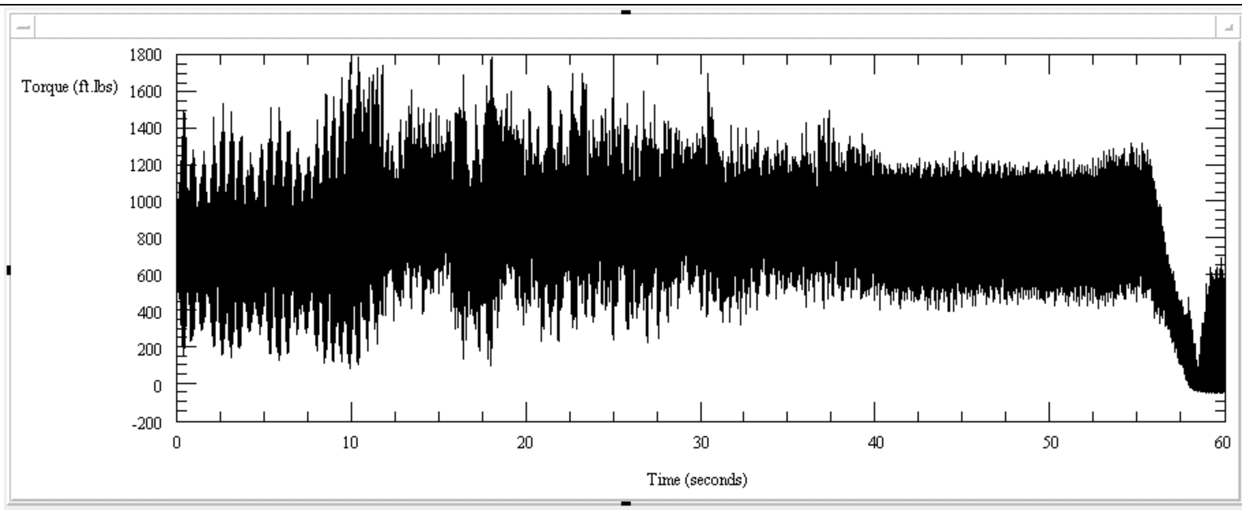


Figure 6 Shaft Torque During Clutch-In: MV Klitsa

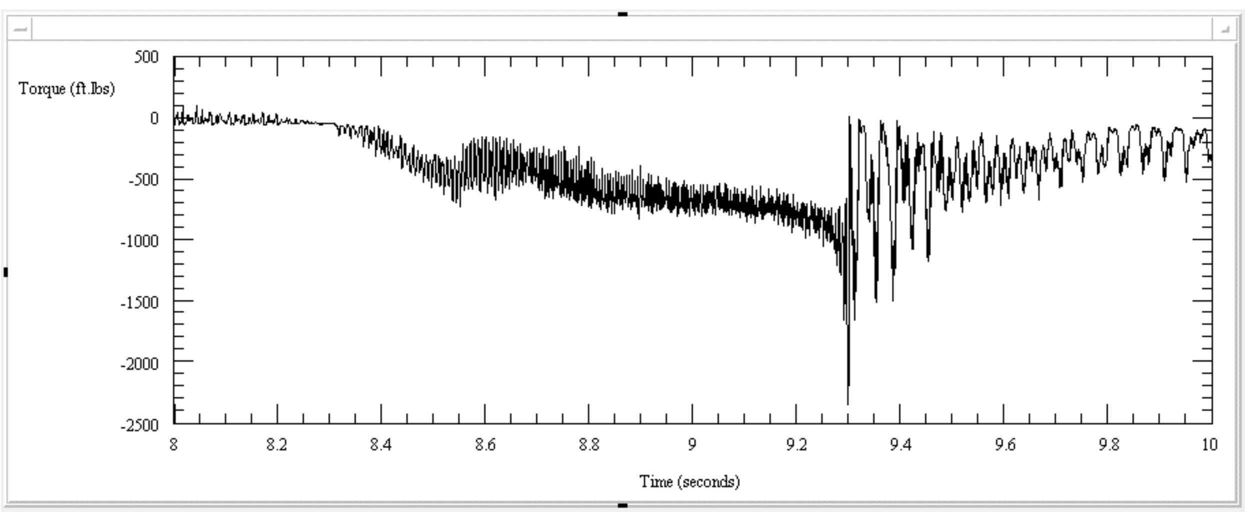
Shaft Torque during a Crash Stop

Two crash stop (emergency stop) tests were conducted. The first procedure involved rotating the SRAD Units 180 degrees when transiting full ahead (9 knots / 1850 RPM). The second was conducted by reversing the propeller rotation. Figure 7 is an example of the measured shaft torque. The results indicate the following:

(i) The maximum torque occurred when the propeller rotation was reversed, and was 231% of the rated torque, and is over 30% higher than when rotating the drive 180 degrees.
(ii) The maximum torque with a 10 Hz low pass filter was 111% of the rated torque.
(iii) The maximum amplitude of vibratory torque was 800 ft-lb. (77% of rated torque).



Stopped by Rotating Drives at 9 knots



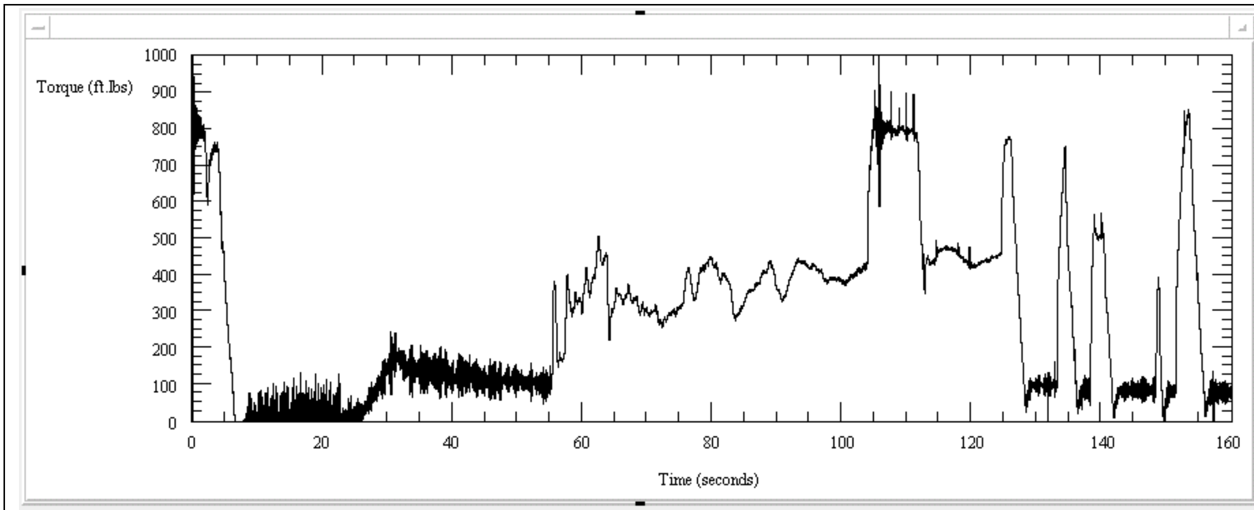
Stopped by Reversing Shaft Rotation at 5 knots

Figure 7 Shaft Torque During a Crash Stop: MV Klitsa

Shaft Torque during Docking Manoeuvres

As described earlier, during the Albion-Fort Langley run, the MV Klitsa is scheduled for about 80 crossings / dockings a day, and about 30 dockings when operating the Chemainus-Thetis Island - Kuper Island operation. Each time the vessel approaches the dock the propellers rotated up to 180 degrees to slow the vessel down and manoeuvre into the dock. In case of a steering failure, the vessel speed is reduced by reversing the rotation of the propeller. In addition, the shafts are de-clutched and clutched-in at each docking. Figure 8 provides a time domain plot over a period of 2.5 minutes during docking and undocking at Albion. The following observations are made:

(i) The power is applied to the propeller then reduced to idle about 5 times both during docking and undocking.
(ii) Full power torque (890 ft. lbs. at 1800 RPM) is absorbed by the propeller during some of the manoeuvres.



Docking at Albion - 10 Hz Low Pass Filter

Figure 8 Shaft Torque: Docking Manoeuvres at Albion

Shaft Torsional Vibrations at Constant Shaft Speed

The vibratory torque was determined for each of the constant speed tests. Figure 9 presents the results. Figure 10 illustrates the resonant vibration present at 1850 RPM, and compares it to the vibrations measured at 1575 RPM. The damping in the system prevents the vibrations from exceeding the allowable values; however, it is recommended that the existing system not be run higher than 1800 RPM, since damage may occur to the gearing. The system with the new engines should be designed so that no resonant vibration exists in the range of 90 to 105% of rated shaft speed (i.e., 1620 to 1890 RPM). There is also a relatively high torsional vibration at idle speed (~600 RPM). This vibration is at the blade rate (3 x shaft rate) and may be due to clearances in the system (e.g., spline, universal joints), since the magnitude of vibration decreases as load is applied.

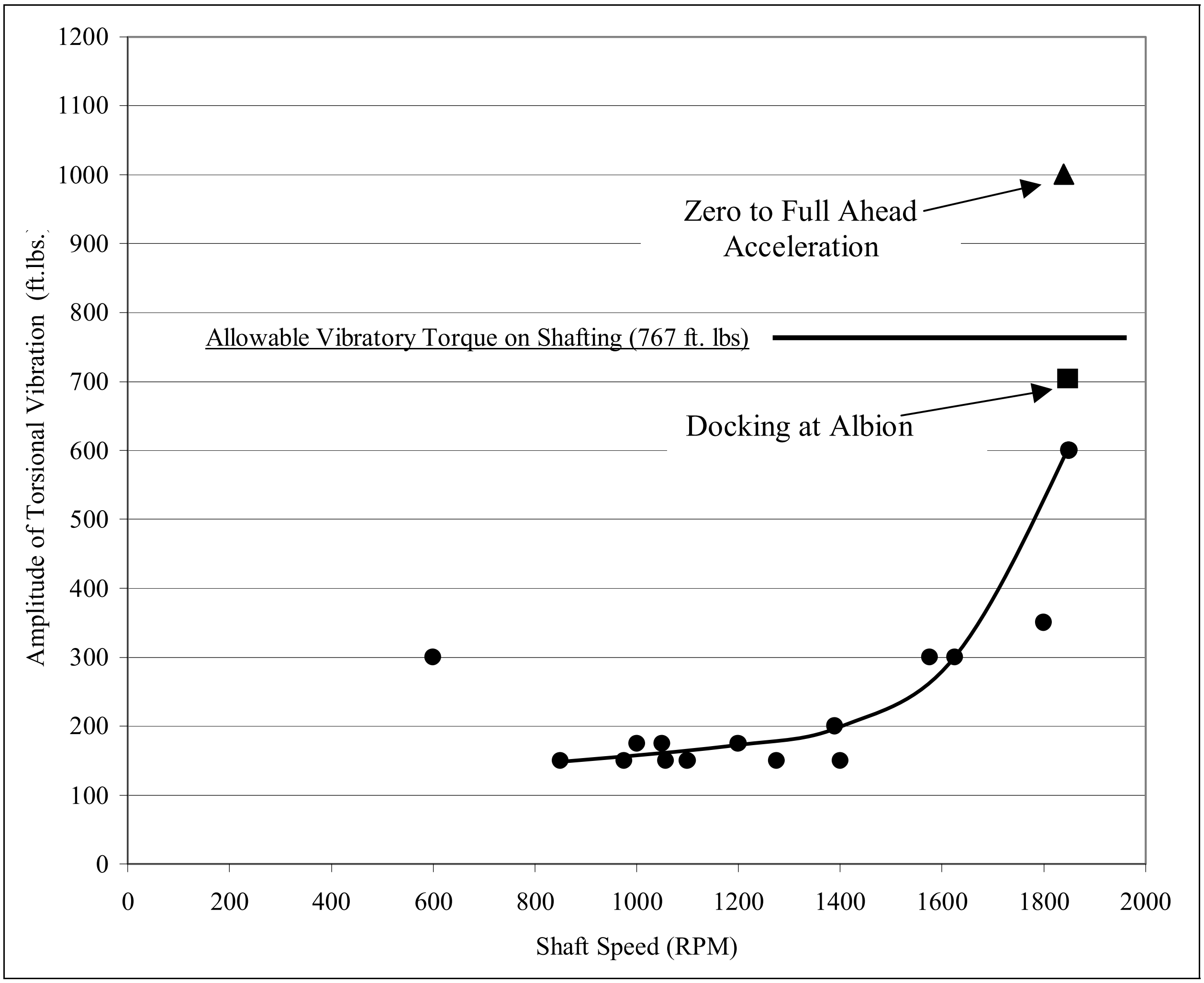


Figure 9 Amplitude of Torsional Vibration Vs Shaft Speed

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made as a result of the work reported herein:

- The existing propellers do not match the engine performance. The power absorbed by the propeller at 1800 RPM is 80% of the rated power. Running at 1850 RPM the power absorbed is about 90% of the rated power at 1800 RPM.
- At full ahead, the average power was 272 HP at an average shaft speed of 1,850 RPM, for a ship speed of 8.9 knots.
- A shaft power of about 330 HP at 2000 RPM is required to achieve the specified service speed of 10 knots.
- The full ahead acceleration command induces 150% of the rated torque
- The new engines should be capable of delivering about 1,150 ft-lb. torque (11% more than current peak rating), and be protected against higher torques.
- The highest vibratory torque measured was 1,000 ft-lb. and was a resonant vibration near 1850 RPM.
- The damping in the system prevents the resonant vibrations from exceeding the allowable values; however, it is recommended that the existing system not be run higher than 1800 RPM, since damage may occur to the gearing.
- The system with the new engines should be designed so that no resonant vibration exists in the range of 90 to 105% of rated shaft speed (i.e., 1620 to 1890 RPM).
- There is a relatively high torsional vibration at idle speed. This vibration is at the blade may be due to clearances in the system (e.g., universal joints, spline).
- The new engines should have torque limiters. Programmed shaft reversal, and programmed crash stop, so the engine is not subjected to excessive torques, should also be considered.
- The engine supplier conducts a complete forced-damped analysis of the torsional response of the propulsion system using the data presented in this report.
- Torque loads during clutch-in should also be considered in the design requirements for the new engines.

After Conversion Performance

The MV Klitsa returned to regular service on April 24, 2003 with new engines and propellers. Detroit Diesel Series 60 (14L) engines with a rating of 400 HP at 1800 RPM were installed, along with new 4 bladed fixed pitch propellers designed to match the performance of the new engines.

The following were the results of the measured mile performance:

- Engine Speed 1850 RPM
- Average of measured mile speed; calm sea, slack water, no wind: 10.6 knots
- Average engine fuel consumption/engine: 13.5 USGPH

The vessel was reported to handle well throughout the speed range, with an average increase in speed of 1 knot. Her top speed of 10.6 knots was 1.5 knots over the previous maximum speed of 9.1 knots, without undue structural vibration in engine rooms or on main car deck. The loading capacity had not been compromised with the conversion. Prior to the propulsion upgrade one or two scheduled crossing could be canceled each day. After the upgrade the vessel was reported to easily complete all its schedule crossings.

Acknowledgements

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Disclaimer

The views expresses in this paper are those of the authors and not necessarily the British Columbia Ferry Services Inc.